11 Vegetation History and Human Impact in the Ciomadul Area During the Holocene

Ioan Tanţău, Roxana Grindean, and Enikő K. Magyari

Abstract

Plant biodiversity is very sensitive to environmental changes, especially changes in climate. The study of vegetation history helps us understand the evolutionary history of plant life, the relationships between different groups of plants and, maybe the most important, how our world has changed through time. Pollen analysis (palynology) is one of the most important and efficient scientific method used in Quaternary palaeoecology and palaeoclimatology. Its main purpose is to reconstruct the past spatial and temporal evolution of vegetation from local and regional environments. In short, it is a method for investigating changes in the vegetation composition by means of the pollen grains and spores that plants produce. The long-term impact of human activities on natural habitats, such as forest clearance, animal husbandry and plant cultivation, can also be described from pollen data, using the anthropogenic pollen indicators. The vegetation history and human impact from the Ciomadul area were reconstructed from two sequences located in the twin craters: Mohoş peat bog and Lake Sf. Ana. These provide fossil pollen records which extend from ca. 11,300 BC to the present and represent an important source of information on changes in the vegetation composition and dynamics for this period.

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11.1 Introduction

Palynological studies are a rich source of information of changes in the vegetation composition and dynamics over long time scales. The most valuable palaeoecological archives for these studies are the peat bogs and lake sediments because pollen and spores typically accumulate over time and provide excellent conditions for preservation. Pollen and spores can provide clues about the source plants and the characteristics of the environments in which these plants lived. Their usefulness is due to their abundance, dispersal mechanisms, resistance to mechanical and

D. Karátson et al. (eds.), *Ciomadul (Csomád), The Youngest Volcano in the Carpathians*,
https://doi.org/10.1007/978-3-030-89140-4_11

chemical destruction, microscopic size, and often distinct morphology. However, pollen analysis is a complex and time consuming method. After the extraction and chemical treatment of samples, an important step is the microscopic identification and counting of all pollen and spore type from each sample. The results should be presented in pollen diagrams as percentages of the total sum, which consists of the total pollen and spores count, generally excluding pollen of aquatic plants, moss spores, and grains that are not identifiable, because the taxa that produce them do not represent terrestrial vegetation. In Romania, broad-scale vegetation dynamics and diversity from the Holocene (since ca. 9700 BC) have been reconstructed by high-resolution pollen analyses and supported by 14C geochronology. According to these investigations, vegetation distribution and diversity patterns during the early to mid-Holocene (ca. 9700–2200 BC) were primarily influenced by climate and location of glacial refugia (see Chap. 9), whereas vegetation dynamics throughout the late Holocene (ca. 2200 BC to present) were more driven by human impact (Feurdean and Tanţău 2017). Thus, the current composition and proportion of various types of land cover (forest, arable land, pastures) are considerably different from other periods of the Holocene.

The current vegetation in the Ciomadul Massif is characterized in many areas by reverse stratification of the vegetation belts due to the effect of basin climate that leads into reversed climatic gradients from the mountain peaks to the basins. As such, conifers can be found at elevations as low as 650 m where the climate is cooler and deciduous mesothermophilous (warmth-loving) trees are frequently found at elevations above 800 m (Fig. 11.1). The history of

Fig. 11.1 Aerial photo of the Mohoş peat bog and Lake Sf. Ana (modified after Google Earth). Reverse stratification of vegetation causes conifers (dark green) to colonise the lake shore, while deciduous trees (rusty brown) dominate higher slopes. The straight line on Mohoş peat bog surface represents an old drainage channel.

vegetation changes in the Ciomadul Massif has been previously presented by Tanţău et al. (2003; Mohoş peat bog) and by Magyari et al. (2009; Lake Sf. Ana). The Mohoş peat bog, in particular, is found in the twin circular crater of Lake Sf. Ana in the Ciomadul Massif. It occupies an area of 80 ha and has often piqued the interest of various researchers over time due to its rich and unique geographical and phytogeographical features. However, human activities on the peat bog over the last century, including artificial draining channels, deforestation and fire, have led to a significantly different picture of the peat bog we see today (Fig. 11.1). In this chapter, we compare results from the Mohoş peat bog and Lake Sf. Ana with a synthesis of vegetation dynamics from other areas of the Romanian Carpathians published by Feurdean and Tanţău (2017) and with other studies. The name of plants included in the present study are listed in Table 11.1.

