The Origin and History of Alpine Farming

A multiproxy palaeobotanic analysis in the Bavarian Alps.

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Summary

Mountain pastures belong to the most species rich habitats in Central Europe. They were shaped by centuries or even millennia of traditional low intensity land use practices. Land use changes in recent decades put these mountain pastures under increasing pressure. Intensification of easily accessible areas and abandonment of remote and steep grasslands have led to biodiversity and habitat losses. This puts them increasingly in the focus of nature conservation efforts. For the effective protection and for the development of suitable management methods, knowledge about the history of these habitats becomes increasingly important. The present thesis therefore aims to shed light on the history and the roots of alpine farming in the Alps, with a special focus on the hitherto neglected Bavarian Alps. In the **second chapter**, scientific literature concerning the age of alpine farming practices at high altitudes in the Alps is reviewed. Archaeological, archaeobotanical and linguistic studies show a very early beginning of mountain pasture use across the Alps beginning in the Bronze Age around 2000 BC. Few palynological studies even indicate Neolithic pasture use at high altitudes in the central Alps. Clear evidence from other scientific disciplines for this finding is however missing. The literature review also shows that research on that topic is concentrated in few hot-spot areas, and large parts of the Alps remain uninvestigated. Especially in the German part of the Northern Alps, conclusive research about the history and onset of alpine farming is missing. **Chapter 3** therefore presents a multiproxy research project about the onset of mountain pasture use in the district of Miesbach in the Bavarian Alps. Palynological, pedoanthracological and geochemical methods were used in this study. The results confirm findings from other parts of the Alps with very strong evidence of alpine farming beginning in the Iron Age around 750 BC. Presence of pasture indicator pollen species and especially evidence of slash and burn activities during the Bronze Age indicate an even earlier onset of alpine farming practices in this region. The presence of open landscape indicator species in the pollen record, and findings of soil charcoals, dating to the Neolithic Age at nearly 5000 BC indicate human activities also during the Neolithic Age. These indicators of human influence on the local vegetation, however, could also originate from late Mesolithic hunters, who burned the forest to gain open landscape for hunting purposes. **Chapter 4** presents more detailed results of the pedoanthracological study. Three phases with increased fire activity could be detected. The first one dating to the Neolithic Age, the second one dating to the Bronze Age and the third to the Middle Ages. This corresponds well to findings of other studies about increased human impact on the vegetation during these times. Identification of the soil charcoal fragments revealed that current forest composition is well reflected in the charcoal spectrum. The missing stratigraphy, probably caused by strong erosion events, prevents an assignment of the different soil layers to different time periods. Interpretations about the development of the forest composition based on soil charcoal analysis are therefore not possible. In conclusion the results of this thesis show that mountain pastures are not only valuable because of their outstanding biodiversity, but they are also an incredibly valuable cultural heritage and one of the very few habitats with a comparatively constant land use history stretching back over several millennia.

Chapter 1

General Introduction

The general public perceives the Alps as an area with a higher degree of wildness and naturalness compared to the Central European lowlands. A perception that is shaped by pictures of wild rivers and creeks, steep rockfaces and screes, pristine lakes, and glacier landscapes. The largest part of the Alps, however, consists of old cultural landscapes, that look back on a long history of human interaction with the environment. Most forests, meadows and pastures in the Alps were shaped by millennia of human land use practices (Bätzing, 2003; Ewald and Klaus, 2010; Küster, 2010; Poschlod, 2017). The most common form of land use at higher altitudes in the Alps are different forms of alpine summer farming.

Different land use systems in the Alps

Until today, summer farming on alpine, subalpine, and montane grasslands in the Alps is still an important economic factor for local farmers (Kirchengast, 2008). The use of summer pastures in the mountains reduces the pressure on the fertile and valuable fields at the valley floor close to the permanent settlements of the farmers. Depending on the region, history and cultural background of the farming communities, there are, however, various different farming systems in the Alps. In the central, northern, and eastern part of the Alps, where winter pastures are unavailable because of permanent snow cover, alpine summer farming (Almwirtschaft) is common practice. According to common definitions of alpine farming the livestock grazes on mountain pastures during the summer and is held in stables in the lowlands during winter (Mandl, 2009). Subalpine and montane pastures below the treeline are usually grazed by dairy cows or mother cows and occasionally horses (Reitmaier, 2010a). Depending on the form of summer farming, milk processing takes place in alpine huts in the vicinity of the summer pastures. Alpine pastures above the treeline are mostly grazed by migrating herds of sheep and goats during the summer months (Reitmaier, 2010a).
In the southern and western part of the Alps, transhumance with movement of the livestock and their herders between summer pastures in the mountains to snow-free winter pastures in the lowlands is practiced (Primas, 2008; Reitmaier, 2010b). Mostly large sheep herds travel distances of up to several hundred kilometres every year between their summer and winter pastures. Transhumance is regarded to be one of the oldest forms of alpine pasture use (Primas, 2008).

Biodiversity of mountain grasslands determined by land use patterns and land use history

Mountain grasslands of the Alps belong to the most species rich habitats in Europe (Väre et al., 2003). Broad scale abiotic factors such as altitude and precipitation form different climatic conditions, and small scale site related factors such as variations in slope, exposition, geologic underground and soil depths and types lead to a big variety of different microclimates and habitats, which creates the basis for this high biodiversity (Bätzing, 2003; Ellenberg and Leuschner, 2010). Another major driver of biodiversity especially below the natural treeline are traditional low-intensity land use practices in the Alps (Bätzing, 2003; Nagy et al., 2003). Especially the creation of subalpine and montane pastures in otherwise forested areas has formed a biodiversity hotspot, which harbours up to three times more plant species than the forests they replace (Zoller and Bischof, 1980). Various effects of grazing like spatially heterogeneous defoliation, trampling, wallowing, and faecal deposition increase the number of microhabitats and thereby the biodiversity in these pastures (Wallis De Vries et al., 1998). Additionally, the movement of livestock from the valley floors to their alpine summer pastures facilitates the dispersal of plants as seeds in the fur, the hooves or digestion system of the animals, which is a major factor in increasing plant species richness in these habitats (Cosyns et al., 2005; Fischer at al., 1996; Manzano and Malo, 2006; Poschlod and Bonn, 1998). This leads to increased habitat connectivity over large distances between grasslands in the lowlands, subalpine and alpine grasslands. Kollmar (2007) could show, that this habitat connectivity is also measurable in the form of increased gene flow between populations of *Medicago minima* along a transhumance route in the French Alps compared to a reduced gene flow between populations of the same species along a reference route without transhumance. According to Poschlod (2017) seed dispersal by livestock movement between the natural pastures above the treeline and pastures in the lowlands was one of the the main drivers in forming species rich grasslands in Central Europe in the Bronze Age. Typical grassland species in Central Europe are thought to have their origin on the natural grasslands above the treeline in the Alps (Poschlod et al., 2009).

Biodiversity in the Alps is also greatly influenced by land use history. In Switzerland different forms of alpine farming based on different cultural traditions (Romanic, Germanic, Walser), have led to different biodiversity patterns in today's landscape (Fischer et al., 2008; Maurer et al., 2006). The Romanic culture is the oldest of the three and developed 1800 BC, when settlers began to populate the inner alpine valleys (Bätzing, 2003). The Romanic cultural tradition was characterized by traditional, self-sufficient mixed farming, and hereditary partitioning of parcels led to a small-grained parcel structure which is still visible today (Rudmann-Maurer et al., 2008). Germanic culture established in Switzerland after 600 AD by immigrating Alemannic people from the north, who were mainly dairy farmers with scattered single farm houses surrounded by their fields and meadows (Rudmann-Maurer et al., 2008). Walser people populated the area from the west after 1200 AD and settled mostly at higher altitudes, since the lower regions were already occupied (Rudmann-Maurer et al., 2008). These different cultural traditions and land use systems led to differences in landscape structure and biodiversity (Bätzing, 2003). And despite the fact, that alpine farming in Switzerland nowadays has become increasingly uniform, caused by subsidy systems which do not differentiate between cultural traditions, species diversity and landscape diversity still varies significantly between Romanic, Germanic and Walser villages (Fischer et al., 2008; Maurer et al., 2006). Another example of former land use practice still influencing todays vegetation are the widespread *Rhododendron hirsutum, R. ferrugineum* and *Alnus viridis* stands above the present-day treeline or on the edges of subalpine pastures. These shrubs are succession plants, which are resistant to grazing (Ellenberg and Leuschner, 2010) and could only establish to this extent on abandoned pastures below the natural treeline (Gobet et al., 2004; Küster, 2010; Poschlod, 2017; Tinner et al., 1999). They are therefore indicators of more intensive pasturing activities in the past and suggest a human induced lowering of the treeline by successively enlarging the existing alpine pastures.

This demonstrates that land use history and past land use patterns still influence the current vegetation of the Alps. An understanding of the land use history is therefore crucial for a real understanding and a competent protection management of these species rich and valuable habitats.

Recent land use changes and biodiversity losses

The younger history of alpine farming shows a continuous expansion of alpine farms since the Middle Ages up to the 19^{th} century (Bätzing, 2003). With the separation of forest and pasture in the late 19^{th} century, however, especially species rich forest pastures in the Alps became increasingly rare, and grazing intensity increased on the remaining open pastures, leading to biodiversity losses (Ringler, 2007). After the Second World War, with the increasing intensification and industrialisation of agriculture in central Europe, traditional alpine farming practices are in decline (Stöcklin et al., 2007). Two opposite developments are taking place in mountain grasslands. Areas that are easily reachable and close to the farms are intensified with the application of liquid manure and an increased mowing frequency or grazing intensity, whereas poorly accessible areas, further away from the farms which are often situated on steep slopes are more and more abandoned (Cocca et al., 2012; Fischer et. al., 2008; Marini et al., 2009). This trend of either abandonment or intensification of traditionally used mountain pastures and hay meadows, has led to a decline in species richness and loss of habitat for many specialized plant and animal species (MacDonald et al., 2000; Spiegelberger et al., 2006; Tasser and Tappeiner, 2002). Increasing farm sizes with improved technologies, higher mowing frequency and higher grazing pressure negatively affect species richness in mountain grasslands (Marini et al., 2009, 2011). Especially increasing nitrogen and phosphorus levels in the soil caused by artificial fertilization proves to be detrimental for species richness (Marini et al., 2007; Maurer et al., 2006). In abandoned grasslands, increasing litter layer, expansion of strong competitive plants and increasing succession by shrubs and trees lead to a strong decline in species richness (MacDonald et al., 2000; Tasser and Tappeiner, 2002).

This development has made the protection of mountain grasslands a priority in nature conservation. The support of local alpine farmers and the development of adequate management methods becomes increasingly important to preserve species rich mountain pastures and to maintain valuable land use practices. Especially ecosystem services that the livestock delivers for habitat connectivity by migrating between mountain pastures and lowland pastures is of incalculable value and even not yet fully understood (Kollmar, 2007; Manzano and Malo, 2006). For the effort to evaluate, protect and manage these mountain pastures and hay meadows, it is of great importance to consider and understand their land use history. As mentioned above, current biodiversity patterns can often only be explained by the land use history and different traditional land use practices (Fischer et al., 2008; Maurer et al., 2006). That is why a profound understanding of the land use history is important for improving species and landscape protection concepts in our cultural landscapes in the Alps.

In order to communicate the value of these alpine land use systems for maintaining biodiversity to the general public, information about the history and especially the age of such land use practices might prove helpful as well. This information would help to additionally assess the cultural value of such land use practices and habitats and underscores the value of alpine farming as part of our cultural heritage.

Methodological aspects

For the age determination of these alpine farming practices, historical records are of limited value because written records about alpine farming systems exist only since the Early Middle Ages (Winckler, 2013). Prehistoric events can be investigated using mainly archaeological and archaeobotanical methods. Especially the reconstruction of the vegetation after the last Ice Age about 12,000 years ago, using pollen analysis can uncover the interaction of humans with their environment. Yet, for a long time, research regarding prehistoric interaction of humans with mountain environments in the Alps has been scarce, mostly because of the difficulty of archaeological excavations and sampling for archaeobotanical studies at high altitudes (exceptions are for example Gleirschner, 1985; Pittioni, 1931). Archaeobotanical research in the Alps used to be focused on climatic factors, influencing the natural vegetation history of the Alps (eg Bortenschlager and Patzelt, 1969; Bortenschlager, 1970, 1972). Since the chance discovery of the Iceman in 1992 (Spindler, 1995), however, much more attention was directed towards the question of prehistoric human impact on mountain ecosystems. The scientific community was eager to find out what the occupation of the famous iceman in the Alps was over 5000 years ago (eg Bortenschlager and Oeggl, 2012, Putzer et al, 2016a). The question whether the iceman was a hunter or herder concerns the scientific community until today (Bortenschlager and Oeggl, 2012; Egg and Spindler 2009; Kutschera et al., 2016; Spindler 1996, 2005) and has led to a number of studies about early human impact on mountain ecosystems (eg Dietre et al., 2020; Hafner and Schwörer, 2018; Mandl, 2006; Reitmaier, 2017). These studies, however, are focused on few specific regions and large parts of the Alps remain unexplored (Gilck and Poschlod, 2019). Especially in the Northern Alps with comparatively harsh environmental conditions studies about the history and begin of alpine farming are scarce (Gilck and Poschlod, 2019). Research from the Dachstein Mountains or the Swiss part of the Northern Alps shows that research in this area as well can yield astonishing results (Mandl, 2006; Schwörer et al., 2014).

Thesis outline

The aim of this thesis is therefore, to contribute to a better understanding of the history of human land use practices in mountain ecosystems in the Alps. This thesis especially focuses on the onset and history of alpine farming (Almwirtschaft) or mountain pasture use in general in the northernmost chain of the Alps in Bavaria, where conclusive research on that topic is missing.

In order to obtain a comprehensive picture about the age of human land use practices at high altitudes, **Chapter 2** for the first time summarizes all relevant research, that has been conducted in the Alps concerning the onset of alpine farming in prehistoric times. Studies from various scientific fields, such as archaeology, archaeobotany and linguistics are reviewed.

Chapter 3, the centrepiece of this thesis, presents a case study from the Bavarian Alps. In a multi proxy analysis, using palynology, pedoanthracology and geochemistry, the vegetation history in the Mangfall Mountains in Bavaria is reconstructed with special focus on the onset of human land use practices in this subalpine environment.

In **Chapter 4** more detailed results of the pedoanthracological analysis are presented and discussed.

Chapter 2

The Origin of Alpine Farming

A Literature Review of Archaeological, Linguistic and Archaeobotanical Studies in the Alps

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Abstract

Alpine farming and pasturing at high altitudes in the Alps has created one of the most species-rich and diverse landscapes in Europe. In order to fully understand, appreciate and protect these habitats it is essential to learn about their history and origin. Until the present day, alpine farming provides essential additional food sources for livestock of farmers in the alpine valleys. Based on written sources, historians are able to track alpine farming back to the Middle Ages. Other approaches from different fields in science, however, can look back even further in search of evidence for alpine farming. This interdisciplinary literature review therefore aims to summarize the scientific work that has been done in different fields of science such as Archaeology, Palynology, Pedoanthracology and linguistic research in order to address the question of the beginning of alpine farming in the Alps. With the discovery of remains from alpine dairy huts, archaeological studies show that there is definite proof of alpine farming beginning in the Bronze Age (2200–800 BC) in different parts of the Alps. Archaeological and palynological data as well as linguistic findings from many different studies and study areas arrived at the same conclusions. Palynological studies found indicators for high-altitude pasture use even earlier, beginning from 4500 BC. The exact type or intensity of this pasture use though remains unclear. In order to confirm these findings, more archaeological research of these areas would be necessary.

Keywords: alpine pastures, cultural landscapes, land-use history, palynology, pedoanthracology, transhumance

Introduction

Alpine farming (Alpwirtschaft) is commonly described as the movement of humans with their livestock between permanent settlements in the mountain valleys in winter and temporary settlements in the alpine and subalpine belt for pasturing in summer. This lifestyle has many advantages for the inhabitants of alpine regions. Open land for arable use is often scarce in the narrow valleys and land for pastures or hay meadows is even scarcer. Keeping the livestock on the naturally open alpine pastures or forest clearances in the subalpine belt, where the soil is not fertile enough for crop cultivation, solves this problem. The fertile land in the valleys can then be used for crop cultivation. Until the present day, using natural pastures above the tree line can provide a farm with approximately one-third of the fodder needed each year (Kirchengast, 2008). Patzelt et al. (1997), Mandl (2009), Reitmaier (2010a) and others further specify the definition of alpine farming by differentiating between different forms of alpine farming. The traditional method includes processing of milk in summer settlements up in the mountains, whereas there are also forms of alpine farming where the livestock grazes on the high pastures, but the milk is transported to the valley for processing. A third method, using the alpine pastures only for livestock breeding and meat production, is also regarded as a form of alpine farming. Nomadic or transhumant livestock keeping have to be distinguished from alpine farming. In many cases, these forms of livestock management are thought to precede the classical form of alpine farming in many regions of the Alps. The nomadic lifestyle differs from alpine farming in that herders travel from pasture to pasture with all their belongings and without permanent settlements (Reitmaier, 2010a). Transhumance, which is probably one of the oldest form of pasturing (Primas, 2008), involves permanent settlements of humans; however, in contrast to alpine farming the livestock is not kept in stables during the winter. Instead, the animals move from their summer pastures in the mountains to their winter pastures in the lowlands, where they find enough fodder until early summer (Reitmaier, 2010b). This, however, is only possible in the marginal regions of the Alps, especially in the southern part where snow-free winter pastures in the lowlands are available. In the Central and Northern Alps, winter pastures do not exist and farmers have to keep their animals in stables during the cold season (Frei-Stolba, 1988). Therefore, when we look at the origins of alpine farming we have to differentiate between actual alpine farming as postulated by Mandl (2009) and others (Patzelt et al., 1997; Reitmaier, 2010a), and different forms of high-altitude pasturing like nomadism and transhumance. These differences though are difficult to detect in the different kind of archives such as sediments, peat deposits and mineral soil, which we have to study in order to understand prehistoric land use. Reitmaier (2010a, 2010b) critically assesses different methods and their suitability to answer questions about the origin of alpine farming. He claims that many studies using only one methodological approach fail to distinguish between actual alpine farming, transhumance, nomadism and simple forest clearing. He concludes that only the use of different methods combined in order to cross-validate the results can produce clear proof of alpine farming in prehistorical times. This review, therefore, aims to summarize the most important studies from different scientific fields, which try to answer questions about the beginning of alpine farming in the Alps and therefore gives an overview of the current state of research on this topic.