Table 11.1 **a** List of plants included in the study grouped into ecological types and **b** human impact indicators types

a

Plant categories	Scientific name	Common name
Conifers	*Pinus* *Picea abies* *Abies alba*	pine spruce silver fir
Cold deciduous trees	*Alnus* *Betula*	alder birch
Temperate deciduous trees	*Ulmus* *Quercus* *Tilia* *Corylus avellana* *Acer* *Fraxinus* *Carpinus betulus* *Fagus sylvatica*	elm oak lime hazel maple ash hornbeam beech
Grass and shrubs	Poaceae *Artemisia* Cyperaceae Ericaceae *Verbascum* Asteraceae Apiaceae *Plantago lanceolata* Rosaceae *Urtica* Cerealia *Secale cereale* *Cannabis sativa* Brassicaceae *Rumex* Fabaceae Ranunculaceae	grass family sagebrush sedges heaths mullein daisy family parsley family ribwort plantain rose family nettle cereals rye hemp mustard family sorrel pea/bean family buttercup family
Xerophytic herbs	*Artemisia* Chenopodiaceae	sagebrush goosefoot family

b

Land use category	Taxa
Cultivated land (crops)	Cerealia, *Secale cereale*, *Cannabis sativa*
Fallow land (ruderals)	Brassicaceae, *Rumex*, *Urtica*, *Artemisia*, Chenopodiaceae
Grasslands/Pastures	Apiaceae, Asteraceae, Poaceae, Rosaceae, *Plantago lanceolata*
Secondary forest (early successional trees)	*Pinus*, *Betula*, *Alnus*, *Fraxinus*

11.2 Vegetation History of the Ciomadul Massif

11.2.1 Changes in Forest Cover and the Composition of Primeval Forests

At the end of the Pleistocene, the vegetation in the Romanian Carpathians was strongly affected by the cold and dry Younger Dryas period (YD; ca. 10,900–9700 BC), when a strong decrease in arboreal pollen (AP) was observed, hinting at the withdrawal of mainly coniferous forests (Tanţău et al. 2006). Based on pollen analysis from Mohoş peat bog (Tanţău et al. 2003) we were able to reconstruct the vegetation in the Ciomadul area. Between 11300 and 9700 BC this was composed of open forests dominated by Scots pine (*Pinus sylvestris*), European larch (*Larix decidua*), Norway spruce (*Picea abies*) and Downy birch (*Betula pubescens*), with few Stone pine (*Pinus cembra*) and alder (*Alnus*) trees and grass steppe communities (sagebrush—*Artemisia*, chenopods—*Chenopodiaceae* and grasses—*Poaceae*) along with sedges (*Cyperaceae*) (Figs. 11.2a and 11.3a). Following the dry and cold YD period, pollen records from the Romanian Carpathians indicate a marked vegetation response to the temperature and precipitation increase at the YD/Holocene transition (ca. 9700 BC). This was manifested as a retreat of the steppe vegetation and a rapid expansion of forests, as observed in pollen diagrams by decreasing percentages of herbaceous pollen and increasing percentages of tree pollen (Feurdean and Tanţău