Methodology

The most common methods include traditional archaeological excavations and different palaeobotanical methods such as palynology and pedoanthracology. Archaeological findings, however, are comparatively scarce in the Alps for several reasons. It is very difficult to find well-preserved settlements due to strong relocation of sediments in the Alps. On slopes, soil erosion is strong and relevant information is often lost. In the valleys and depressions, the accumulation of sediments is a problem. In the Reichenhall basin in southeast Germany, for example, 15 m of sediment have accumulated since the Bronze Age (Brunnacker et al., 1976). Therefore, many studies use palaeobotanical methods to reconstruct the past vegetation using, for example, pollen or pedoanthracological archives. Starting with the beginning of the past century, palynological studies have been conducted mainly in order to reconstruct the forest history of the Alps, to study the recolonization of plant species after the last Ice Age and to identify past climate changes (e.g. Bortenschlager, 1970; Bortenschlager, 1972; Bortenschlager and Patzelt, 1969; Welten, 1950). This method can also be used to detect human impact in the vegetation. Studies in the Alps often use the ratio between arboreal and non-arboreal pollen as a proxy for human impact as the first humans cleared the naturally closed mountain forests to gain more pastures. However, there are also specific pollen types, which are correlated to human activities like agriculture or pastoral activities. Behre (1981) defined different groups of pollen types that indicate human land use. Pollen types such as Poaceae, Asteraceae, Plantago lanceolata or Rumex acetosa among others may indicate pastoral activities (for more information about the different indicator pollen groups see Behre, 1981 and Faegri and Iversen, 1989). As different studies use different sets of indicator pollen for human activity, a spreadsheet containing all indicator pollen types, which were used by the authors cited in this review, is given in the Appendix. The value of many of the older palynological studies for determination of the beginning of alpine farming, however, is often limited, as only few of them already used radiocarbon dating to determine the age of the pollen deposits. Only after the discovery of radiocarbon dating by Arnold and Libby (1949) and the following perfection and calibration of the method, could pollen deposits be effectively dated and interpreted accordingly. Further information is often obtained from pedoanthracological analysis. Former forest clearings by burning are often well preserved as charcoal horizons in the soil (Kutschera et al., 2014; Reitmaier and Walser, 2007). The micro- and macrocharcoal content in pollen deposits often serves as an important indicator for human-induced fire in order to create open pastures below the tree line (e.g. Wick et al., 2003). According to Reitmaier (2010a, 2010b), however, a clear confirmation of alpine farming is only possible when there are archaeological remains of former huts and, ideally, remains of tools for milk processing or livestock remains. Palynological data and charcoal analysis can serve as evidence of ancient pasture use in general without allowing a closer definition of the exact form of pasture use. In the following section, we want to summarize the most important scientific studies that try to answer the question about the beginning of alpine farming and pasturing in high regions of the Alps in history. To find the respective literature, we searched in Google Scholar and Scopus for literature applying the search terms (both, English and German) 'origin', 'prehistory', 'history', 'archaeology', 'palynology', 'pedoanthracology', 'Alps', 'alpine land use', 'alpine farming' and 'alpine pastures', which gave comparatively few results. Most literature was found by searching in the references of the papers we found via the database.

Results

The oldest signs of human presence in the Alps were found in caves in the Western Alps dating back between 40,000 and 100,000 years ago (Pauli, 1980). Palaeolithic and later Mesolithic hunters populated the Alps in search of hunting game. Fireplaces at 2000 m a.s.l. from Mesolithic hunters dating between 7900 and 7000 BC in the Ötztal Alps prove regular human presence at these altitudes during that period (Kutschera et al., 2014; Schäfer, 2011). Around 4500–4000 BC, humans began to settle in the big valleys and started with livestock breeding and cultivation of grains (Pauli, 1980). From that time onwards, it is imaginable that farmers began to use natural pastures above the treeline to graze their livestock, as open land in the often narrow valleys was scarce and valuable and, therefore if available, was used as arable land. Clear proof for alpine farming in the form of written sources exists only from the Middle Ages, but historians from the 18th century already believed that the use of alpine pastures goes back even beyond the time of the Roman Empire (4th century BC to 4th century AD). Already in 1758, the Swiss Politician and Historian, Aegidius Tschudi, claims pre-Roman use of alpine pastures:

> *Es seyd ohne Zweifel von Königs Prisci Tarquinii Zeitn beyderseits in Italien und Gallia Völcker bis nächst an die AlpGebirg wohnhaft gewesen, die werden wohl bis in die obersten Firsten der Alpen, von Wegen der Vieh-Weidungen zu Sommers-Zeiten, Steg und Weeg gemacht haben, mit dem Vieh aufund abzufahren, dieweilen doch grosser Genuss an Fleisch und Molchen allda zu gewünnen, dardurch viel Strassen über alle Alpen mithin gemacht- und aufgethan worden, ohne Zweiffel vor viel hundert Jahren, ehe Rom je gebauen […] (Pauli, 1980: p. 223)*
>
> (During king Prisci Tarquiniis times without doubt people lived on both sides of the Alps in Italy and Gallia. They went to the highest places to graze their livestock in summer and built tracks and bridges to walk up and down the mountains to enjoy from milk and meat. Many roads have been constructed all over the Alps without doubt many hundred years before Rome was even built. (Translated by the authors)

Later, other scientists supported this thesis with further proof from different scientific disciplines. Pittioni (1931) suggested that alpine farming most likely took place already during the Bronze and Iron Ages. He mentioned many archaeological findings on present-day alpine farms that led him to this conclusion. Most of these artefacts included features like fireplaces, bronze, or other metal tools, which suggest human presence at this time. Pittioni (1931), however, thought it was very reasonable to assume that people used these places as pastures, as many of these findings were made on present-day alpine pastures. Even more convincing, he cited linguistic studies according to which many places and meadows at high altitudes in the Alps have pre-German or Rhaetian (pre-Roman) names, which points to their pre-Roman origin (Pittioni, 1931; Wopfner, 1920, 1995). In Grass (1990) and Hubschmid (1951), an overview of the Roman and pre-Roman (often Gallic) terminology associated with milk processing and alpine farming was provided and serves as a further indicator for the beginning of alpine farming before the Roman Empire (see Table 1). Nowotny (1991), Finsterwalder (1990) and others conducted similar linguistic studies and found many pre-German names for places at high altitudes in the Alps (see Table 1). Interesting in this context is also the fact that places at the head of valleys often possess older, pre-German or even pre-Roman, names and places lower in the valleys have German names originating mostly from the Middle Ages (Grass, 1990; Hubatschek, 1950;

Nowotny, 1991) (see also Table 1). This may indicate that colonization of these valleys started in the alpine belt where naturally open pastures above the treeline were used before the people turned to the lower forested and often steep slopes in search of more pasture grounds. Gleirscher (1985) also summarized many archaeological findings from high altitudes that indicate pasture usage at high altitudes in the Alps during the Bronze Age, but he is more careful with their interpretation. According to Gleirschner, alpine farming can be assumed, at least for the Roman period and the late Iron Age. During the Bronze Age, archaeological findings are not sufficient to prove the existence of alpine farming, but Gleirscher (1985) assesses a high likelihood for its presence at that time. In the following sections, different regions of the Alps will be addressed where more recent archaeological and palaeobotanical studies have been conducted to detect early human influence on alpine ecosystems.

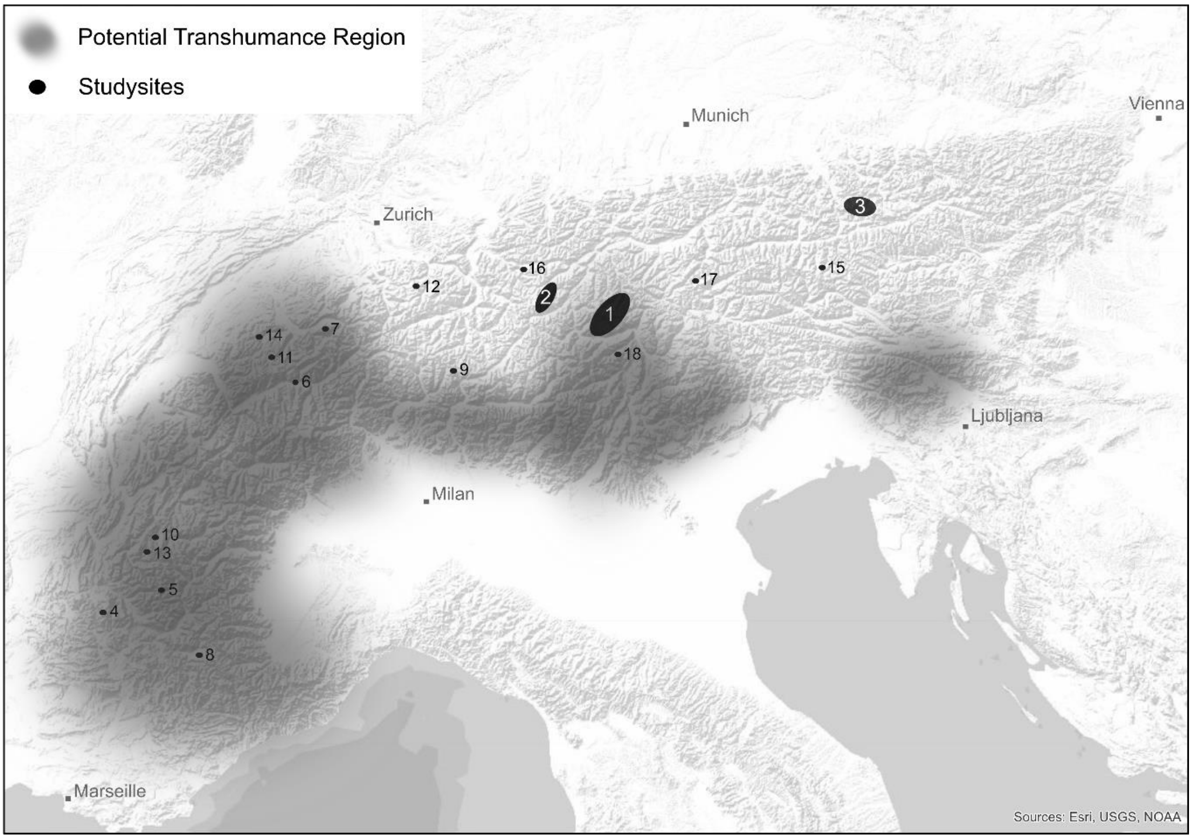

Figure 1. Overview map of the study sites mentioned in this review. Numbers of the study sites correspond to the numbers in Table 2. Potential transhumance regions are marked according to Braudel (1985). The remaining uncoloured regions of the Alps are regions where mainly alpine farming takes place because the winters in the lowands are too cold and too rich with snow, so that the animals cannot graze outside.

Table 1. Linguistic findings about names of places and terms associated with alpine farming from different time periods, indicating the beginning of alpine farming before the Middle Ages and even before the time of the Roman Empire. Gaulish and pre-Roman origins indicate human land use during the Iron Age or earlier. German origin indicates use during the Middle Ages and pre-German origin indicates use before the Middle Ages.

Category	Name	Description	Origin	Source
Farm and pasture names in higher regions of the Alps	Nemesalm	Mountain pasture close to Innichen	Gaulish	Grass, 1947
	Leiers	Valley- and pasture name	Pre-Roman	Patzelt, 1996
	Vent	Village name in the Ötztal above 1800m a.s.l.	Pre-Roman	Patzelt, 1996
	Tisen-farm	High altitude farm in the Schnals-valley	Pre-Roman	Patzelt, 1996
	Stanzer valley	63% of mountain pastures in this valley have pre-Roman names	Pre-Roman	Moritz, 1956
	Junsalm, Junsberg	mountain pasture in the Tuxer Alps	Pre-Roman	Finsterwalder, 1990
	Kapaunsalm	campone = large field	Roman	Finsterwalder, 1990
	Sidanalm	saeta = matgrass	Roman	Finsterwalder, 1990
	Rofen-farms	High altitude farms in the Ötztal Alps	Roman	Patzelt, 1996
	Alpeinalm, Seducker Hochalm, Tschangelairalm	Mountain pasture names in the upper Stubai valley	Pre-German	Hubatschek, 1950
	Ischgl, Mathon, Galtür	Mountain pasture names in the upper Paznaun valley	Pre-German	Nowotny, 1991
	Lizum, Möls, Melan, Waz, Pofers	Names of high mountain pastures in the Wattental	Pre-German	Grass, 1990
	Brandstattalm, Klamperbergalm, Mischbachalm	Mountain pasture names in the lower Stubai valley	German	Hubatschek, 1950
	See, Kappl	Mountain pasture names in the lower Paznaun valley	German	Nowotny, 1991
	Stubenbrandalm, Ochsenbrandalm, Sennach, Aresbichl, Zirmach	Names of lower mountain pastures in the Wattental	German	Grass, 1990
Terms related to milk processing	Senn, Senner	Sanion = milker on an alpine farm	Gaulish	Hubschmid, 1951
	randen	Ranne = to partition, partitioning of pastures between farmers	Gaulish	Hubschmid, 1951
	Kaser	Caseria = chalet	Roman	Hubschmid, 1951
	Ziger	Special type of cheese	Roman	Hubschmid, 1951
Terms related to meadow irrigation	Waal	Aquale = Irrigation canal in mountaneous regions. Especially in South Tirol	Roman	Hellebart, 1994
	Road, Rod	Rota = circle, row -> circulation time of irrigation rights	Roman	Hellebart, 1994
	Kandl	Canalis = wooden channel made of one trunk to channel the water for irrigation	Roman	Hellebart, 1994

Ötztal Alps

During the past few decades, three main areas with a focus on the research of the history of alpine farming in higher regions of the Alps emerged. The first and probably most intensively researched region evolved around the place of discovery of the 5000-year-old Iceman in the 'Ötztal', in the Central Alps. Researchers aimed to study the environment in which the Iceman lived and his way of life over 5000 years ago (Bortenschlager and Oeggl, 2012; Kutschera et al., 2014). In the valleys adjacent to the Tisenjoch where the iceman was found, archaeological and palaeobotanical studies were conducted to answer the question of whether the iceman was a hunter or a herder (Bortenschlager, 2000; Festi et al., 2014; Kutschera et al., 2014; Patzelt et al., 1997; Putzer, 2009; Putzer et al., 2016b; Vorren at al., 1993). In most of the palaeobotanical studies, an increase in pasture indicator pollen types (for particular species see Supplemental Appendix) indicated the very early beginnings of pasturing above 2000 m a.s.l. around 4000– 4500 BC in the Neolithic Age (Bortenschlager, 2000; Kutschera et al., 2014; Patzelt et al., 1997; Vorren et al., 1993). These results, however, can only indicate pasture use but fail to distinguish between nomadism, transhumance and alpine farming. Accompanying archaeological research revealed the remains from alpine huts above 2000 m a.s.l. that were dated to 1600 BC and therefore present definite proof of alpine farming in the Bronze Age (Festi et al., 2014; Patzelt et al., 1997; Putzer and Festi, 2014) (see also Table 2). In the 'Maneidtal' and around the 'Schwarzboden' mire in the 'Vinschgau' region, archaeological and palynological results yielded proof for first alpine farming during the Iron Age between 800 and 200 BC (Festi et al., 2014; Putzer, 2009). Here again, pasture indicator pollen from the palynological examination of the Schwarzboden mire and the accompanying discovery of Iron Age building remains provide strong evidence for alpine farming (Festi et al., 2014; Putzer, 2009). Thus, the matching of the results from both the palaeobotanical and archaeological research provides clear evidence for the existence of high-altitude pasturing and alpine farming in the Ötztal Alps, beginning at least in the Bronze Age and probably even earlier. Linguistic examination of farm names in the upper Ötztal also supports this hypothesis as many of the names have a pre-Roman origin (Finsterwalder, 1990; Patzelt, 1996) (see Table 1). Another noteworthy finding in this region is the discovery of irrigation sediments in the soil profiles from alpine pastures that date between 1600 and 1110 BC after a phase of intensive use as pastures (Kutschera et al., 2014; Patzelt et al., 1997). Irrigation of hay meadows in order to increase their productivity in the dry inner alpine valleys exists verifiably only since the Middle Ages (Poschlod, 2017; Poschlod et al., 2009). Linguistic findings, however, indicate irrigation already for the Roman Age as some terms for tools in the ancient irrigation systems are of Roman (Latin) origin (Hellebart, 1994) (see Table 1). The findings of dated sediments in soil profiles, which indicate artificial irrigation, suggest that irrigated hay meadows at considerable altitude might have existed even before that (Kutschera et al., 2014; Patzelt et al., 1997).

Dachstein

Beginning from 1980 the Association for Alpine Research, Rock Art and Settlement in the Alps 'ANISA' established another hotspot for the research of alpine farming in the history of the Alps in the 'Dachstein' region in Austria. The group around Franz Mandl discovered many archaeological artefacts providing evidence of alpine farming in pre-Roman times. Most important among these finds are the foundations and remains of alpine huts together with bones from livestock that date back to the Bronze Age and doubtlessly prove the existence of alpine farming during that time (Mandl, 2006).

Table 2. Beginnings of alpine farming in different parts of the Alps according to archaeological (Arch), palynological (Pal) and pedoanthracological (Ped) data from different studies. The numbers in the last column refer to the situation of the study site in Figure 1.

Region	Time	Location	Altitude (m a.s.l.)	Publication	Type
Ötztal Alps	4500 BC	Ötztal	2400	Kutschera et al., 2014	Pal, Ped
	4510 - 4360 BC	Gurgler Tal	2200-2400	Patzelt et al., 1997	Pal
	4350 - 4250 BC	Ventertal	2640	Patzelt et al., 1997	Pal
	1600 BC	Vinschgau	2180 - 2330	Festi et al., 2014	Pal, Arch
	1600 - 1450 BC	Bergmahd "Löble" bei Obergurgl	2150	Patzelt et al., 1997	Arch
	1500 BC	Tisental, Schnalstal	2000	Putzer and Festi, 2014; Putzer et al., 2016b	Pal, Arch
	1000 BC	Upper Ötztal	2250	Vorren et al., 1993	Pal
	800 - 200 BC	Maneidtal, Vinschgau	2150	Putzer, 2009	Arch
	550 BC	Vinschgau, Schwarzboden mire	2150	Festi et al., 2014	Pal, Arch
Silvretta	3300 - 3000 BC	Jamtal, Silvretta	2150	Reitmaier and Walser, 2007	Arch, Ped
	1500 BC	Fimbatal, Silvretta	2300	Dietre et al., 2012	Pal, Arch
	390 - 110 BC	Val Tasna, Silvretta	2100	Reitmaier and Walser, 2007	Arch, Ped
Dachstein	1685 BC	Dachstein-plateau, Handgrube	2078	Mandl, 2006	Arch
	1440 BC	Dachstein-plateau, Königreichalm	1598	Mandl, 2006	Pal, Arch
	1360 BC	Dachstein-plateau, Lackofengrube	1960	Mandl, 2006	Arch
Western Alps	3000 BC	Lake Lauzon	1980	Argant et al., 2006	Pal
	2200 - 800 BC	Rhone-valley	900 - 1700	Curdy et al., 1999	Arch
	1650 BC	Sägistal-lake	1935	Wick et al., 2003	Pal, Ped
	1500-800 BC	Valon de clapouse, Jausiers	2100	Wegmüller, 1977	Pal
	1150 - 450 BC	Valle Spluga	1820 - 2300	Moe et al., 2007	Pal, Arch
	950 BC	Wallis	~ 1600	Antonietti, 2005	Pal, Arch
	700 BC	Valoire	1834	Wegmüller, 1977	Pal
	650 BC	Simmental	1800	Tschumi, 1938	Arch
	550 BC	Silberenalp im Muotatal	1890	Haas et al., 2013	Pal
	400 BC	Les Gypsieres, Col du Galibier	2500	Wegmüller, 1977	Pal
	50 AD	Schwarzmoos, Simmental	1770	Wegmüller and Lotter, 1990	Pal
Eastern Alps	4000 BC	Oberer Bockhartsee, Gastein	2070	Kral, 1993	Pal
	2580 - 2400 BC	Wildes Ried, Montafon	1560	Oeggl et al., 2005	Pal
	1740 - 1520 BC	Oberer Zemmgrund, Zillertaler Alps	2185	Haas et al., 2007; Pindur et al., 2007	Pal, Arch
	750 BC	Totenmoos bei St. Walburg	1718	Heiss et al., 2005	Pal

An additional palynological study of a mire close to the archaeological sites confirmed these findings with increasing pasture indicator pollen types and an increase in non-arboreal pollen during the Bronze Age (DrescherSchneider, 2009). This makes the 'Dachstein' plateau one of the best-researched areas in the Alps to date. Radiocarbon dating of material from the archaeological sites and from the pollen profile dated the beginning of alpine farming between 1685 and 1360 BC (Cerwinka and Mandl, 1996; Hebert et al., 2007; Hebert and Mandl, 2009; Mandl, 2006, 2009; Mandl and Mandl-Neumann, 1990; Mandl and Stadler, 2010; Pucher, 2010) (see also Table 2). This first occurrence and high intensity of alpine farming in the Dachstein region correlates strongly with the salt mining activities in Hallstatt, in the close vicinity (Barth, 1998) and the climate optima that occurred during that time (Poschlod, 2015). This indicates that alpine farming could have developed as a way to supply food to the mining communities in the valley where sufficient land for crop cultivation and pastures was not yet in existence.

Silvretta

A third hotspot for the research on alpine farming in history formed in the Silvretta mountains where fireplaces and archaeological artefacts at high altitudes (>2000 m a.s.l.), dating as far back as 9000 BC, proved early human presence in this area (Reitmaier and Walser, 2007; Reitmaier, 2012). Palaeobotanical data confirmed very early human land-use activities at high altitudes, where pollen of the first pasture indicator species appeared around 4200 BC and charcoal findings indicate the first forest clearings at the same time (Dietre et al., 2012, 2014, 2017; Kothieringer et al., 2015). The oldest archaeological remnants of seasonal settlements, found above 2000 m a.s.l., were dated to the late Neolithic period (around 2800 BC). Big ceramic vessels that could have been used to transport and store food and evidence of fire in peat deposits and soil profiles suggest the presence of seasonal settlements during that time (Kothieringer et al., 2015). Clear proof for alpine farming emerges after 2200 BC in the Bronze Age. Dietre et al. (2012) found evidence of Bronze Age alpine huts at 2300 m a.s.l. in the Fimba Valley and conducted a pollen analysis that confirmed these results. Findings of the remains from a shelter and a corral at 2100 m a.s.l. in the neighbouring Tasna Valley, dating back to the late Iron Age (390–110 BC) confirmed (pre-) Roman farming at these altitudes (Reitmaier and Walser, 2007). The discovery of dairy fats on clay pots from three different sites between 2000 and 2400 m a.s.l. in the Silvretta mountains, dating back to the Iron and Bronze Ages undoubtedly proved alpine farming and dairying for this time (Carrer et al., 2016). These findings also demonstrate that despite the aforementioned difficulties of archaeological research in the Alps, research in this field and new advancements in archaeological scientific methods can yield promising results.

Western Alps

Apart from these three centres of alpine farming research, many more studies have been conducted all over the Western Alps (see table 2). Most of them rely only on palynological data (Argant et al., 2006; Haas et al., 2013; Moe et al., 2007; Wegmüller, 1977; Wegmüller and Lotter, 1990; Wick et al., 2003). They also confirm the use of alpine pastures with an increase in non-arboreal pollen and pasture indicators during the Bronze and Iron Ages but the exact form of pasture use remains unclear due to the lack of other research methods that could provide clear proof or provide alternative lines of evidence to the results from the pollen analysis. In the Ecrins National Park, however, the combination of archaeological and palynological research provided solid evidence for the beginning of alpine pasture use around 2500 BC at altitudes around 2000 m a.s.l. and above (Walsh, 2013; Walsh and Mocci, 2011). In these studies, archaeological findings from remains of livestock corrals and the increase of indicative pollen types from peat cores in the close vicinity of the sites clearly point to human presence and pasturing beginning around 2500 BC. Curdy et al. (1999) and Curdy (2007) summarized archaeological findings (settlements, tombs, isolated artefacts, deposits, cultural areas) from the Rhone Valley at altitudes between 900 and 1700 m a.s.l. and concluded that intensified land use at higher altitudes and the locally typical alpine farming system called 'remuage' (a form of seasonal nomadism) slowly began to form in the Bronze Age and clearly manifested itself during the Iron Age after 800 BC. This mainly confirms the results from palynological data throughout the West Alps and complements the findings in other parts of the Alps.

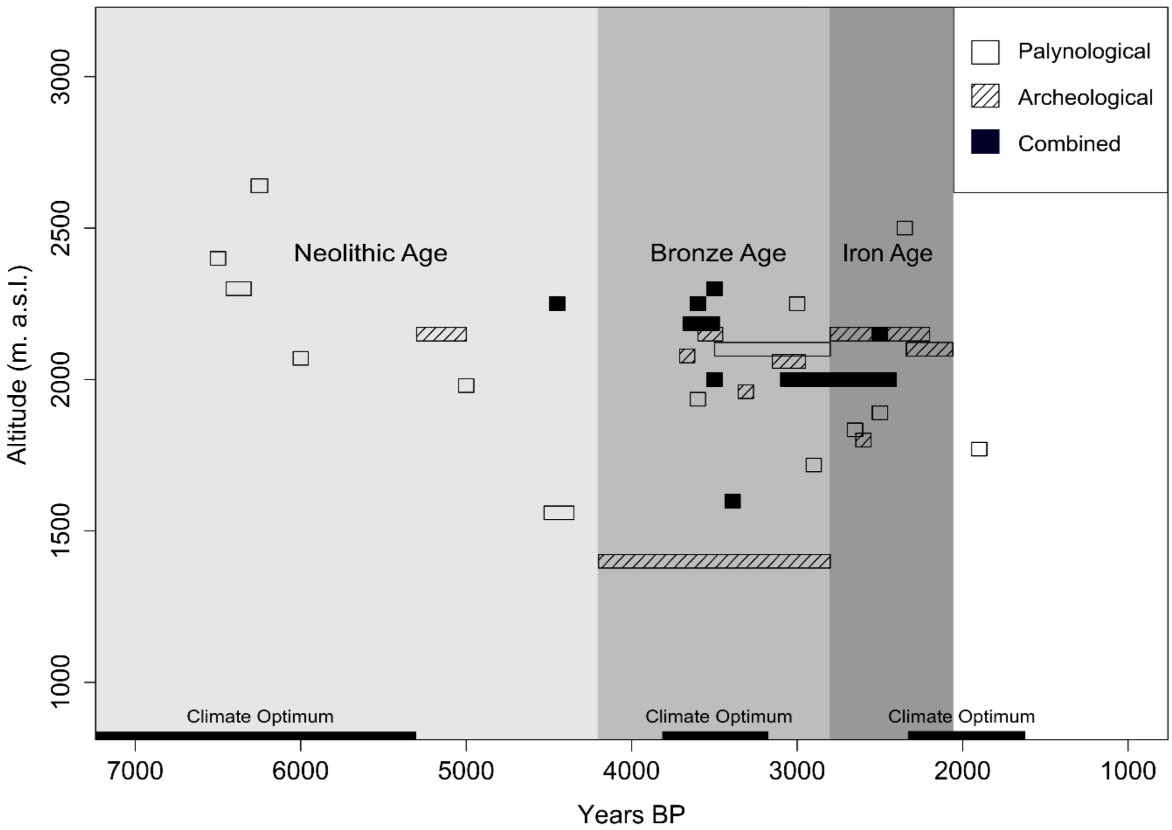

Figure 2. Beginning of alpine farming at different altitudes presented by the different types of approaches. Data from the studies in Table 2 were used to generate this graph.

Eastern Alps

In the Eastern Alps, apart from the two mentioned hotspots for alpine farming research in the Ötztal and Dachstein area, scientists conducted more palaeobotanical studies at high altitudes. One emphasis was made on the vegetation and settlement history in the Montafon region. Pollen analysis indicated that the first human impact at higher altitudes started at the transition from the Neolithic Age to the Bronze Age (~2500 BC). First pasture use with increasing numbers of pasture indicator pollen and microcharcoal influx presumably occurred at the end of the early Bronze Age (Kostenzer, 1996; Oeggl et al., 2005; Schwarz et al., 2013). However, it remains unclear which form of land use was present and the study lacks clear evidence of alpine farming in pre-Roman times. Another palynological study in the adjacent area confirms Bronze Age forest clearings and possible alpine farming on a present-day alpine farm at 1960 m a.s.l. (Wahlmüller, 2002). The palynological study of Kral (1993) with sediments of the ‘Oberer Bockhartsee’ in the Gastein region dated the beginning of forest clearings (micro-charcoal influx) and following pasture use (increase in pasture indicator pollen types) very early to 4000 BC. That is a confirmation of the palynological studies from the Ötztal Alps where the first human influence on the alpine and subalpine vegetation was dated to roughly the same period (see above and Table 2). In spite of that, these results have to be interpreted with caution. Reitmaier (2010a, 2010b) stated that changes in the vegetation according to pollen profiles can serve only as an indicator of human impact in general and that it is very difficult to deduce any specific land use type from this kind of data. Similar palynological studies in the ‘Zemmgrund’ Valley in the Zillertal Alps also indicated Neolithic pasturing beginning around 4100 BC and intensifying with fire clearings of the forest and increasing pasture indicators in the pollen profiles during the Bronze Age (Haas et al., 2007). Additional findings of a fireplace from around 1600 BC confirmed human presence in this area at that time (Pindur et al., 2007). In a short summary of palynological records in the Eastern Alps, Oeggl (1994) observed that pasturing has an older history at higher altitudes, and subalpine or montane pastures are generally younger. This would also complement the results of the aforementioned linguistic studies of farm names (see Table 1). These publications confirm the idea that first pastures in the Alps were situated above the natural treeline and from there early farmers moved to lower altitudes by clearing the forest and establishing new pastures below the forest line.

Conclusion

In conclusion, we can state that there is good evidence for alpine farming with findings of archaeological remains from seasonal huts beginning in the Bronze Age at subalpine to alpine altitudes. Archaeological and palynological data as well as linguistic findings from many different studies and different study areas come to the same conclusion. The data also indicates pasturing activity at high altitudes much earlier during the Neolithic age. Palynological studies found indicators for pasture use beginning from 4500 BC (Figure 2). The exact type or intensity of pasture use though remains unclear. Up to now no archaeological evidence of seasonal shelters, huts or livestock corrals dating to that time is available. Therefore, we can state with certainty that alpine farming was present in the Alps during the Bronze Age whereas for the Neolithic Age we can only assume unspecified pasture use at high altitudes in the Central Alps. More research in this field is necessary, especially archaeological investigation of areas where palynological and pedoanthracological results showed forest clearings and occurrences of pasture indicator pollen during the Neolithic period would be promising study areas. Nevertheless, the results of this review demonstrate, that alpine farms are not only worth protecting because of their positive effect on biodiversity but also because of their long history, which makes them cultural monuments of great value for our society (see Poschlod, 2017).

Supplemental Tables

Table S1.Pasture indicator pollen types according to different palynological studies carried out in the Alps at altitudes above 1500m a.s.l.

Ötztal			
Pasture indicator pollen	**Pasture indicator pollen**	**Pasture indicator pollen**	**Pasture indicator pollen**
Apiaceae			Apiaceae
	Artemisia type	Artemisia	
	Brassicaceae	Brassicaceae	
		Campanula	
Chenopodiaceae	Chenopodiaceae	Chenopodiaceae type	Chenopodiaceae
	Cichorioidae	Cichorioidae	
Fabaceae			Fabaceae
Filipendula			Filipendula
Gentianaceae		Gentianaceae	Gentianaceae
Ligusticum			Ligusticum
Lotus			Lotus
		Phyteuma	
Plantago		Plantago alpina type	Plantago
Plantago			Plantago
Plantago			Plantago
Ranunculaceae			Ranunculaceae
Rhinanthus		Rhinanthus type	Rhinanthus
Rosaceae			Rosaceae
Rumex			Rumex
Rumex		Rumex acetosella type	Rumex
Urtica		Urtica	Urtica
Bortenschlager, S. (2000). The Iceman’s environment. In: Bortenschlager S and Oeggly K (eds.) *The Iceman and his natural environment.* Vienna: Springer: 11-24	Putzer A and Festi D (2014) Nicht nur Ötzi?–Neufunde aus dem Tisental (Gem. Schnals/Prov. Bozen). Praehistorische Zeitschrift 89(1): 55-71.	Festi D, Putzer A and Oeggl K (2014) Mid and late Holocene land-use changes in the Ötztal Alps, territory of the Neolithic Iceman “Ötzi”. Quaternary International 353: 17-33.	Patzelt G, Kofler W and Wahlmüller B (1997) Die Ötztalstudie–Entwicklung der Landnutzung. In: Oeggl K, Patzelt G and Schäfer D (eds) Alpine Vorzeit in Tirol. Begleitheft zur Ausstellung. Innsbruck: University Press, pp. 46-62.

Silvretta	Dachstein
Pasture indicator pollen	**Pasture indicator pollen**
Achillea type	
	Apiaceae
Artemisia	
	Brassicaceae
Campanula/Phyteuma type	
	Caryophyllaceae
Chenopodiaceae	
	Cichorioidae
	Cirsium/Carduus
	Gentianaceae
	Heracleum
Plantago alpina type	
Plantago lanceolata type	
	Polygonum viviparum
Ranunculus acris type	
Rumex acetosa type	
Rumex acetosella type	
	Scabiosa
	Senecio type
Tallictrum	
Fungal spores	**Fungal spores**
Cercospora	Cercospora
Podospora type	Podospora
Sordariaceae	
Sporomiella	Sporomiella
Arnium type	
Chaetomium sp.	
Coniochaeta cf. Ligniaria	
Dietre B, Walser C, Lambers K et al. (2014) Palaeoecological evidence for Mesolithic to Medieval climatic change and anthropogenic impact on the Alpine flora and vegetation of the Silvretta Massif (Switzerland/Austria). *Quaternary International* 353: 3-16.	Drescher-Schneider R (2009) Erste pollenanalytische Untersuchungen zur Frage der bronzezeitlichen Vegetationsverhältnisse in der Hirschgrube (Dachstein, Oberösterreich). In: Hebert B and Mandl F (eds.) *Almen im Visier. Dachsteingebirge, Totes Gebirge, Silvretta.* Gröbming: Forschungsberichte der ANISA, 2.

Western Alps				
Pasture indicator pollen	**Pasture indicator pollen**	**Pasture indicator pollen**	**Pasture indicator pollen**	**Pasture indicator pollen**
		Asteraceae		
Chenopodiaceae type	Chenopodiaceae			
	Cichorioidae			
		Juniperus		
		Ligusticum mutellina		
Plantago alpina	Plantago alpina	Plantago alpina		
Plantago lanceolata type	Plantago lanceolata	Plantago lanceolata		
Plantago major type				
	Poaceae	Poaceae		
Potentilla type		Potentilla type		
		Ranunculaceae		
Rhinanthus				
	Rosaceae			
Rumex acetosa type		Rumex		
Rumex acetosella		Rumex		
Scrophulariaceae				
Thalictrum				
Urtica	Urtica	Urtica		
	Other unspecified taxa	Other unspecified taxa	No Information	No Information
Fungal spores	**Fungal spores**	**Fungal spores**	**Fungal spores**	**Fungal spores**
Cercophora sp.				
Podospora/Zopfiella				
Sordariaceae				
Sporomiella				
Haas JN, Wahlmüller N, Kappelmeyer T et al. (2013) Zur Vegetationsgeschichte der Silberenalp im Muotatal SZ an Hand der paläoökologischen Untersuchung der Schattgaden-Moorsedimente. Mitteilungen des Historischen Vereins des Kantons Schwyz 105: 11-32.	Wegmüller S and Lotter AF (1990) Palynostratigraphische Untersuchungen zur spät- und postglazialen Vegetationsgeschichte der nordwestlichen Kalkvoralpen. Botanica Helvetica 100(1): 37-73.	Wick L, van Leeuwen JF, van der Knaap WO et al. (2003) Holocene vegetation development in the catchment of Sägistalsee (1935 m asl), a small lake in the Swiss Alps. Journal of Paleolimnology 30(3): 261-272.	Moe D, Fedele FG, Maude AE et al. (2007) Vegetational changes and human presence in the low-alpine and subalpine zone in Val Febbraro, upper Valle di Spluga (Italian central Alps), from the Neolithic to the Roman period. Vegetation History and Archaeobotany 16(6): 431-451.	Walsh K and Mocci F (2011) Mobility in the mountains: Late third and second millennia alpine societies' engagements with the high-altitude zones in the Southern French Alps. European Journal of Archaeology, 14(1-2): 88-115.

Eastern Alps		
Pasture indicator pollen	**Pasture indicator pollen**	**Pasture indicator pollen**
		Achillea
		Apiaceae
	Artemisia	Artemisia
		Campanulaceae
	Chenopodiaceae	
Ericaceae		
Juniperus		Juniperus
Plantago lanceolata	Plantago lanceolata	Plantago lanceolata
		Plantago major
Poaceae		Poaceae
		Pteridium aquilinum
		Ranunculaceae
		Rosaceae
Rumex type	Rumex	Rumex acetosa
Rumex type	Rumex	Rumex acetosella
Urticaceae	Urtica	
Other unspecified taxa	Other unspecified taxa	Other unspecified taxa
Fungal spores	**Fungal spores**	**Fungal spores**
Cercophora		
Podospora		
Sordaria		Sordaria
Sporomiella		Sporomiella
Heiss AG, Kofler W and Oeggl K (2005) The Ulten Valley in South Tyrol, Italy: Vegetation and settlement history of the area, and macrofossil record from the Iron Age Cult Site of St. Walburg. Palyno-Bulletin of the Institute of Botany, University of Innsbruck 1: 63-73.	Kral F (1993) Ein pollenanalytischer Beitrag zu archäologischen Fragen im Gasteiner Raum. In: Lippert A (ed.) Hochalpine Altstraßen im Raum Badgastein-Mallnitz. Ein interdisziplinäres Forschungsprojekt. Wien: Böcksteiner Montana 10.	Oeggl K, Kofler W and Wahlmüller N (2005) Pollenanalytische Untersuchungen zur Vegetations- und Siedlungsgeschichte im Montafon. In: Rollinger R and Rudigier A (eds): Montafon. Geschichte, Kultur und Naturlandschaft. Band 1: Die naturräumlichen Grundlagen: 183 -207.

Table S2. Anthropogenic indicator pollen types according to different palynological studies carried out in the Alps at altitudes above 1500m a.s.l.

Silvretta	Dachstein	Ötztal
Anthrop. indic. Pollen	**Anthrop. indic. Pollen**	**Anthrop. indic. Pollen**
		Achillea
		Artemisia
		Calluna
	Castanea	Castanea
	Centaurea cyanus	
Cerealia type	Cerealia	Cerealia
	Chenopodiaceae	Chenopodiaceae
		Gentianaceae
		Heracleum
	Juglans	
		Leontodon/Taraxacum type
		Ligusticum mutellina
		Melampyrum
	Plantago lanceolata	Plantago lanceolata
		Plantago major/media
	Pteridium	
	Rumex	Rumex
Secale cereale	Secale	
Urtica	Urtica	Urtica
	Xanthium spinosa type	
		Other unspecified taxa
Dietre B, Walser C, Lambers K et al. (2014) Palaeoecological evidence for Mesolithic to Medieval climatic change and anthropogenic impact on the Alpine flora and vegetation of the Silvretta Massif (Switzerland/Austria). *Quaternary International* 353: 3-16.	Drescher-Schneider R (2009) Erste pollenanalytische Untersuchungen zur Frage der bronzezeitlichen Vegetationsverhältnisse in der Hirschgrube (Dachstein, Oberösterreich). In: Hebert B and Mandl F (eds.) *Almen im Visier. Dachsteingebirge, Totes Gebirge, Silvretta.* Gröbming: Forschungsberichte der ANISA, 2.	Vorren KD, Mørkved B and Bortenschlager S (1993) Human impact on the Holocene forest line in the Central Alps. *Vegetation History and Archaeobotany* 2(3): 145-156.

Western Alps		Eastern Alps	
Anthrop. indic. Pollen	**Anthrop. indic. Pollen**	**Anthrop. indic. Pollen**	**Anthrop. indic. Pollen**
Apiaceae			
Artemisia			
Asteroidae			
Brassicaceae			
Cannabis			Cannabaceae
		Castanea	Castanea sativa
Centaurea cyanus	Centaurea cyanus		
Centaurea jacea type			
Cerealia	Cerealia	Cerealia	
Chenopodiaceae			
Cichorioidae			
			Hordeum
Juglans		Juglans	Juglans
			Panicum
Plantago			
Poaceae			
Rubiaceae			
Rumex			
	Secale		Secale
			Triticum
Urtica			Urticaceae
			Zea mays
		Other unspecified taxa	Other unspecified taxa
Fungal spores	**Fungal spores**	**Fungal spores**	**Fungal spores**
different fungal spores			
as fire and eutrification			
indicators			
Argant J, López-Sáez JA and Bintz P (2006) Exploring the ancient occupation of a high altitude site (Lake Lauzon, France): comparison between pollen and non-pollen palynomorphs. Review of Palaeobotany and Palynology 141(1-2): 151-163.	Haas JN, Wahlmüller N, Kappelmeyer T et al. (2013) Zur Vegetationsgeschichte der Silberenalp im Muotatal SZ an Hand der paläoökologischen Untersuchung der Schattgaden-Moorsedimente. Mitteilungen des Historischen Vereins des Kantons Schwyz 105: 11-32.	Kral F (1993) Ein pollenanalytischer Beitrag zu archäologischen Fragen im Gasteiner Raum. In: Lippert A (ed.) Hochalpine Altstraßen im Raum Badgastein-Mallnitz. Ein interdisziplinäres Forschungsprojekt. Wien: Böcksteiner Montana 10.	Oeggl K, Kofler W and Wahlmüller N (2005) Pollenanalytische Untersuchungen zur Vegetations- und Siedlungsgeschichte im Montafon. In: Rollinger R and Rudigier A (eds): Montafon. Geschichte, Kultur und Naturlandschaft. Band 1: Die naturräumlichen Grundlagen: 183 -207.