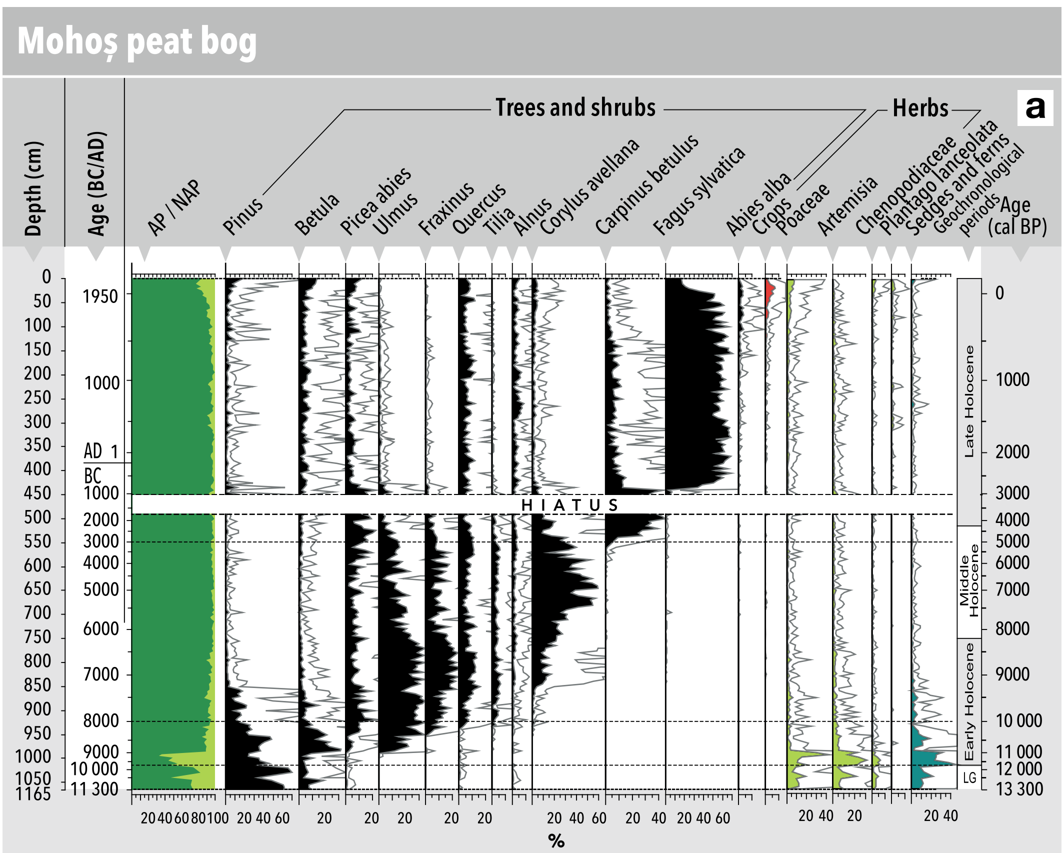

Fig. 11.2 Percentages of selected pollen and spores from **a** Mohoş peat bog and **b** Lake Sf. Ana; AP = arboreal pollen, NAP = non-arboreal pollen. The dashed lines are used to separate the important phases of vegetation changes described in the text at Sects. 11.2.1–11.2.4

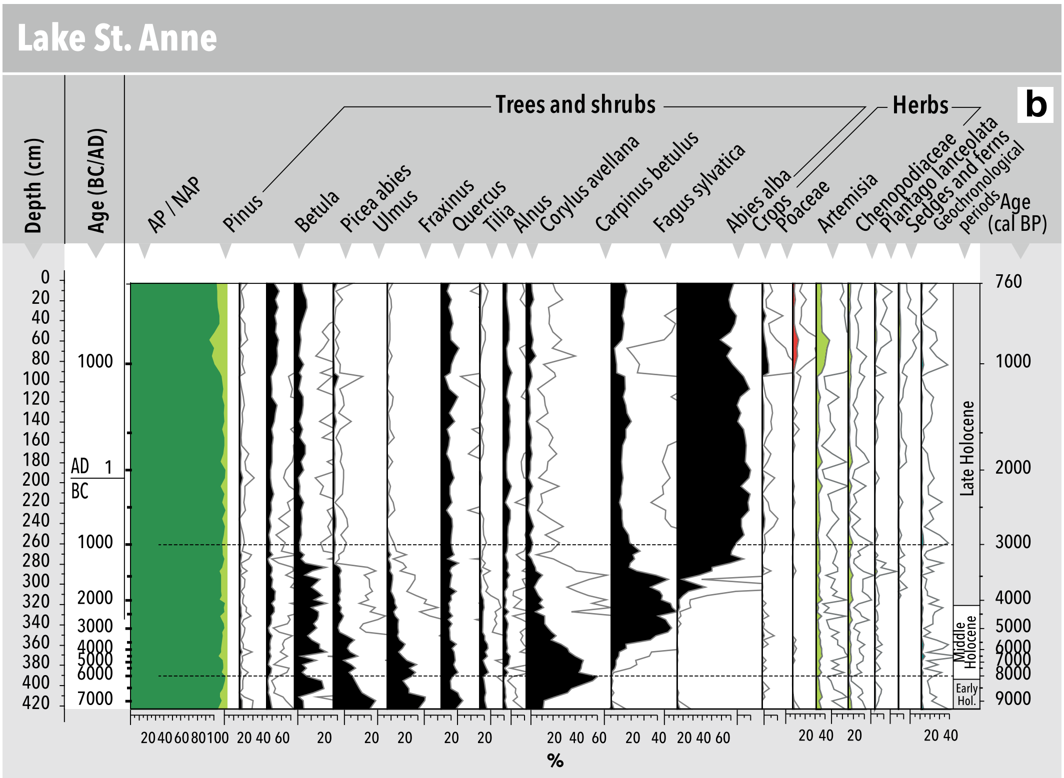

Fig. 11.2 (continued)