Chapter 3

The history of human land use activities in the Northern Alps since the Neolithic Age.

A reconstruction of vegetation and fire history in the Mangfall Mountains (Bavaria, Germany)

Fridtjof Gilck, Peter Poschlod

The Holocene 31(4): 579–591.

Abstract

Millenia of sustainable, low intensity land use have formed the cultural landscapes of central Europe. Studies from the Central Alps show that mountain pastures also look back onto many thousand years of land use history. In this palynological and pedoanthracological study in the border region between Germany and Austria in the Mangfall Mountains, we aim to close the knowledge gap that exists for the German part of the Northern Alps, where no conclusive evidence for the onset of pastoral activities has been presented so far. Our results reveal strong evidence, that mountain pasture use in this region reaches back to the Iron Age at least. However, the reconstruction of vegetation and fire history indicates human interaction with the environment much earlier, starting in the Neolithic Age, where we found evidence of slash and burn activities and first occurrences of pasture indicator pollen. A rising number of mega charcoal pieces dated the Bronze Age suggest increased slash and burn activities, possibly linked to the creation of open space for pasturing. Due to methodological constraints the differentiation between pasturing, hunting or other activities proves difficult. Nevertheless, our results provide profound evidence of human interaction with the mountain environment, beginning in the Neolithic Age and clear evidence of mountain pasture use beginning in the Iron Age at 750 BC. Further archaeological studies in this area could add valuable information to our findings and shed more light onto the early history of farming activities in the Northern Alps.

Keywords: prehistoric alpine farming, palynology, pedoanthracology, prehistoric land use, fire history, Northern Alps

Introduction

Central European landscapes are strongly shaped by millennia of human land use practices (Poschlod, 2017). Among these cultural landscapes, mountain pastures are an especially species rich and therefore valuable habitat (Chemini and Rizzoli, 2003). High altitudes in the European Alps though have often been regarded as an ecosystem with a shorter and less intensive history of human land use activities. More and more studies, however, reveal that human interaction with the environment and land use at high altitudes in the Alps have a much longer history than previously thought (eg Dietre et al., 2020; Hafner and Schwörer, 2018; Kutschera et al., 2014; Mandl, 2006; Putzer et al., 2016b; Reitmaier, 2017). The use of mountain pastures enabled early farmers to expand their settlements or even produce excess food for purposes by reducing the pressure on the scarce agricultural land in the often-narrow alpine valleys (Reitmaier and Kruse, 2019). Seasonal livestock management is a common practice in mountain regions until today and farmers still value mountain pastures as an important part of their farming practice. Most of the studies dedicated to understand early land use history at high altitudes in the Alps are concentrated in the Central Alps, and the northern fringe of the Alps, especially the German part, remains poorly investigated (Gilck and Poschlod, 2019). Very few archaeological single discoveries indicate human presence in the German Alps in prehistoric times and allow for no precise understanding of their interaction with their environment (Uenze and Katzameier, 1972). Archaeological and archaeobotanical studies from Tyrol in Austria however show, that the northern fringe of the Alps was a region which was already frequented starting very early by Mesolithic and Neolithic hunters, miners, and settlers (Bachnetzer and Leitner, 2011; Leitner, 2003; Schumacher, 2004; Von Scheffer et al., 2019). This study therefore aims to fill this knowledge gap and investigate human interaction with the environment throughout the Holocene in the Bavarian Alps. To achieve this, we reconstructed the vegetation of the last 7500 years using palynological methods to identify signs of first human impact on the vegetation. Additionally, we used charcoal analysis to reconstruct the fire history of the region. Previous studies could show that additional charcoal analysis can be a very useful tool for better understanding human impact on the environment (eg Gobet et al., 2003; Nelle et al., 2010; Poschlod and Baumann 2010; Tinner et al., 2005). Especially the use of identifiable soil charcoals as indicators of local fire events provides additional and valuable information (Nelle et al., 2010). Furthermore, we used geochemical parameters, like organic matter content and C/N-ratio, which gives us more information about the history of the peatland and local factors influencing the peatland. The results of our study were compared with recent climate reconstructions, which allows for a better differentiation between natural and human induced vegetation changes in our study area.

Material and Methods

Study area

The study was carried out in a peatland situated at 1450m a.s.l. in the district of Miesbach in Bavaria (Germany; fig. 1). The complex geology of the site with a mixture of marl (Kössener Schichten), dolomite (Hauptdolomit), different sorts of limestone (Plattenkalke, Jurakalke, Kreidegesteine, Rhätkalk) and glacier deposits combined with the typical sub oceanic mountain climate of the northernmost chains of the Limestone Alps facilitated the forming of several peatlands in the surrounding (Dietmair, 2001). The area is protected by the European NATURA 2000 network and the Ramsar Convention on Wetlands of International Importance since 2007 (Faas et al., 2007). The peatland covers the whole bottom and the slopes of a Polje (Karst depression with a natural brook that vanishes into a Ponor) and is divided by the Austrian-Bavarian border. The size of the peatland is approximately seven hectares and it is part of an alpine pasture system (Bayerische Wildalm), which is still grazed by horses on the Bavarian side and by cattle on the Austrian side (Faas et al., 2007). Grazing intensity, and land use intensity in general, however decreased over the last centuries (Faas et al., 2007).

Several archaeological findings from the surrounding of the study area indicate very early human activities in the region. Research from the Rofan Mountains, only 15km south of our sampling site, reveals proof for human activities in high mountain areas beginning in the Mesolithic Age (Bachnetzer and Leitner, 2011; Kompatscher and Kompatscher 2005; Leitner et al., 2011). Beginning in the Mesolithic Age, humans reportedly began to hunt and mine flint stone and radiolarite deposits in the Rofan Mountains at altitudes around 2000m a.s.l. (Bachnetzer and Leitner, 2011; Kompatscher and Kompatscher, 2005; Leitner et al., 2011). This, together with findings from the Fotschertal (Ullafelsen) south of Innsbruck, demonstrates, that Mesolithic hunters and miners already populated the Northern Alps (Schäfer, 1998). Excavations of stone tools of northern alpine and southern alpine origin in the Fotschertal revealed, that these tools were transported via mountain pass routes over the whole Alpine ridge from the Italian- to the Bavarian Alps during the Mesolithic Age (Schäfer, 1998). The excavations in the Rofan Mountains show a continuous presence of humans throughout the Mesolithic, Neolithic, Bronze, and Iron Age. Bones from goat and sheep dating to the Iron Age indicate alpine pasture use at approximately 2000m a.s.l. in the Rofan Mountains (Bachnetzer and Leitner, 2011). Further proof for the early use of mountain passes between the Inntal and the Bavarian lowlands is provided by Raetian rock inscriptions close to the Schneidjoch at 1600m (2.5km from our study site), which clearly prove human presence at a time around 500 BC (Schumacher, 2004). Contrary to the Austrian side, the Bavarian side of the study area lacks substantial evidence for Mesolithic and Neolithic activities. Findings of rock engravings from another site at 1200m a.s.l. in the vicinity of the peatland suggest human presence during the early Bronze Age (Scherm, 2012). This finding, however, has not been scientifically confirmed yet, but together with the inscriptions at the Schneidjoch indicates human presence along mountain pass routes from the Inn Valley to the German foothills of the Alps. Further evidence of prehistoric human activities on the Bavarian side of our study area is scarce and based only on single discoveries (Uenze and Katzameier, 1972). Noteworthy is the excavation of a big ceramic vessel on the northern side of the Tegernsee, which dates to the late Bronze Age and by its size indicates settlements in the foothills of the Alps, as the transport of such a vessel seems unlikely (Heim, 2012).

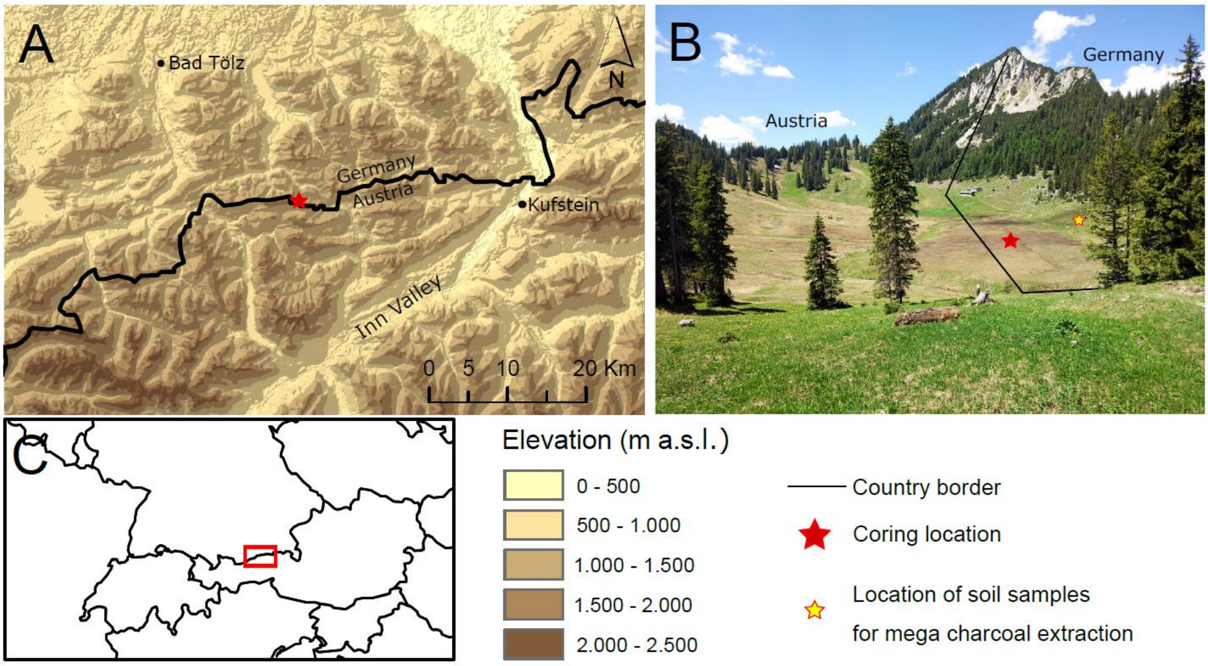

Figure 1. Location of the Bayerische Wildalm peatland. Source of the Digital Terrain Model: EU-DEM v.1.1 from Copernicus. Foto: F. Gilck

Field work

On the 4th of November 2016, a fist sediment core (WA-1) was taken with a Russian-type peat corer (Belokopytov and Beresnevich, 1955) with a 6cm wide and 50cm long coring chamber on the Bavarian side of the peatland. A depth of 360cm was reached. Due to physical constraints we were not able to cover the whole depth of the mire. Therefore, another attempt was made on the 21st of September 2017, where a second sediment core (WA-2) with a length of 425cm was taken at the identical location following the same sampling approach. Both cores were immediately wrapped in plastic and after transportation to the University of Regensburg, the cores were stored at 4°C in a cooling chamber. In the summer of 2017 two soil profiles from the direct surrounding of the peatland were taken for soil charcoal analysis. The samples were washed through a 1mm sieve and charcoal pieces were extracted. Ten selected charcoal pieces were sent to the Curt-Engelhorn-Zentrum for Archäometrie in Mannheim, Germany for radiocarbon dating.

Chronology

The age-depth model of the core is based on eight radiocarbon dates (tab. 1) obtained from plant macro remains at selected depths from the two peat cores WA-1 and WA-2. The radiocarbon dates were measured with Accelerated Mass Spectrometry (AMS) at the Curt-Engelhorn-Zentrum for Archäometrie in Mannheim, Germany and calculated according to Stuiver and Polach (1977). Calibration of the ^{14}C-dates took place with the software SwissCal (L. Wacker, ETH-Zürich) using the IntCal13 calibration curve (Reimer et al. 2013). The package Clam (Blaauw, 2010) within the R environment v. 3.4.0 (R Core Team, 2017) was used to calculate an age-depth model (fig. 2) based on Monte Carlo sampling with 10 000 iterations, using a smoothing spline (with a smoothing level of 0.3). According to the model, accumulation rates are very stable, varying between 12 years/cm in the upper part of the core and 27 years/ cm in the lowest part of the core.

Table 1: AMS radiocarbon dates performed on peat cores from the Bayerische Wildalm.

Lab Nr.	Depth [cm]	14C Age [years BP]	δ13C AMS [‰]	Cal 2-sigma	C [%]	Material
30497	59	943 ± 22	-46.0	cal AD 1029-1154	15.2	Bulk peat
30498	81	939 ± 21	-35.4	cal AD 1032-1154	22.5	Bulk peat
30499	133	1967 ± 22	-32.3	cal BC 36-cal AD 77	37.3	Bulk peat
44689	160	2490 ± 23	-24.6	cal BC 770-540	51.4	Bulk peat
30500	240	3864 ± 23	-31.3	cal BC 2461-2214	32.4	Bulk peat
44690	315	4625 ± 27	-26.7	cal BC 3506-3352	2.7	Bulk peat
30501	360	5102 ± 25	-32.3	cal BC 3967-3802	45.3	Bulk peat
44691	422	6586 ± 28	-19.1	cal BC 5612-5482	40.7	Bulk peat

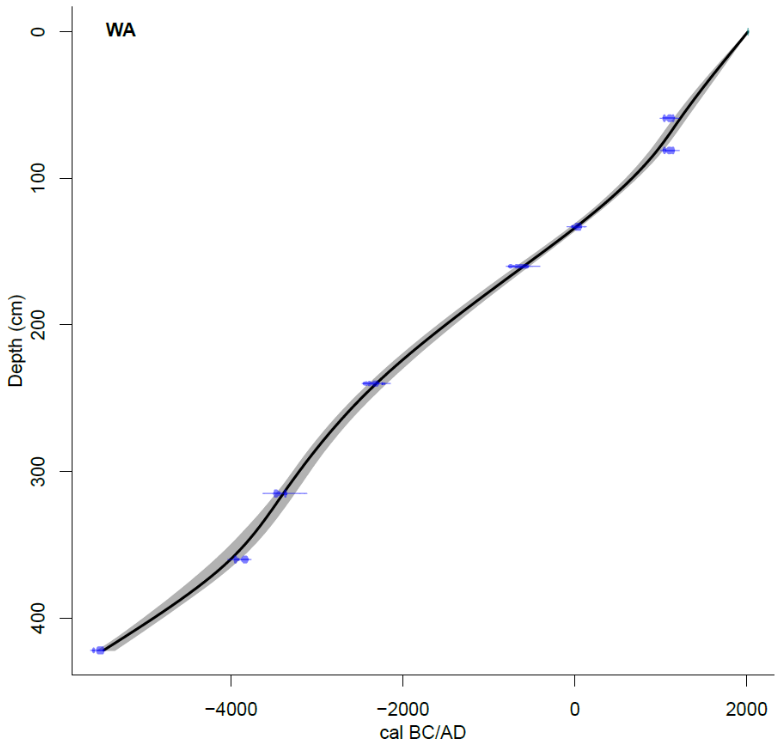

Figure 2: Age-depth model of the Bayerische Wildalm stratigraphy based on 14C-dating.

Palynological analysis

For the pollen analysis subsamples of the first 360cm sediment core (WA-1) and the lowest part (360cm–425cm) of the second 425cm sediment core (WA-2) were taken. Size of the subsamples was 1cm³. In a first step subsamples from every 5-6cm were selected and analysed. In a second step, after reviewing preliminary pollen data, areas of special importance were selected, and further subsamples were taken at these selected depths. In some parts of the core, samples from every 3cm were analysed so that the total number of samples reached 96. Unfortunately, due to the local occurrence of *Lycopodium clavatum* and *Lycopodium annotinum* we could not use *Lycopodium* spores for the calculation of concentrations and influx values (Stockmarr, 1971). The samples were treated following the standard acetolysis method (Fægri et al., 2000; Moore et al., 1991). After treatment with 10% HCl and 10% KOH, samples were sieved with 160µm mesh size. Treatment with concentrated cold HF for 48h prior to acetolysis was used for samples with high mineral content. Samples were mounted in glycerine. Pollen and spores were identified under the light microscope at 160x-1000x magnification, using a refence collection, as well as identification keys and pollen atlases (Beug, 2004; Fægri et al., 2000; Moore et al., 1991). A minimum of 350 pollen was counted per slide and a total of 94 pollen types was identified. The sum for calculation of pollen percentages includes trees, shrubs and herbs, whereas spores and Cyperaceae pollen were excluded due to their possible local origin from the peatland. The definition of pastoral pollen indicators follows Behre (1981), Festi (2012) and Gilck and Poschlod (2019). Following the method of Poschlod and Baumann (2010), linear regression analysis between the most acknowledged and most used pasture indicator species, *Plantago lanceolata* and other potential indicator species was performed to identify further local indicator species (tab. 3).

Geochemical analysis

For the geochemical analysis 96 subsamples with a size of 4cm³ were taken from the exact depths where pollen analysis was conducted. A small part of these subsamples was pulverized, and total Carbon and total Nitrogen was measured by the Institute of Analytical Chemistry of the University of Regensburg. The remaining part of the subsamples was used to measure organic matter content of the peat using Loss on Ignition (LOI). Our protocol followed the recommendations of Heiri et al. (2001). The second heat treatment at 950°C for estimating carbonate content was left out, since it does not add information, relevant to our research questions. The samples were dried for 48h at 75°C, weighed and then treated with 550°C in a furnace for 4h, before being weighed again.

Statistical Methods

Non-metric Multidimensional Scaling (NMDS) using Bray-Curtis dissimilarity was performed on the complete pollen dataset with the community ecology package vegan v. 2.4-5 (Oksanen et al., 2017). The pollen diagrams were constructed using the quaternary science package rioja v. 0.9-21 (Juggins, 2019). CONISS, temporally constrained hierarchical clustering (Grimm, 1987) based on Euclidean vegetation dissimilarity was used to estimate stratigraphic zones in the pollen data. The broken stick method (Bennett, 1996) was used to evaluate the number of significant stratigraphic clusters. All analyses were performed in the R environment v. 3.4.0 (R Core Team, 2017).

Results

Pollen analysis

The NMDS graph partly reflects the chronology of cultural epochs and shows a correlation of the pollen spectrum with time (fig. 3). Generally, older samples from the Neolithic Age and the Bronze Age are located in the lower part of the diagram, whereas more recent samples from the Iron Age, Middle Age or Modern Times are situated more in the upper part.

Pollen samples dating to the early Neolithic Age form a distinct group in the lower left part of the graph and are characterized by tree species like *Ulmus, Corylus avellana,* and *Tilia,* together with aquatic and semi aquatic plants like *Potamogeton* and *Sparganium*. Pollen samples assigned to the Neolithic Age show a wide distribution but are also located in the lower part of the graph. These samples are characterized by coniferous forest species like *Picea abies, Abies alba* and *Pinus.* The amount of charcoal and Arboreal Pollen (AP) is also correlated to these samples. The Bronze Age samples exhibit a denser pattern and are located centre-right in the NMDS graph. They are characterized by *Picea abies, Abies alba* and *Fagus sylvatica.* Samples from the Iron Age are widely distributed over the right side, many of them tending to the upper part of the graph, which correlates to pasture indicator species (eg *Plantago lanceolata*) and Non-Arboreal Pollen (NAP) such as *Cyperaceae, Cereal type* and *Poaceae*. Samples assigned to the Roman- and especially the Migration Period are again located lower in the graph and are therefore characterized by typical closed forest species (*Picea abies, Abies alba, Fagus sylvatica*). The Middle Age and Modern Time pollen samples are clearly differentiated in the upper part of the graph and are characterized by *Cyperaceae, Poaceae, Plantago lanceolata* and Cereal type pollen. Additionally, Non-Arboreal Pollen are correlated to these samples.