2017). Initially the open woodlands were primary composed of cold deciduous trees (alder, birch, and willow). This was followed (ca. 9300 BC) by the expansion of temperate deciduous forests dominated by elm (*Ulmus*), and from ca. 8700 BC included oak (Quercus), lime (*Tilia*), maple (*Acer*), ash (*Fraxinus*) and hazel (*Corylus avellana*). Analyses on plant macroremains from several sites in the Romanian Carpathians indicate that larch was also a significant component of the very early Holocene forests (Feurdean and Tanţău 2017).

11.2.2 Rapid Expansion of Deciduous Tree Species (9700–8000 BC)

The pollen data from the Mohoş peat sequence indicate the presence of an open boreal forest with pine, and birch, and an extensive cold continental steppe in the Ciomadul area at 9700 BC, corresponding to the YD/Holocene transition (Figs. 11.2a and 11.3b). A very rapid change in vegetation composition manifested as a decline in pine and steppe elements, and an increase in birch, elm, and spruce at ca. 9000 BC (Fig. 11.2a). This abrupt change could be due to a drier climate episode, which generated a hiatus of several centuries in the accumulation of peat and thus, lack of pollen data. The abundant presence of montane tree types in this period (including pine, birch and spruce) is concurrent with other pollen records from the Harghita Mountains (Luci peat bog; Tanţău et al. 2014), and also corresponds well with general vegetation development in the Romanian Carpathians (Tanţău et al. 2006, 2011; Feurdean et al. 2009; Fărcaş et al. 2013; Magyari et al. 2018; Grindean et al. 2019). The early Holocene forested landscapes also contained a diverse herbaceous vegetation (alpine grassland) and shrubs suggesting a more open character of these forests, in