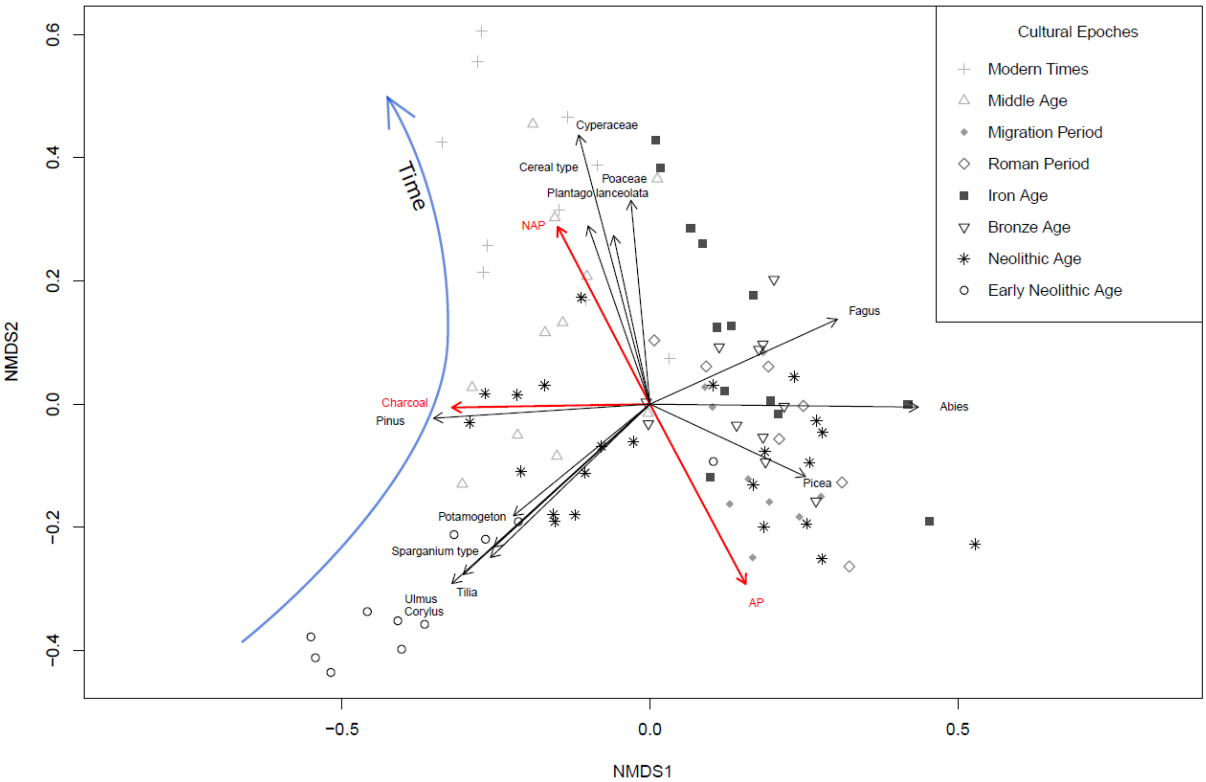

Figure 3: Non-metric Multidimensional Scaling (NMDS) of the whole pollen data set from the Bayerische Wildalm peatland (district of Miesbach, Bavaria, Germany, 1450m a.s.l.). Stress of the NMDS is 0,12. Samples are categorized according to their age and affiliation to cultural epochs.

The Broken Stick Model based on the CONISS cluster analysis identified two main pollen zones, which are subdivided to a total of eight significant subzones (fig. 4). The first main pollen zone, LPAZ 1 ranges from 5500–2100 BC and is characterized by a high abundance of tree pollen (> 80%), with strongly changing proportions of the different taxa over time. LPAZ 2 is characterized by a drop in tree pollen and increases in pollen from herbaceous plant species, especially *Poaceae* and pasture indicator species. In the following a brief description of the different subzones is given.

LPAZ 1a: 5500 – 4200 BC, Early Neolithic Age

In the lowest section of the core, Arboreal Pollen largely dominates the pollen spectrum with a share of more than 85% (fig. 4). Among them the most common pollen types are *Picea abies, Pinus* and *Corylus avellana* with appr. 20% each. Other common Arboreal Pollen types in this zone are *Alnus, Betula, Quercus* and *Tilia*. The pollen spectrum of herbaceous species consists of aquatic or semi-aquatic plants like *Potamogeton* and *Sparganium* but also includes open landscape indicator species like *Cichorioidae*, *Apiaceae* and *Ranunculus acris* type. Pasture indicator pollen are represented by *Artemisia, Chenopodiaceae, Senecio* type and *Campanula* type. The amount of micro charcoal is high in this zone with up to 0.75 charcoal fragments/pollen.

LPAZ 1b: 4200 – 3400 BC, Neolithic Age

Arboreal Pollen values remain high, or even increase to values between 85-95%. Compared to LPAZ 1a, the composition of the Arboreal Pollen taxa changes substantially. *Picea abies* increases up to 40% of the pollen sum, whereas the amount of pollen from *Pinus* and *Corylus avellana* decreases. *Abies alba* and *Fagus sylvatica* pollen show an increase, whereby the curve of *Fagus sylvatica* seems to react slightly delayed. *Alnus, Betula* and *Quercus* do not change much, however values of *Ulmus* and *Tilia* decrease. Interestingly *Poaceae* pollen values show a slight increase in this zone, even though Arboreal Pollen are increasing their dominance. Open landscape indicators and pasture indicators decrease to nearly zero. Equisetum spores exhibit a very high abundance in LPAZ 1b with values close to 60% relative to the pollen sum. Micro charcoals decrease substantially to a minimum of 0.04 fragments/pollen.

LPAZ 1c: 3400 – 2100 BC Late Neolithic Age – Early Bronze Age

At the begin of LPAZ 1c the share of Arboreal Pollen drops to values below 80% and *Poaceae* simultaneously increase to values up to 12%. Towards the end of this zone Arboreal Pollen slowly increase back to values around 90% and *Poaceae* decrease to a minimum of 1%. The composition of Arboreal Pollen changes again. *Abies alba* and *Fagus sylvatica* decrease while *Pinus, Corylus avellana,* and to a smaller extent *Alnus* increase. This pattern, however, is reversed toward the end of the zone, where *Abies alba* and *Fagus sylvatica* increase and *Corylus avellana* and *Pinus* decrease again. The *Picea abies* pollen curve drops sharply at the beginning of LPAZ 1c but recovers to maximum values close to 50% toward the end of the zone. *Ulmus* and *Tilia* are still present at the beginning of the zone and vanish around 2500 BC. Open landscape indicator species on the contrary are increasing. Amongst them especially *Cichorioidae* and *Apiaceae* increase to maximum values of 4.5% and 1.9% in the first half of the zone. Beginning at 2800 BC, pasture indicator species like *Rumex, Plantago lanceolata* and *Senecio type* have scattered occurrences. *Equisetum* spores, which have very high numbers in the previous zone, decrease in this zone to nearly zero, before increasing again at the end of the zone. Simultaneous to this decrease *Filicales* spores increase, and the amount of micro charcoal particles reaches its maximum over the whole core with values up to 1.7 fragments/pollen.

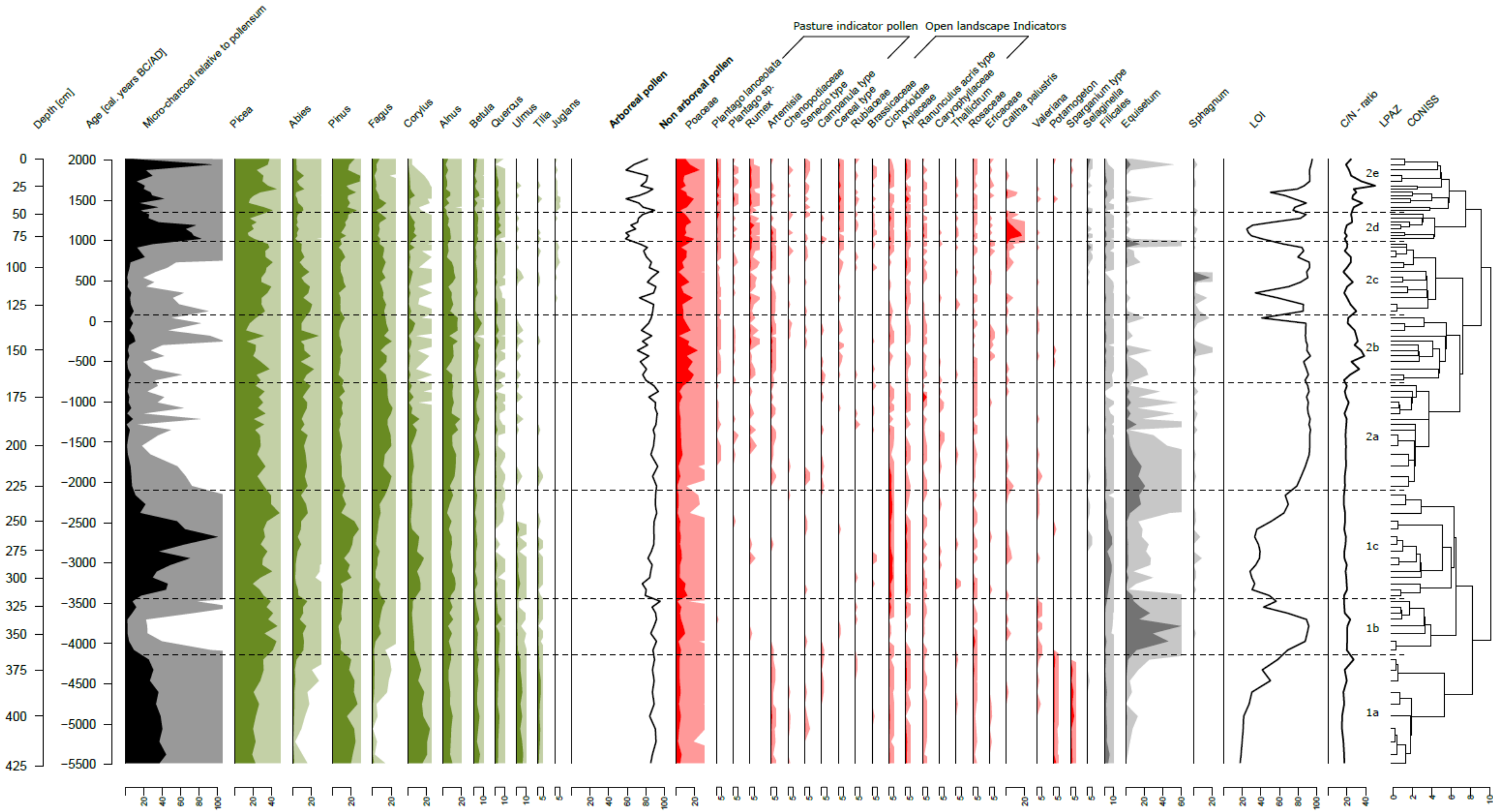

Figure 4: Palynological diagram for selected pollen taxa and spores from vascular cryptogams as well as micro charcoal particles found in 96 peat samples from the Bayerische Wildalm peatland (district of Miesbach, Bavaria, Germany, 1450m a.s.l.). Pollen and spore taxa are expressed as percentage values of the 100% pollen sum (excluding Cyperaceae). Micro charcoals are also weighed by the 100% pollen sum and normalized to 100%. Light-colour silhouettes represent a 10-fold exaggeration of the percentage values. LOI (Loss on Ignition) shows the organic matter content of the sediment core in percent.

LPAZ 2a: 2100 – 800 BC Bronze Age

In LPAZ 2a Arboreal Pollen remain largely dominant with a relative share around 90%. The composition of the species though changes again. *Pinus* and especially *Picea abies* decrease, whereas *Fagus sylvatica* and *Alnus* increase. Among the herbaceous species, open landscape indicators like *Cichorioidae* and *Apiaceae,* which had high abundances in the previous zone, decrease. However, pasture indicator pollen types like *Plantago* species and *Rumex* show a first continuous occurrence starting at appr. 1600 BC. *Artemisia,* another pasture indicator pollen type is present from the beginning of the zone. *Equisetum* spores are especially frequent at the beginning, micro charcoals show low values throughout the zone (mostly below 0.1 fragments/pollen).

LPAZ 2b: 800 BC – 50 AD Iron Age – Early Roman Period

At the beginning of this zone at 800 BC, Arboreal Pollen decrease sharply from values around 90% to values below 75%. Especially *Picea abies* shows a strong decrease after a short initial increase. There is also a slightly negative trend for *Abies alba*. Other arboreal species show a more variable picture. *Fagus sylvatica* and *Alnus* curves recover after an initial decrease and the *Pinus* curve is stable on a comparatively low level. Amongst Non-Arboreal Pollen especially the strong increase of *Poaceae* pollen to values above 15% (in one sample 23%) is noteworthy. The main pasture indicator pollen types, *Plantago lanceolata, Rumex, Artemisia* and to a lesser extent *Campanula* have continuous occurrences in this zone. Cereal pollen as another indicator for human presence show an increased occurrence in this zone as well. *Equisetum* spores decrease after a peak in the previous zone (LPAZ 2a) and the amount of micro charcoal fragments remains low with 0.1 fragments/pollen on average.

LPAZ 2c: 50 – 1000 AD Roman Period – Migration Period – Early Middle Age

LPAZ 2c is characterized by higher amounts of Arboreal Pollen with values mostly above 85% of the pollen sum. Compared to the previous zone especially *Picea abies* increases strongly whereas *Abies alba, Fagus sylvatica* and *Alnus* show a slight decrease over time. Another noteworthy finding is the first occurrence of *Juglans* at 300 AD which consolidates around 500-600 AD. Amongst pasture indicator species, *Plantago lanceolata* and *Artemisia* show a decrease before increasing again at the end of the zone. *Rumex* exhibits a more indifferent pattern but also increases toward the end. Other pasture indicators and cereal pollen are nearly absent and only reappear at the end of LPAZ 2c. In the second half of the zone, beginning at 500 AD *Selaginella* spores show a continuous presence, and micro charcoal fragments remain on a low level before increasing slightly towards the end of this zone.

LPAZ 2d: 1000 – 1350 AD Middle Age

This zone reveals the strongest drop in the share of Arboreal Pollen to values below 60%. *Picea abies* and *Abies alba* show the largest decline, whereas *Pinus, Corylus avellana* and, to a small extend, *Quercus* increase. The *Poaceae* curve remains high and among the pasture indicator species especially *Rumex* becomes more frequent. Other pasture indicator species, however, show a more scattered occurrence or even a decline (eg *Artemisia*). The cereal pollen curve is now completely closed, and open landscape indicator species show an increase compared to the previous zone. Noteworthy is also a marked peak in *Caltha palustris,* which reaches more than 15% of the pollen sum around 1100 AD. Micro charcoal fragments show a big increase in this zone, peaking at 1.4 fragments/pollen.

LPAZ 2e: 1350 AD – Modern Day

In the most recent section of the core the share of Arboreal Pollen varies strongly with two minima of 59% around 1500 AD and around 1900 AD. In between of these two minima the share of Arboreal Pollen reaches values above 80%. These strong changes are reflected in the curves of most arboreal species as well. Especially pollen of *Pinus* and *Picea abies* vary strongly with a generally slightly increasing trend for both. *Abies, Fagus* and *Quercus* are decreasing and *Juglans* reaches its highest share over the whole core at 0.6% around 1400 AD. The *Poaceae* curve fluctuates strongly, opposite to the curve of Arboreal Pollen and reaches its maximum at 25% around 1900 AD. Among the pasture indicator pollen, *Plantago lanceolata, Rumex* and *Senecio* type have a continuous occurrence

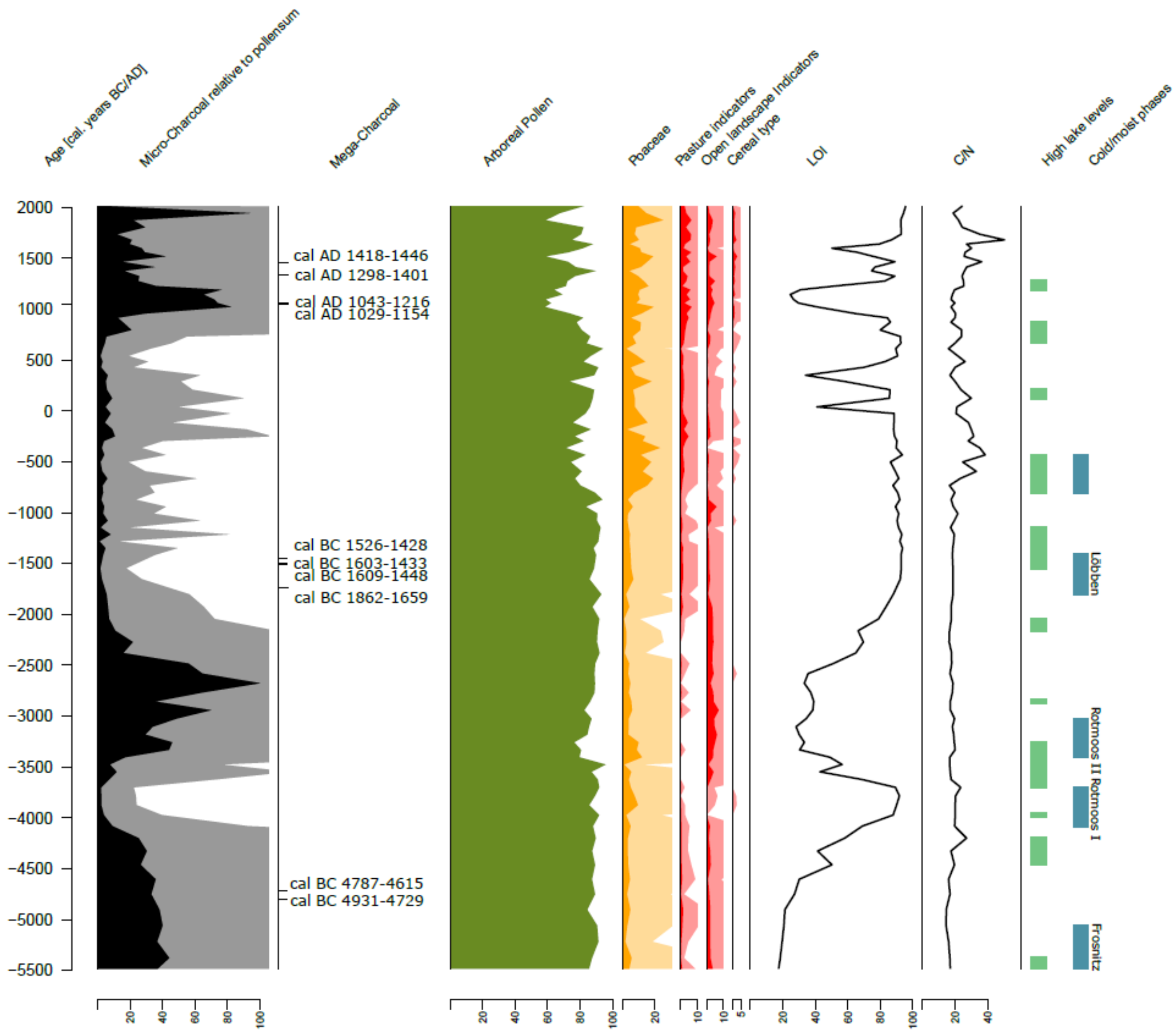

Figure 5: Palynological diagram for selected groups of pollen taxa. Pollen and spore taxa are expressed as percentage values of the 100% pollen sum (excluding Cyperaceae). Micro charcoals are also weighed by the 100% pollen sum and normalized to 100%. Light-colour silhouettes represent a 10-fold exaggeration of the percentage values. LOI (Loss on Ignition) shows the organic matter content of the curve in percent. Additional information about radiocarbon dated Soil charcoal fragments is given, as well as high lake levels indicating phases with cooler climate according to Magny (2004) and cold phases inferred from glacier movements according to Patzelt (1977).

Soil charcoal analysis

The analysis of soil charcoals from two soil profiles close to the peatland reveals evidence for three major fire events. The oldest one dates to the Neolithic Age with nearly 5000 BC consisting of two *Gymnosperm* charcoal pieces (fig. 5 and tab. 2). Another four pieces date to the early Bronze Age between 1500 – 1800 BC. They consist of two pieces of *Picea/Larix,* one piece of *Abies alba* and one piece of *Gymnosperm* charcoal. The last fire event dates to the Middle Age around 1100 – 1400 AD and consists of two fragments of *Pinus,* one fragment of *Picea/Larix* and one fragment of *Acer* sp.

Table 2: AMS radiocarbon dates, performed on soil charcoals from the Bayerische Wildalm (district of Miesbach, Bavaria, Germany, 1450m a.s.l.).

Lab Nr.	Depth [cm]	14C Age [years BP]	δ13C AMS [‰]	Cal 2-sigma	C [%]	Weight [mg]	Species
38517	20-30	476 ± 19	-25.9	cal AD 1418-1446	56.4	7.6	*Acer sp.*
44695	20-30	609 ± 21	-22.4	cal AD 1298-1401	56.6	6.7	*Pinus sp.*
44699	40-50	889 ± 27	-32.6	cal AD 1043-1216	59.9	0.8	*Picea/Larix*
44693	30-40	944 ± 19	-23.6	cal AD 1029-1154	61.7	3.2	*Pinus sp.*
44698	20-30	3208 ± 25	-27.3	cal BC 1526-1428	25.7	9.6	*Picea/Larix*
44696	10-20	3229 ± 25	-23.5	cal BC 1603-1433	28.7	6.0	Gymnosperm
44697	10-20	3245 ± 24	-22.4	cal BC 1609-1448	53.3	10.8	*Picea/Larix*
38518	40-50	3420 ± 21	-21.1	cal BC1862-1659	60.4	6.7	*Abies alba*
44694	30-40	5841 ± 28	-28.6	cal BC 4787-4615	21.9	10.0	Gymnosperm
44692	40-50	5951 ± 36	-36.6	cal BC 4931-4729	20.2	1.8	Gymnosperm

Geochemistry

Organic matter content, measured with the Loss on Ignition method (LOI), varies greatly throughout the whole peat core (fig. 4 and 5). At the beginning, in the deepest and oldest part, it is very low with 18% but rises continuously to a maximum of 91% at 3800 BC. It decreases again quickly and reaches a low point at 3100 BC with 28%. Over the course of the next 1500 years it rises slowly and reaches 92% around 1600 BC. It remains very high, around 90%, until 50 AD, when a phase with several short minima begins with an initial minimum of 40% at 50 AD. At 300 AD, there is another very short minimum of 34% before recovering back to values around 90%. The biggest minimum is centered around 1000 AD, with 24% at 1150 AD and a subsequent rise to 88% at 1300 AD. Around 1600 AD the organic matter content falls to another local minimum of 50% before it reaches its maximum value of 95% in the uppermost part of the core. The various minima in organic matter content, especially in the younger part of the core were also visible with the bare eye as grey sandy/silty bands in the otherwise brown/black peat.

C/N-ratio starts with low values around 15 in the deepest and oldest part of the core (fig. 4). Right before the transition from LPAZ 1a to LPAZ 1b at 4200 BC it shortly rises to 27, before decreasing to around 20, where the C/N ratio remains low between 17 and 21 for 3500 years until 700 BC. At this point, at the transition between LPAZ 2b and LPAZ 2c the C/N ratio rises quickly to maximum values of 38 around 400 BC. There is a general decreasing trend with a few ups and downs for the next 800 years, with minimum values of 16. After that, the ratio increases again strongly, reaching its maximum of 50 at 1700 AD and then decreases to values around 20 at the upper end of the core.

Discussion

Pasture Indicator Pollen

As this research is especially aimed at identifying the begin of alpine pasturing in the Bavarian Alps, special consideration is given to the selection of pasture indicator pollen types. Pasture indicator pollen types are widely used to detect human impact on the vegetation, but only few publications are dedicated to the question of defining indicator pollen types. This causes an inconsistency in the use of pasture indicator pollen types in palynological studies across the Alps (see appendix of Gilck and Poschlod, 2019). Frequently used are the indicator pollen types defined by Behre (1981) and Oeggl (1994) for pasture indicator pollen types in an alpine environment. Festi (2012) used an experimental approach, comparing modern pollen rain with the present vegetation, to detect local pasture indicator pollen types in a montane and subalpine environment. Still, the selection of suitable indicator pollen types for our study poses difficult for several reasons.

First, many typical pasture plants for subalpine and alpine pastures are summarized in large groups because morphological differentiation of the pollen to species level is difficult or impossible. Examples for these are *Ranunculus* type*, Cichorioidae, Brassicaceae, Apiaceae,* and others. This entails the problem, that these groups, besides typical pasture plants, often include species which are not typical for open pastures. Yet, many of these pollen types are used in palynological studies at subalpine and alpine elevations as pasture indicator pollen (eg Drescher-Schneider, 2009; Oeggl et al., 2005; Röpke et al., 2011; Wick et al., 2003; for more see appendix of Gilck and Poschlod, 2019). Because of the abovementioned problem we decided against the use of these groups as pasture indicator pollen types (with the exception of *Chenopodiaceae,* which in the Alps are an ecologically very homogeneous group and generally accepted as a good pasture indicator pollen type). We, however, included most of these groups in another, broader category as open landscape indicators, because a majority of the plant species in these groups are inhabitants of open landscapes and they are generally regarded as indicators of human impact in the Alps (Oeggl, 1994).

Another difficulty with the identification of pasture indicator pollen types are the different pollination systems and differences in pollen production of plants. Due to insect pollination and low pollen production, many typical pasture indicator species are strongly underrepresented in pollen records, which makes them unsensitive indicators for small scale changes. Wind pollinated pasture species on the other hand have the disadvantage, that they are potentially of a regional source, which makes local landscape changes difficult to assess (Brun, 2011). Nevertheless, wind pollinated pasture species with a high pollen production like *Plantago, Rumex, Artemisia, Chenopodiaceae*, due to their strong representation in pollen records are the most popular and most used pasture indicator species in palynological studies in the Alps (see Appendix Gilck and Poschlod, 2019). Therefore, we decided to include them into the selection of pasture indicator species in this study as well. *Campanula* type was included following the suggestions of Oeggl (1994) and especially Festi (2012), who found this pollen type indicative of subalpine meadows and pastures.

The regression analysis performed with the most acknowledged pasture indicator species *Plantago lanceolata* and other potential pasture indicators confirms the abovementioned selection of pasture indicator species (tab. 3). Additionally, it shows, that *Senecio* type might also be a suitable pasture indicator. This group includes many plant genera typical for alpine pastures, like *Antennaria, Aster, Bellis, Doronicum, Erigeron* and *Homogyne*. *Selaginella* and *Ericaceae* were not considered despite their correlation with *Plantago lanceolata*, because of their local occurrence in the peatland (*Calluna vulgaris* and *Selaginella selaginoides* are both present in the current vegetation of the peatland). *Brassicaceae* and *Cichorioidae,* which showed correlations with *Plantago lanceolata* as well, were excluded due the wide ecological range of their species. One shortcoming of this regression analysis, however, is that *Plantago lanceolata* is considered to be an archaeophyte (Kühn and Klotz, 2002). This might make it an unsuitable pasture indicator species for the early Neolithic Age because the species arrived in Central Europe only during the Neolithic Age. This could be the reason why we could not find a correlation with *Artemisia,* which is strongly represented in our pollen record in the Neolithic Age (fig. 4).

As our study site and the wider surrounding is situated well below the natural tree line, the ratio between Arboreal Pollen and Non-Arboreal Pollen is also a good indicator for human impact on the vegetation since the natural vegetation at our study site is closed forest, and climate induced tree line shifts can be ruled out in the time period covered by this study.

Table 3: Results of the correlation analysis of potential pasture indicator pollen with Plantago lanceolata. Significant results are indicated by bold script ($p < 0.05$). Species used as pasture indicators in our study are indicated with grey background.

Species	R^2 adj.	p
Rumex	**0.36**	**7.1E-11**
Plantago non lanceolata	**0.38**	**1.5E-11**
Poaceae	**0.20**	**3.37E-06**
Chenopodiaceae	**0.14**	**0.0001**
Senecio	**0.13**	**0.0002**
Ericaceae	**0.13**	**0.0002**
Brassicaceae	**0.07**	**0.0062**
Selaginella	**0.04**	**0.025**
Cichorioidae	**0.03**	**0.044**
Thallictrum	0.03	0.064
Valeriana	0.02	0.081
Rubiaceae	0.02	0.1
Artemisia	0.01	0.14
Caryophyllaceae	0.00	0.31
Ranunculus acris type	0.00	0.41
Campanula	0.00	0.47
Rosaceae	0.00	0.58
Apiaceae	0.00	0.87

General patterns

The results of the NMDS give a good overview over the general patterns and major changes in the pollen composition and reveal changes on three different levels. First, the development of the local vegetation in the peatland can be observed. Aquatic plants, like *Potamogeton* and *Sparganium* type in the Early Neolithic Age indicate the presence of a shallow water lake, and high amounts of *Cyperaceae* pollen in the more recent samples, indicate the terrestrialisation and development of a *Cyperaceae*-rich peatland from the lake.

Secondly, the change in forest composition becomes apparent. The change from *Ulmus, Tilia* and *Corylus avellana* in the Early Neolithic to *Picea abies, Abies alba, Pinus* and increasingly *Fagus sylvatica* in the following epochs mirrors the general development in the forest composition during the Holocene (Küster, 2010; Magry, 2008; Poschlod, 2017). Third, the strong association of the old samples with Arboreal Pollen and the more recent samples with Non-Arboreal Pollen reflects the landscape changes, from closed natural forests to a more open landscape with *Plantago lanceolata, Poaceae* and cereal type pollen. This indicates human impact on the vegetation with deforestation followed by pasture use and crop cultivation in the lowlands.

LPAZ 1a: 5500 – 4200 BC, Early Neolithic Age

The presence of *Potamogeton* and *Sparganium* type pollen in this layer clearly suggests the presence of a (shallow water) lake at our study site during the Early Neolithic Age. The low organic matter content values further support the idea of a small lake on mineral underground. Rising levels of organic matter content toward the end of this zone show a process of terrestrialisation of the lake and the development of a mire. The strong dominance of Arboreal Pollen suggests forest landscape, however the high amount of micro charcoal and the presence of identifiable soil charcoal pieces at the border of the peatland are strong indicators of local fire events. As already observed in other studies (eg Tinner at al., 2005), fire activity changes the forest composition with decreases of fire sensitive species like *Fagus sylvatica* and *Picea abies* and increases in *Corylus avellana* and *Pinus* (most likely *Pinus mugo*)(fig.4). Since natural fires in this climate zone are rare and unlikely (Carcalliet, 1998; Müller at al., 2013) and climate reconstructions show a cooling phase until around 5000 BC (fig. 5, Magny, 2004; Patzelt, 1977), the high amount of micro- and soil charcoal could be explained by human slash and burn activities in the vicinity of the peatland. Especially the dated soil charcoals from our study site at nearly 5000 BC (fig. 5) are strong evidence for local fires. Mesolithic or Neolithic hunters could have populated the area and burned the forest in the surrounding of the peatland for hunting purposes. This theory is further supported by archaeological proof of Mesolithic hunting and mining activities in the nearby Rofan Mountains (Kompatscher and Kompatscher, 2005; Bachnetzer and Leitner, 2011; Leitner et al., 2011) and Mesolithic movements of humans across alpine pass routes (Schäfer, 1998). Another indicator for local human disturbance is the strong presence of open landscape and pasture indicator pollen types for this time (fig. 4). Especially the presence of pollen from insect pollinated plants (*Senecio* type, *Campanula* type, *Apiaceae, Cichorioidae, Ranunculus acris* type) suggests the local establishment of open meadow patches after disturbance by fire. These results could therefore also indicate the use of summer pastures by Neolithic settlers. Studies from the Central Alps show, that Neolithic settlers already used mountain pastures around 4500 BC with small ruminants like sheep and goat (Hafner and Schwörer, 2018; Kutschera et al., 2014). The area of the forming peatland might have been a very attractive site for early herders or hunters as it provided a naturally open area and drinking water for the animals.

LPAZ 1b: 4200 – 3400 BC, Neolithic Age

This zone is characterized by a strong increase in organic matter content, together with a strong peak in *Equisetum* spores, which indicates the progressing terrestrialisation and peat formation. The begin of this zone at 4200 BC coincides with the begin of the Rotmoos I glacier advances (Patzelt, 1977), and high lake levels (Magny, 2004), indicating a phase of cold and moist climate. This is reflected in the pollen diagram by decreasing curves of the warm adapted species *Ulmus* and *Tilia*. This climatic deterioration might also have triggered a decrease of human activity in the region, which is supported by very low micro charcoal values, together with a decreasing frequency of pasture and open landscape indicator pollen types (fig. 4 and 5). The decreasing fire activity is also reflected in the forest composition, where fire sensitive species such as *Abies, Picea* and *Fagus* increase and pioneer species like *Corylus* and *Pinus* (*Pinus mugo*) show strong decreases.

LPAZ 1c: 3400 – 2100 BC Late Neolithic Age – Early Bronze Age

The transition to LPAZ 1c at 3400 BC is marked with a drop in both, organic matter content and *Equisetum* spores, indicating a permanent or periodical flooding of the peatland. As the peat accumulation rate remains stable it can be assumed, that periodical flooding of the growing peatland caused the influx of mineral material into the peat. This flooding could be caused by different drivers. The Rotmoos II glacier advances (Patzelt, 1977) and high lake levels (Magny, 2004) suggest, that a climatic deterioration with higher precipitation, increased snowfall in winter and periodical flooding of the mire during snowmelt might have led to this development. This scenario gains credibility by the fact, that in recent years in cases of strong snow melt, the peatland was also temporarily flooded (Faas et al., 2007). Deforestation for hunting purposes on the slopes around the peatland could also have led to an increased water runoff, facilitating more frequent flooding events or avalanches in winter. High micro charcoal contents, together with increasing open landscape indicator pollen types show, that increasing human activities could indeed have played a role (fig. 4 and 5). The observed increase in *Filicales* spores could also be a reaction to fire events as many ferns profit from fire (eg *Pteridium* aquilinum). The increased fire activity is again reflected in the forest composition. Fire sensitive species (*Picea, Abies, Fagus*) decline, whereas pioneer species (*Pinus, Corylus, Alnus*) increase. The lack of dated soil charcoal pieces and the scarcity of pasture indicator pollen for this period, however, suggests, that the source of the increased micro charcoal influx is of a rather regional origin, and not caused by local fires of farmers around the peatland.

LPAZ 2a: 2100 – 800 BC Bronze Age

In the Bronze Age indicators of human impact on the local vegetation become more frequent. Most importantly four out of ten dated soil charcoal pieces date to this period between 1900 – 1400 BC. This is strong evidence for local fire events, possibly linked to slash and burn forest clearings around the peatland. This is further supported by an increase in pasture indicator pollen types, which show continuous presence in this zone. The increase of *Alnus* pollen could also be explained by human slash and burn activities in the vicinity of the peatland, since *Alnus alnobetula* (= *Alnus viridis*) is a strong pioneer plant, which profits from open landscapes and disturbance (Ellenberg and Leuschner 2010). Increased hunting activities, or pasture use around the mire by Bronze Age farmers could be the reason for the observed changes in the pollen spectrum. This would be in agreement with many other studies, which found evidence for first pasture use at high altitudes in the Alps, beginning in the Bronze Age (eg Dietre et al., 2012, 2020; Drescher-Schneider, 2009; Festi et al., 2014; Mandl, 2006; Putzer et al., 2016b; Walsh et al., 2007; Walsh and Mocci, 2011; Wick et al., 2003). Archaeological and dendrochronological studies from several sites in Tyrol in Austria show, that the Bronze Age was also a period of intensive copper mining in the Northern Alps (Pichler et al., 2009, 2018). Alpine pasturing, therefore, could have developed or intensified for providing mining communities in the mountains with food.

LPAZ 2b: 800 BC – 50 AD Iron Age – Early Roman Period

The strong decrease in Arboreal Pollen at the begin of LPAZ 2b at 750 BC indicates strong human impact on the vegetation around the peatland. The amount of Arboreal Pollen drops below 75%, which according to Magny et al. (2006) and Dietre et al. (2020) represents a threshold value for open landscapes. Since the peatland is situated well below the tree line, climatic factors cannot be made responsible for these changes. Simultaneous rises in *Poaceae* pollen and pasture indicator pollen suggest that land use and pasturing took place in the surrounding of the peatland. Especially the presence of *Campanula* pollen indicates local pasturing activities, as this is an underrepresented pollen type originating from local sources only (Oeggl, 1994). The low values of micro charcoals and the lack of dated soil charcoals are evidence for only small and possibly regional fire events and could indicate that the main slash and burn forest clearings in the direct surrounding of the peatland already took place during the Bronze Age (fig. 4). The simultaneous rise in cereal pollen suggests intensified settling activities with crop cultivation in the Bavarian lowlands and the Inn valley. Some authors suggest that cereal pollen, found at higher altitudes could have been transported there also by livestock during migration to their summer pastures (Argant et al., 2006; Moe, 2014). This would add further emphasis to the suggestion of summer pastures in the direct vicinity of the peatland. Archaeological and archaeobotanical studies from the Central Alps confirm our findings by showing the begin or an intensification of alpine pasture use at higher altitudes during the Iron Age (eg Carrer et al., 2016; Festi et al., 2014; Haas et al., 2013; Heiss et al., 2005; Putzer 2009). The Raethian inscriptions at the Schneidjoch at 1600m a.s.l. close to our coring site (Schuhmacher, 2004) and archaeological evidence for summer farming in the Rofan Mountains above 2000m a.s.l. (Bachnetzer and Leitner, 2011) are further proof for human activities in this area during the Iron Age and complement the results of our study very well. Another interesting feature is the sudden rise in C/N ratio at the begin of this zone after it remained very stable throughout the lower part of the core. These changes could be triggered by local disturbances in the peatland caused by intensive pasturing and local dung deposition by the grazing animals.

LPAZ 2c: 50 – 1000 AD Roman Period – Migration Period – Early Middle Age

This period is characterized by recovering Arboreal Pollen values and decreasing curves of *Poaceae* and pasture indicator values. This trend could be associated to the crisis and population decline during the migration period, followed by the downfall of the Roman Empire. This population decline lead to decreasing land use intensity, and since arable land and pastures were better available in the lowlands, mountain pastures became less attractive for farmers. The nearly complete absence of pasture indicators from local sources like *Campanula* type and *Senecio* type further emphasizes the decline in land use intensity. Absence of cereal pollen in the first half of this zone further demonstrates, that land use intensity also decreased strongly in the lowlands. Toward the end of this zone, in the early Middle Ages, Arboreal Pollen decreases strongly, and pasture indicators increase. This development corresponds to the increasing population density in the Middle Ages and the associated increased land use intensity (Poschlod, 2017). The first occurrence of *Juglans* pollen in this zone is evidence for the introduction of this species as a fruit tree by the Romans (Poschlod, 2017).