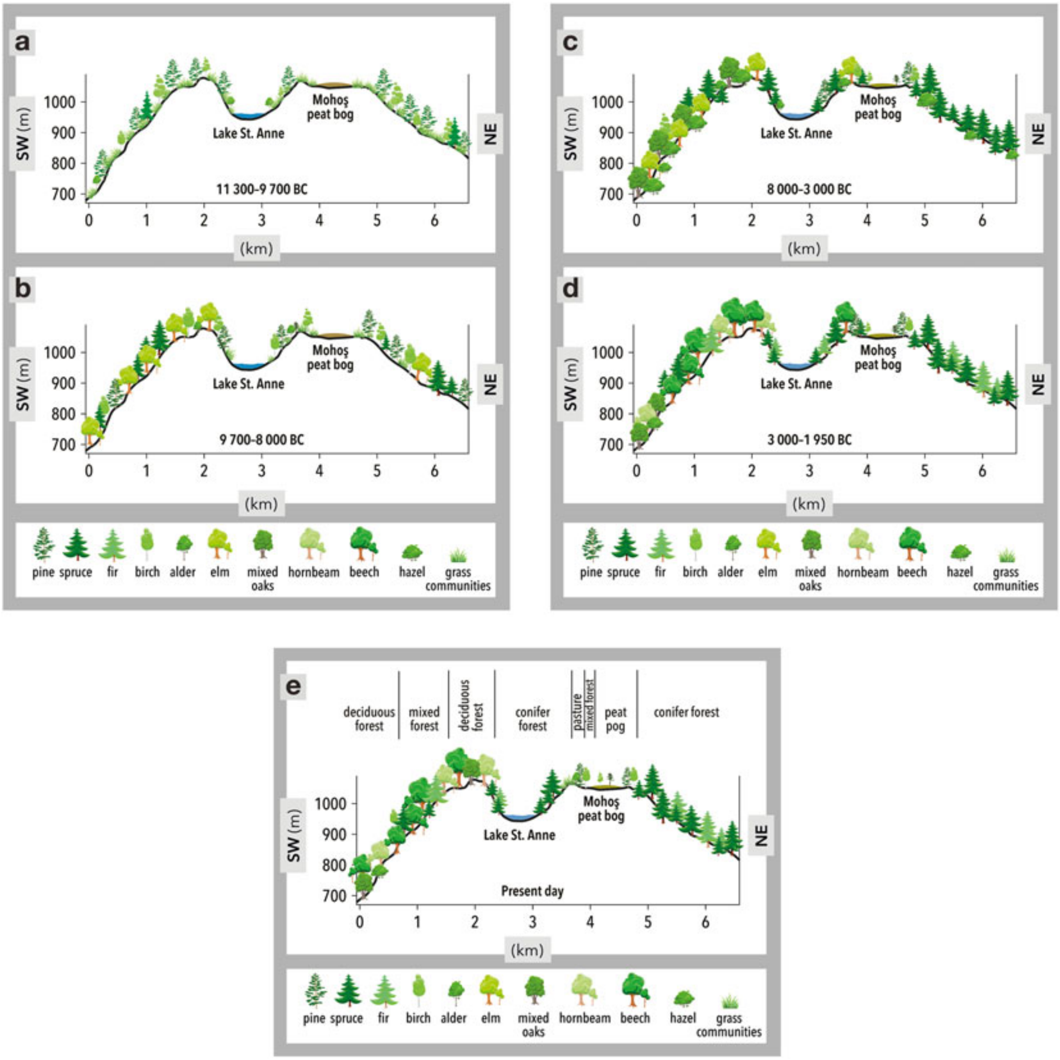

Fig. 11.3 SW-NE transect showing the changes in vegetation composition and distribution in Ciomadul Massif since the end of the Pleistocene and until present. Each panel/drawing (**a**-**e**) depicts the vegetation/land cover composition described in Sects. 11.2.1–11.2.4

agreement with the general inference of the prevalence of more open forests in Romania prior to 7000 BC. At this mid-altitude (ca. 1000 m) site, the forest dynamics of mesothermophilous (warmth-loving) deciduous trees are clearly recorded. It is one of the regions in Europe where elm played a pioneer role competing with birch. The forests also contained other deciduous species, such as ash, and oak (*Quercus*), maple, lime, and hazel (*Corylus avellana*) (Fig. 11.2a). Based on the climatic requirements of these taxa, such a shift in vegetation likely indicates an increase in temperature and moisture availability in the early Holocene. The observed forest succession, beginning with birch and then immediately followed by the mesothermophilous deciduous trees is typical for the Carpathian region (Feurdean and Tanţău 2017). As a specific feature of the vegetation dynamics in the Ciomadul area, oak, lime, maple and hazel expanded from ca. 8000 BC, later than ash (from ca. 8300 BC).

11.2.3 Dominance of Deciduous Trees and Spruce (ca. 8000–3000 BC)

An important change in the vegetation composition occurred at approximately 8000 BC when a decline in birch and pine and a marked rise in spruce and elm could be observed (Figs. 11.2a and 11.3c). The spruce maximum in the Ciomadul massif began at around 8000 BC (Tanţău et al. 2003), which was ca. 1000 years earlier than in the northern part of the Harghita Mountains (Tanţău et al. 2014), but synchronous with other areas of the Eastern Romanian Carpathians (Rodna Mountains) (Tanţău et al. 2011; Grindean et al. 2019). Spruce was a significant taxon in the Holocene forests of many regions in Romania indicating the strong competitive abilities of this tree compared to all other tree species at this altitude (Feurdean and Tanţău 2017). Elm, lime, oak and ash were the main components of the mountain mixed deciduous forests until 6000 BC, and began to decline from about 3000 BC, never regaining their former importance in the forests of this region (Fig. 11.2a, b). However, oak has been able to maintain its abundance throughout the Holocene. This is in agreement with many other pollen records from Romania in which elm, lime, ash and maple can be seen to have declined at around 2000 BC, while oak maintained its abundance until the present day. Hazel occurred in the Ciomadul area at ca. 8000 BC, and expanded from ca. 7300 BC, with a maximum abundance recorded between 6500 and 3000 BC (Fig. 11.2a, b). The hazel expansion was an asynchronous process within Romania, occurring from about 8300 BC at western sites and around 7300 BC in the Eastern Carpathians (Feurdean and Tanţău 2017). It has declined from around 3000 BC, being largely replaced by hornbeam (*Carpinus betulus*). The dominance of deciduous trees and spruce in the Harghita Mountains was affected by two short-term cooling events at 7300 and 6200 BC. Short-term changes in the vegetation composition have been noticed in north western and south eastern Romania and connected to rapid climate changes from the Holocene (Feurdean et al. 2009; Magyari et al. 2012, 2018).