LPAZ 2d: 1000 – 1350 AD Middle Age

During the High Middle Age landscape openness reaches its maximum, which is reflected in very low Arboreal Pollen values below 60%. According to Magny et al., (2006) and Dietre et al., (2020) this is a strong indicator for open landscapes. Simultaneously pasture- and open landscape indicator pollen increase, indicating expanding pasturing activities. This corresponds well to historical information, which believes the Middle Ages to be the period in human history with the maximum of open landscape and very intensive land use, caused by a strong population growth in Central Europe (Poschlod, 2017). More evidence for increased land use intensity is provided by the results of the pedoanthracological analysis. Micro charcoals have a large peak during the High Middle Ages, indicating regional forest clearings by fire, and several dated soil charcoals from the edge of the peatland are evidence for local fire clearing activities as well. Increasing *Corylus* and *Alnus* pollen suggest disturbance, probably caused by slash and burn activities. Forest clearings and intensive pasturing in the surrounding of the peatland could have increased soil erosion, and in the case of extreme weather events, strong runoff from the slopes could have washed mineral material into the peatland.

This is supported by a very high amount of mineral material in the peat during the High Middle Ages (fig. 4 and 5). Also, frequent avalanches from the surrounding slopes, caused by a lack of protecting tree cover, could transport mineral material into the peatland. The strong peak of *Caltha palustris* pollen around 1100 AD could be a result of these changes in the peat. The high amount of mineral material could have facilitated the strong spread of the species over the whole peatland.

LPAZ 2e: 1350 AD – Modern Day

The strong fluctuations of the Arboreal Pollen curve, *Poaceae* pollen and pasture indicator pollen in the last period between the Late Middle Ages and modern day indicate strong changes in land use intensity, locally and regionally, around the peatland. Frequent wars and climatic deteriorations (Little Ice Age) might have contributed to declines in land use intensity. However, the closed cereal pollen curve and the high pasture indicator pollen curve demonstrate, that land use was never given up entirely in the direct surrounding of the mire and in the adjacent valleys. Several peaks in micro charcoals could be signs of more forest clearing events by fire but could also originate from burning of villages and towns during eg the Thirty-Years' War, since micro charcoal particles can travel large distances by wind.

Conclusion

Our study demonstrates that human interaction with the vegetation in the Bavarian Alps has a very long history. Pollen data and soil charcoal analysis revealed possible hunting or herding activities in the Early Neolithic Age above 1400m a.s.l., which is a unique finding for the German Alps. Further signs of summer pasturing around the Bayerische Wildalm appear in the Bronze Age, with evidence for local fire clearings and subsequent occurrences of pasture indicator pollen. Very strong evidence for summer pasturing is found beginning in the Iron Age around 800 BC. Strong decreases in Arboreal Pollen, increases in pasture indicator pollen and archaeological data from the surrounding suggest intensified land use activities in the area for that time. Further changes in land use intensity, linked to population fluctuations (decline in the Migration Period, increase during the Middle Ages) are reflected very well in the pollen curves and the charcoal data. This illustrates that our multi proxy approach, using soil charcoal analysis together with palynology is a reliable method to reconstruct former land use patterns and can uncover the interaction of our ancestors with nature for time periods where written sources are unavailable.

Chapter 4

Reconstruction of the fire history in the Bavarian Alps

A pedoanthracological study in a mountain pasture system

Abstract

Pedoanthracology or soil charcoal analysis is a powerful tool for the reconstruction of the local fire history of a region throughout the Holocene. Especially in the Northern Alps, due to the rarity of naturally induced fires, this method enables us to reconstruct past human land use patterns. Slash and burn forest clearance facilitated the establishment of summer pastures in the subalpine and montane belt of the Alps. To reconstruct such fire events, we analysed charcoal from five soil samples and two soil profiles from a mountain pasture system at 1450m a.s.l. in the Bavarian Alps. 10 selected charcoal pieces were radiocarbon dated. Our results reveal three periods of increased fire activity. The first in the Early Neolithic Age at nearly 5000 BC, the second in the Bronze Age around 1500 BC and the third in the Middle Ages around 1100-1400 AD. This indicates very early human activities in this area. In the begin, fire could have been used to create open space for hunting purposes, later for the establishment of summer pastures in this naturally forest covered landscape.

Introduction

The use of soil charcoal (mega charcoal) for the reconstruction of past human influences on the vegetation offers great additional possibilities compared to classical palynological methods as well as micro- and macro charcoal approaches (Nelle et al., 2010). In contrast to micro- and macro charcoal, soil charcoal or mega charcoal has the advantage, that the fragments are big enough (> 1mm) to be identified under the microscope, based on the wood anatomy which remains mostly intact after burning of the wood. This approach therefore allows to draw conclusions on past forest compositions and dynamics (Carcaillet, 1998; Carcaillet and Muller, 2005; Poschlod and Baumann, 2010; Saulnier et al., 2011; Talon, 2010; Touflan et al., 2010). Another advantage based on the size of mega charcoal is the inability of the charcoal pieces to travel large distances by wind or in water. Thus, the analysis of mega charcoal pieces allows the reconstruction of fire events and forest compositions on very fine and local scales (Nelle et al., 2013; Robin and Nelle, 2014). For example, altitudinal changes of the alpine treeline throughout the Holocene can be reconstructed using soil charcoal analysis (Carcaillet and Muller, 2005; Talon, 2010).

In this study we use soil charcoal analysis for the reconstruction of human induced fire events (slash and burn activities) in a mountain pasture system in the Bavarian Alps. Müller et al. (2013) showed, that naturally induced fires in the Northern Alps are rare, and fire history reconstruction from the Northern Alps reveal, that Holocene fire events are mostly human induced and not correlated with climatic changes (Carcaillet, 1998; Tinner et al., 2005). This demonstrates that soil charcoal is a good proxy for reconstructing past human land use practices in our study area. Since it is often difficult to differentiate between local and regional signals in palynological studies (see data from the same study site in the previous chapter), this approach gives us a good opportunity to better understand local and site-related changes of vegetation and fire activity.

Materials and Methods

The study was carried out at the Bayerische Wildalm peatland (1450m a.s.l.) in the Mangfall Mountains in the district of Miesbach. The peatland covers the whole bottom and the slopes of a Polje (Karst depression) and is divided by the Austrian-Bavarian border. The size of the peatland is approximately seven hectares and it is part of an alpine pasture system (Bayerische Wildalm), which is still grazed by horses on the Bavarian side and by cattle on the Austrian side (Faas et al., 2007).

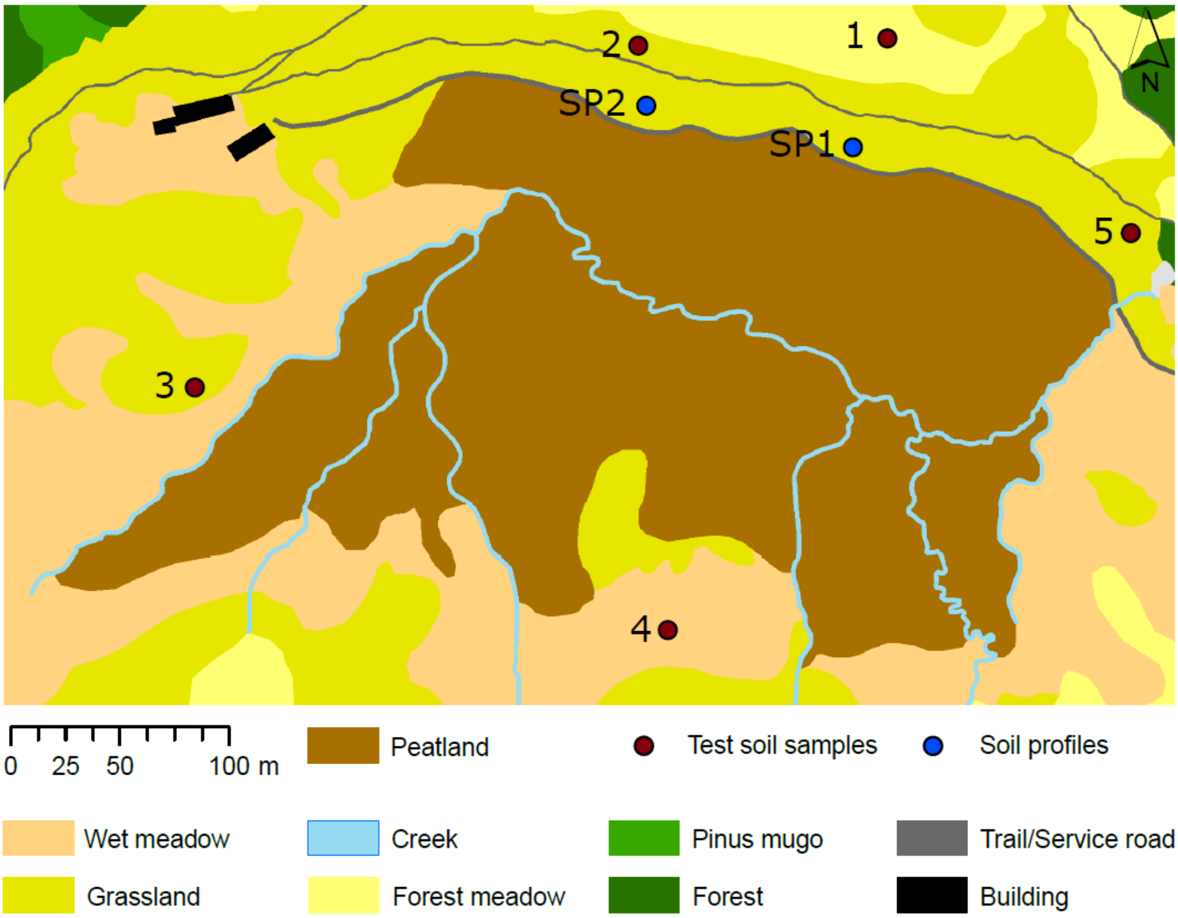

Figure 1: Location of the soil samples and soil profiles taken around the Bayerische Wildalm peatland at 1450m a.s.l. For more information on the location, geology and history of the peatland see the Material and Methods section of the previous chapter.

Several archaeological findings from the surrounding of the study area indicate very early human activities in the region. Research from the Rofan Mountains, only 15km south of our sampling site, reveals proof for human mining activities in high mountain areas beginning in the Mesolithic Age and throughout the Neolithic, Bronze, and Iron Age (Bachnetzer and Leitner, 2011; Kompatscher and Kompatscher 2005; Leitner et al., 2011). Proof for the early use of mountain passes between the Inntal and the Bavarian lowlands is provided by Raetian rock inscriptions close to the Schneidjoch at 1600m (2.5km from our study site), which clearly prove human presence at a time around 500 BC (Schumacher, 2004). Contrary to the Austrian side, the Bavarian side of the study area lacks substantial evidence for Mesolithic and Neolithic activities. Findings of rock engravings from another site at 1200m a.s.l. in the vicinity of the peatland suggest human presence during the early Bronze Age (Scherm, 2012). This finding, however, has not been scientifically confirmed yet, but together with the inscriptions at the Schneidjoch indicates human presence along mountain pass routes from the Inn Valley to the German foothills of the Alps.

In a first step, five test soil samples with a size of approximately 5-10l were taken at random sites all around the peatland in June 2017 (fig. 1). Samples covered a soil depth of 0-30cm. After evaluation of the charcoal content in these test samples, two soil profiles were dug in the colluvial sediments of the south facing slope directly adjacent to the peatland (see fig. 1). 20l of soil were extracted every 10cm in soil profile 1. Maximum depth of this profile was 80cm. In soil profile 2 the samples were smaller with 10l per 10cm. Maximum depth of soil profile 2 was 70cm. The soil was wet sieved with a mesh width of 1mm and all charcoal pieces bigger than 1mm in diameter were selected for further analysis. The charcoal pieces were identified, using a reflected-light microscope with magnification up to 500x (Zeiss, Axio Imager 2, light and dark field) and the identification keys of Schweingruber (1990) and Schoch et al. (2004) as well as a reference collection of charred wood, which was compiled by the author. The fragments were cut manually to obtain surfaces of transversal, tangential and radial orientation. Ten selected charcoal pieces were sent to the Curt-Engelhorn-Zentrum for Archäometrie in Mannheim, Germany for radiocarbon dating. In order to test for an age-depth relationship, at least one piece of charcoal from every layer, which contained charcoals of a sufficient size (except from the uppermost layer), were dated.

Results

Results of the five test soil samples from the surrounding of the Bayerische Wildalm peatland show, that the charcoal concentration in the samples varies strongly from only one piece of charcoal in sample 5, up to 50 charcoal pieces in sample 3. In sample 2-5 *Picea/Larix* and *Picea/Larix/Abies* charcoal fragments make up the majority of the identified charcoal pieces. *Pinus* is largely dominant in sample 1 and otherwise occurs only in sample 3.

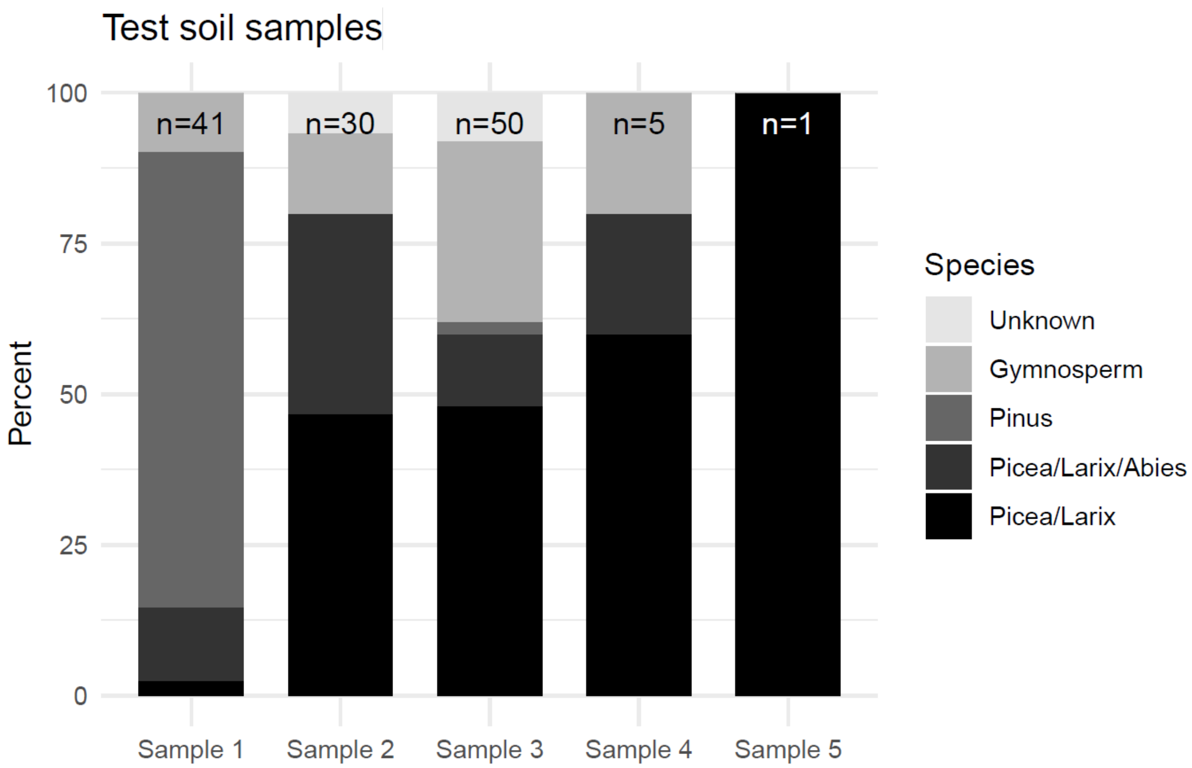

Figure 2: Results of the charcoal analysis of the five test soil samples from the surrounding of the Bayerische Wildalm peatland.

Table 1: AMS radiocarbon dates, performed on soil charcoals from the Bayerische Wildalm (district of Miesbach, Bavaria, Germany, 1450m a.s.l.).

Lab Nr.	Soil Profile	Depth [cm]	14C Age [years BP]	δ13C AMS [‰]	Cal 2-sigma	C [%]	Wei ght [mg]	Species
38517	WA SP1	20-30	476 ± 19	-25.9	cal AD 1418-1446	56.4	7.6	*Acer sp.*
44695	WA SP1	20-30	609 ± 21	-22.4	cal AD 1298-1401	56.6	6.7	*Pinus sp.*
44699	WA SP1	40-50	889 ± 27	-32.6	cal AD 1043-1216	59.9	0.8	*Picea/Larix*
44693	WA SP1	30-40	944 ± 19	-23.6	cal AD 1029-1154	61.7	3.2	*Pinus sp.*
44698	WA SP2	20-30	3208 ± 25	-27.3	cal BC 1526-1428	25.7	9.6	*Picea/Larix*
44696	WA SP1	10-20	3229 ± 25	-23.5	cal BC 1603-1433	28.7	6.0	Gymnosperm
44697	WA SP2	10-20	3245 ± 24	-22.4	cal BC 1609-1448	53.3	10.8	*Picea/Larix*
38518	WA SP1	40-50	3420 ± 21	-21.1	cal BC1862-1659	60.4	6.7	*Abies alba*
44694	WA SP1	30-40	5841 ± 28	-28.6	cal BC 4787-4615	21.9	10.0	Gymnosperm
44692	WA SP1	40-50	5951 ± 36	-36.6	cal BC 4931-4729	20.2	1.8	Gymnosperm

Soil profile 1 (WA SP1) contained a total of 107 charcoal pieces in all layers. The layer between 20cm and 30cm contained the highest number of charcoals with more than 50 pieces. The number decreases continuously in the layers above and below. Gymnosperm species dominate the spectrum and amongst them *Picea/Larix* charcoals occur with the highest frequency. Angiosperm charcoal is only present between 20cm and 30cm with few charcoal pieces from *Fagus* and *Acer*.

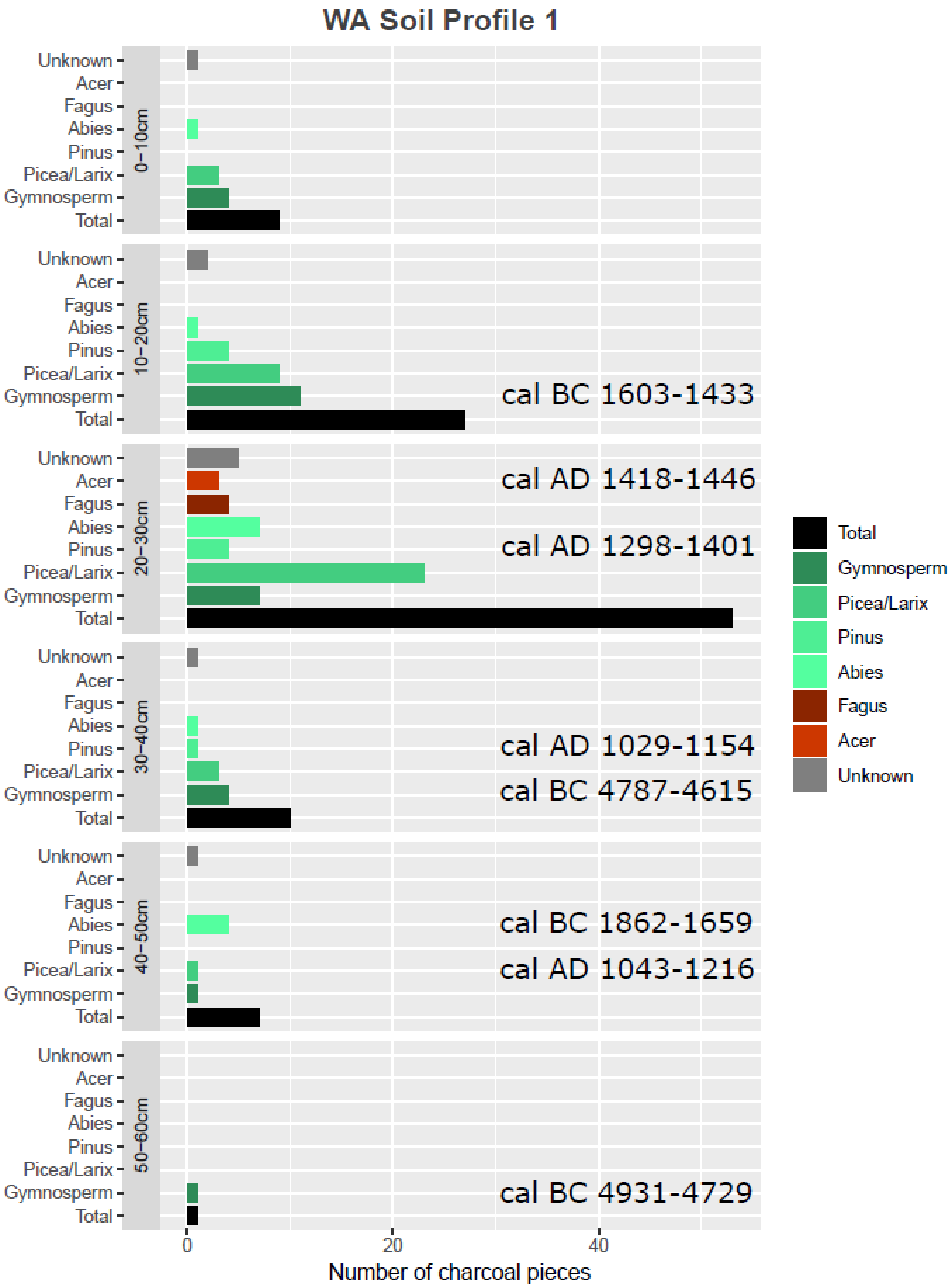

Figure 3: Result of the mega charcoal analysis of soil profile 1. For location of the soil profile see fig. 1.

Radiocarbon dating reveals no clear correlation between depth and age of the dated charcoals. Soil profile 2 (WA SP2) shows a similar distribution of the charcoal fragments with the highest number of charcoals at 20-30cm and declining numbers above and below. This soil profile contained a total of 57 charcoal pieces. However, concentrations (2.5/l at 20-30cm) are comparable to soil profile 1 (2.7/l at 20-30cm) because of the smaller sample size in soil profile 2. The species composition is also similar to the first soil profile, with a dominance of *Picea/Larix* and only one piece of *Fagus* and one piece of *Acer* in the uppermost layer of soil profile 2. The two radiocarbon dates allow no final assessment of a depth-age relationship.

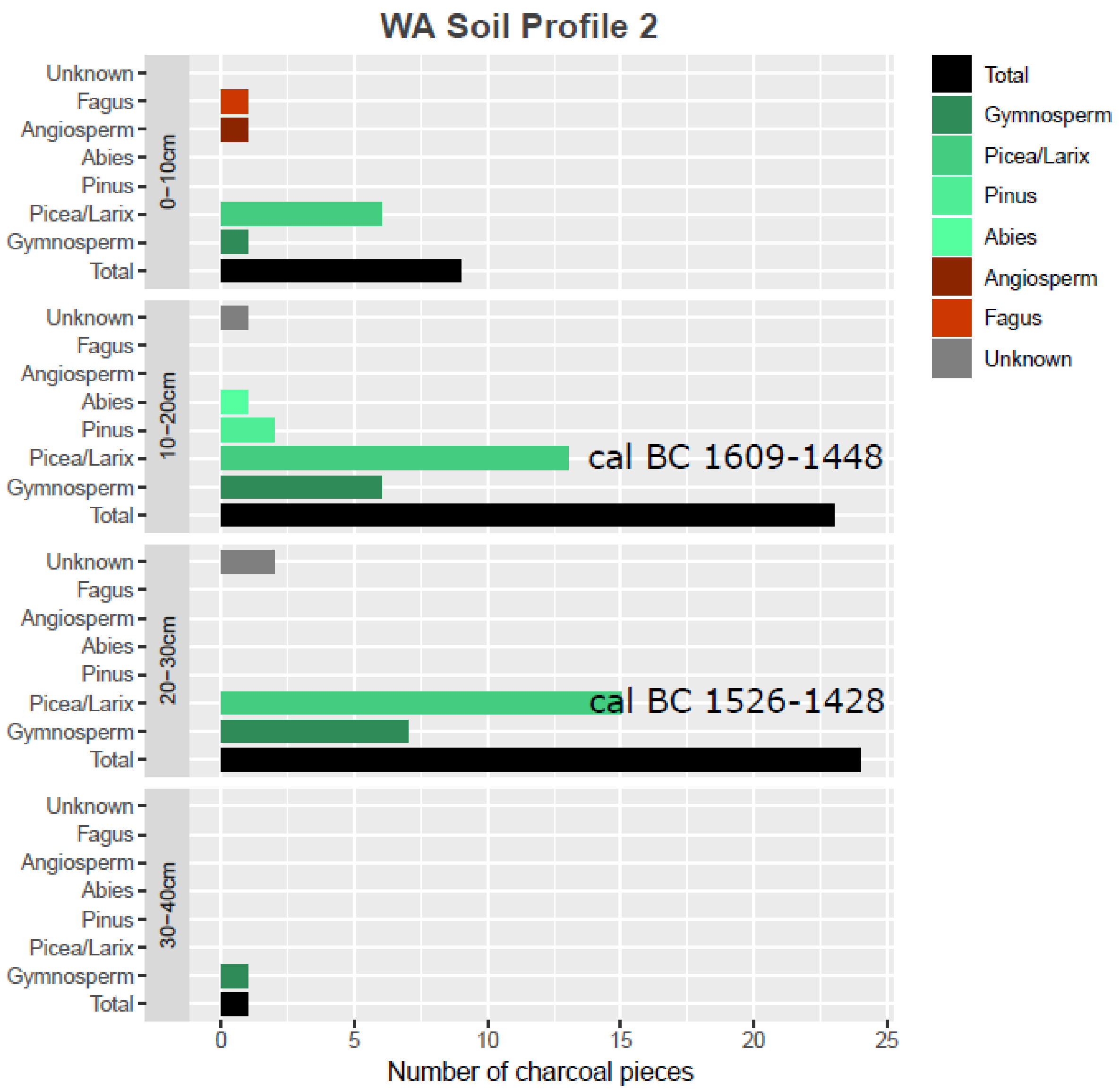

Figure 4: Result of the mega charcoal analysis of soil profile 2. For location of the soil profile see fig. 1.

Discussion

The analysis of the test soil samples reveals very big differences in the charcoal concentration depending on the location of the sampling site. Two samples from the eastern and southern side of the peatland contained nearly no charcoal, whereas the charcoal concentration in the remaining three samples was very high in comparison. This shows, that with the analysis of soil charcoal, reconstructions of fire events on a very fine spatial scale are possible (Nelle et al. 2013, Robin and Nelle 2014). The strong differences in species composition between the test samples (especially between sample 1 on the others) puts further emphasis on the local source area of the soil charcoals. In general, however, the current forest composition with a dominance of spruce (*Picea abies*), frequent occurrence of mountain pine (*Pinus mugo*) at the forest edges and few sycamore (*Acer pseudoplatanus*) and beech (*Fagus sylvatica*) trees in the forest is well reflected in the species composition of the charcoals from the test soil samples. The soil profiles reveal a more detailed picture, caused by larger samples and vertical sampling. Compared to the test samples, the current forest composition is reflected more precise in the charcoal composition in both soil profiles with additional findings of *Fagus* and *Acer* charcoal pieces. It is, however, difficult to infer past forest composition from these results. Radiocarbon dating shows, that some of the charcoal pieces date back to nearly 5000 BC but the dates also show, that the different soil layers cannot be assigned to distinct age groups. Soil layers are intermixed and therefore charcoal pieces from the same layers date to very different time periods. Carcaillet (2001) explained an observed missing stratigraphy in alpine and subalpine soils in the French Alps with increased bioturbation by soil fauna, soil reworking by uprooted trees and freeze thaw processes. Since the soil in our samples was extremely loamy and therefore very compact, bioturbation by soil fauna seems unlikely. The absence of trees in the direct vicinity of the sampling sites and a very shallow rootzone (10cm) in the soil profiles make bioturbation by roots seem unlikely as well. Another possible cause for the lack of stratigraphy at our sampling sites could be extreme weather events with strong soil erosion from the slopes around the peatland which could have led to a rearrangement of charcoal fragments in the soil. Such extreme weather events did occur especially toward the end of the Middle Ages when landscape openness reached its maximum (Poschlod 2017). Flooding events like the infamous millennial flood in 1342 could have caused extreme soil erosion events around the Bayerische Wildalm peatland. Findings of mineral horizons in the peat stratigraphy of the mire (see previous chapter) which were probably caused by erosion of soil from the surrounding slopes further support this theory. Regardless of the missing stratigraphy, the results of this analysis allow to identify three distinct periods of local fire activity. One in the Early Neolithic Age at nearly 5000 BC (two dated charcoal pieces from soil profile 1), another one in the Bronze Age around 1500 BC (four dated charcoal pieces from both soil profiles) and a last period with high fire activity in the Middle Ages around 1100-1400 AD (four charcoal pieces from soil profile 1). All these fire events could be linked to human slash and burn activities, since natural fires on the northern side of the Alps are unlikely and were rare throughout the Holocene (Carcaillet, 1998; Müller et al., 2013; Tinner et al., 2005). In the Early Neolithic Age forest clearing by fire could have been used to open the landscape for hunting purposes and to improve the landscape for foraging (eg Innes et al., 2013). The allocation of the Bronze Age charcoal pieces to both soil profiles shows, that a very local origin of, for example, lightning induced fire is unlikely and therefore a scenario of human induced slash and burn activities gains credibility. Studies from many parts of the Alps show, that the Bronze Age is a time of intensifying land use practices and for many parts the begin of mountain pasture use (Dietre et al., 2012, 2020; Drescher-Schneider, 2009; Festi et al., 2014; Mandl, 2006; Putzer et al., 2016b; Walsh et al, 2007; Wick et al., 2003). This could explain intensified slash and burn activities around our study site during that time. The findings of charcoal pieces dated to the Middle Ages are hardly surprising, since land use intensity and landscape openness reached a maximum during the Middle Ages (Poschlod, 2017). Our results therefore indicate that in our study region land use intensity increased, and more open pastures were created directly around the peatland on the Bayerische Wildalm during the Middle Ages. Hence, this study presents valuable additional information to our palynological study (see previous chapter), especially about local land use changes and human slash and burn activities in our study area.

Chapter 5

Conclusions and Perspectives

The protection of species rich mountain grasslands in the Alps has gained increasing attention in recent years, caused by a decline in traditional low-intensity land use practices, which are responsible for the formation and preservation of these habitats. Intensification and abandonment of mountain grasslands have led to a strong decline in species richness and biodiversity (MacDonald et al., 2000; Spiegelberger et al., 2006; Tasser and Tappeiner, 2002). The high and unique biodiversity of traditionally managed mountain grasslands has been studied in recent years under various aspects (Marini et al., 2009; Rosbakh et al., 2014; Rudmann-Maurer et al., 2008; Spiegelberger et al., 2006; Stöcklin et al., 2007). One increasingly important factor in this discussion is the influence of land use history on the current biodiversity patterns. While for alpine and subalpine grasslands, studies about the effect of land use history on the current vegetation are still scarce (eg Maurer et al., 2006), there have been many studies showing effects of land use history on species diversity and community composition in calcareous grasslands (Gustavsson et al., 2007; Karlík and Poschlod, 2009; 2019; Reitalu et al., 2010). The findings of these studies demonstrate that knowledge about the history and origin of grasslands is an important factor for an understanding of the underlying processes and for an effective management of these increasingly endangered habitats. The determination of the age of man-made grassland habitats in alpine regions and the history of the underlying land use practices can further add important information about the cultural value of these habitats. This study is therefore aimed at identifying the beginning of alpine farming practices - specifically the beginning of mountain pasture use in the Alps.

The second chapter of this thesis gives an overview over the current state of research concerning the begin of alpine farming throughout the Alps. Research from different scientific fields such as archaeology, archaeobotany and linguistics were considered in this research review. It provides evidence of alpine farming practices at high altitudes beginning in the Bronze Age and few palynological studies even suggest pastoral activities for the late Neolithic Age beginning around 4000 BC. This demonstrates the value of mountain pastures above and below the natural tree line not only as biodiversity hotspots but also as part of a many thousand-year-old cultural heritage. Most of these research projects, however, are strongly concentrated at few hot spot areas, mostly in the central Alps. Studies on the history and origin of mountain pasture use in the Northern Alps are therefore scarce. Still, studies in the Montafon (Bringmeier et al., 2015) and Dachstein region (Mandl, 2006) in Austria, and the Bernese Alps in Switzerland (Schwörer et al., 2014) show that mountain pasture use in the Northern Alps began very early as well, at least during the Bronze Age. This seems remarkable since the Northern Alps are commonly characterized by comparatively harsh environmental conditions and are therefore considered to be marginal areas for agricultural production. Archaeological and archaeobotanical evidence of alpine summer farming during the Bronze Age in the Dachstein and Montafon region represent a special case and cannot easily be applied to other parts of the Northern Alps, since alpine farming in these regions might be strongly linked to prehistoric mining activities in the area (Bringmeier et al., 2015; Mandl, 2006). The age determination of alpine farms in the German part of the Northern Alps is mainly based on linguistic studies of alpine farm names (Finsterwalder, 1990; Nowotny, 1991) or archaeological single finds (Uenze and Katzameier, 1972). Linguistic age determination however allows only very unprecise age determinations, and farm names can only be a first indicator of the age of an alpine pasture system. Archaeological single finds are often difficult to interpret, since many artefacts, such as bronze needles, allow no differentiation between for example hunting or pasturing activities.

The third and fourth chapter of this thesis, therefore, aim to add information about the onset and history of alpine farming practices in a hitherto neglected area of the Northern Alps. In these chapters we present a case study based on Palynology, Pedoanthracology and Geochemistry from the Bavarian part of the Northern Alps (Mangfall Mountains), aimed at investigating the history of human impact on the mountain vegetation during the last 7500 years. The results present strong evidence for subalpine pasture use beginning at least in the Iron Age. But pollen data and especially fire reconstructions, based on soil charcoal analysis, indicate human influence on the vegetation much earlier, beginning in the late Neolithic Age around 4500 BC. These results agree with archaeological data from the wider region (Kompatscher and Kompatscher, 2005; Leitner et al., 2011; Scherm, 2012; Schumacher, 2004), which showed evidence for human presence at high altitudes in bordering Tirol (Austria) since the late Mesolithic Age. This study makes it possible to further specify the different forms of pre-historic human impact on this mountain ecosystem. Archaeological research in this region was focused mainly on the flint stone and radiolarite mining activities of local communities in the nearby Rofan Mountains (Kompatscher and Kompatscher, 2005; Leitner et al., 2011). With evidence of slash and burn activities, aimed to create open space for pasturing of livestock at altitudes above 1400m a.s.l., the results of our study can add another aspect to the research of pre-historic human activities in the Northern Alps. Considering the scarcity of archaeological evidence for pre-historic human presence in the surrounding lowlands, especially on the Bavarian side (Uenze and Katzameier, 1972), our results seem even more remarkable and demonstrate the big potential for archaeobotanical and archaeological research in this region. Our findings of human impact on the mountain vegetation in the Neolithic Age would also be in agreement with the findings of Schwörer et al. (2014), who in a multiproxy study found evidence of Neolithic pasture use at high altitudes in the Swiss part of the Northern Alps. There is, however, one general difficulty with the interpretation of palaeobotanical data from the Neolithic Age. Based on pollen and charcoal data alone, it is often very difficult, if not impossible, to differentiate between the effects of late Mesolithic hunters, who burned the forest for hunting purposes and early Neolithic settlers, who might have burned the forest for pasturing purposes. Another problem, which is often underestimated in such studies, is the difficulty to differentiate between local and regional effects based on pollen, spore, and micro-charcoal data. Many indicator pollen and spore types are wind dispersed and for example the findings of cereal pollen in deposits at high altitudes demonstrates the ability of many pollen and spore types to fly over large distances, covering also large distances in altitude. Especially in alpine regions above, and close to the treeline regional and extra-regional pollen make up an increasing share of the pollen rain caused by a low local pollen production (Birks and Birks, 2000; Pardoe, 2001). This makes it difficult to differentiate between local vegetation changes caused by alpine farming and pasturing, and regional vegetation changes at the valley floor or in the adjacent lowlands. The interpretation of palaeobotanical data, especially from the Neolithic Age, must therefore be done with the great care, and additional archaeological or macrofossil studies could be a good way to substantiate the results. In many studies about the history of alpine farming practices only the combination of archaeological and palaeobotanical work has led to clear proof of specific land use practices at high altitudes (Carrer et al., 2016; Festi et al., 2014; Mandl, 2006; Putzer et al., 2016b).

Nevertheless, the results of this thesis clearly show, that alpine farming systems throughout the Alps date back to at least the Bronze Age, a result, that we could confirm for the northernmost chain of the Alps in Bavaria. This underscores the value of alpine and subalpine grasslands not only as biodiversity hotspots, but also as part of a cultural heritage, which is thousands of years old. The land use types, which have formed these habitats are therefore worth protecting from several viewpoints. Firstly, from a nature conservation and biodiversity point of view, they are essential in forming and maintaining some of the most species rich habitats in Central Europe (Bätzing, 2003; Nagy et al., 2003). Furthermore, the migration of livestock between summer and winter pastures, across more than thousand meters altitude constitutes probably one of the best mechanisms for habitat connectivity or gene flow in our cultural landscape. It enables seeds or propagules of plants to travel large distances in the fur, guts, or hooves of the livestock between different habitats, connecting different grassland types (Fischer et al., 1996). Thousands of years of low intensity land use methods and habitat connectivity have led to the biodiversity hotspots, as which we know our mountain grasslands today. This long continuity of traditional management makes these grasslands one of the oldest, if not the oldest cultural landscape element in Central Europe. This makes them worth protecting also from a cultural and historical point of view. These grasslands and the landscapes they form, are cultural monuments of incalculable value and part of the cultural heritage of our Central European societies, together with the underlying land use systems and the traditional knowledge that was acquired by the management of these habitats over the course of several millennia.

Outlook

The results of this thesis show that a new appreciation of the value of traditionally managed grasslands in the Alps is necessary. Additional to the exceptionally high biodiversity, the long continuity of traditional low intensity land use on these mountain grasslands make them especially valuable habitats from a nature conservation point of view as well as from a cultural-historical point of view. This study also shows that also very remote regions in the Alps with seemingly harsh environmental conditions were used already very early in prehistory. Archaeological and palaeobotanical studies in these areas, although they are often difficult to access, can yield astonishing results. Integrated approaches with the cooperation of various scientific fields in some alpine regions have demonstrated, that there are many buried treasures waiting to be uncovered by us (Mandl, 2006; Reitmaier, 2017, Putzer et al., 2016b). Chance findings of sensational archaeological artefacts in different parts of the German Alps show, that there is a huge potential for further investigations (Leitner, 2003; Scherm, 2012). The finding of a stone tool on the "Schneiderkührenalpe" in the border region between Germany and Austria, near Oberstdorf, has led to a large-scale archaeological project, uncovering intensive Mesolithic human activities in this region (Leitner, 2003). Other findings like the (possibly Bronze Age) rock inscriptions in the Tegernsee Mountains sadly remain uninvestigated (Scherm, 2012). A possibility to improve the results of this thesis and to gain more precise information on the land use history of the Alps could also be the additional use of macrofossil analysis. This could add interesting information about the local vegetation history and the formation of the peatland (Birks and Birks, 2000). Furthermore, the identification of macrofossils can be done with higher taxonomic precision compared to pollen analysis, which allows a more precise reconstruction of the local vegetation (Birks and Birks, 2000). It would also be interesting to repeat a similar study at another suitable site in the same region of the Bavarian Alps to confirm the findings of this thesis. In the frameworks of nature conservation efforts, further research about the species composition of subalpine and alpine pastures with different land use histories and age classes could help to identify especially valuable habitats. Many present pastures in the subalpine or montane belt have been used as arable fields in the past. It would be interesting to compare the species composition and diversity of these more recent pastures to ancient pastures.

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