11.2.4 Dominance of Hornbeam and Beech (3000 BC–present)

In the Ciomadul area, as in other parts of Romania, the pollen records show that the spread of hornbeam preceded that of beech. The evolution of hornbeam (*Carpinus betulus*) in the Ciomadul area is better recorded in the Lake Sf. Ana sequence than at Mohoş, where the continuity of the sequence was probably interrupted by several hiatuses probably caused by an abrupt cold and wet period (Piora Oscillation) Figs. 11.2a, b and 11.3d). The expansion of hornbeam is recorded between ca. 5600 and 3500 BC, with higher percentages at Lake Sf. Ana than at Mohoş (Tanţău et al. 2003; Magyari et al. 2009). The beginning of the hornbeam spread coincided with a decline in elm, ash and hazel, and a minor rise in light-demanding tree taxa, such as birch and alder (*Alnus*). Pollen diagrams show that hornbeam was an important canopy constituent in the area between 3000 and 800 BC (Fig. 11.2a, b). There is considerable regional distinction in the proportion of past hornbeam forests, which were much greater in eastern than in the northern or north western parts of Romania (Fărcaş et al. 2013). Hornbeam expanded much earlier in the southern Romanian Carpathians (5700 BC on the southern slopes of Retezat Mountains) in comparison to the northern part of the Eastern Romanian Carpathians (Magyari et al. 2012, 2018). The abundance of hornbeam in the Ciomadul area and in the Romanian forests was of rather short duration, as the tree was mainly replaced by beech as a dominant species, first in the western parts of Romania (ca. 3000 BC), and then in the eastern parts of the country (ca. 1000 BC). A plausible explanation is that dry climatic conditions induced increased wildfire occurrence, thus creating openings in the forest and allowing the rapid spread of hornbeam.

Beech, a shade tolerant species, has been continuously present in the sub-mountain and mid-altitudinal forest belts of Romania from ca. 3000 BC onwards. The expansion of beech in the Eastern Carpathians took place between ca. 1700-1000 BC (Fig. 11.2a, b). This spread is concurrent with a decline in spruce and hornbeam. The expansion of beech occurred asynchronously in Romania, with an earlier advancement (5000 BC) in the Apuseni Mountains (Feurdean et al. 2009), and then a later advancement at about 3500 BC and 2500 BC in the southwestern (Magyari et al. 2012, 2018) and northern Romanian Carpathians (Tanţău et al. 2011; Fărcaş et al. 2013). The expansion of beech in Europe is thought to be associated with either climate changes or a combination of fire, human impact and inter-specific competition (competition between different taxa of the same ecological area).

Silver fir (*Abies alba*), a slow growing species, is the latest advancing tree species in the Romanian forests. It has low pollen productivity and heavy pollen grains that are deposited in the proximity of the parental trees and thus the low pollen percentages of this tree are a good indicator of local tree presence. Silver fir first expanded in the Retezat Mountains and in Apuseni Mountains (ca. 3600–3000 BC) then in the Eastern Carpathians (ca. 1000 BC). Isolated pollen grains of silver fir were recorded at Lake Sf. Ana between 6500 and 1000 BC (Magyari et al. 2009), and at Mohoş between 6000 BC and 1 AD (Fig. 11.2a, b) (Tanţău et al. 2003). Fir pollen has been found abundantly in the Ciomadul area during the late Holocene, as well as other pollen records from Romania, at elevations between 900 and 1500 m, but in contrast to results from neighbouring sequences, such as Luci peat bog (Harghita Mountains; Tanţău et al. 2014), where fir had a modest pollen occurrence until the present day. Based on the pollen percentages of fir, we assume that this species was more important in the forest cover surrounding the Mohoş and Sf. Ana craters than in the northern part of the Harghita Mountains (Luci peat bog), during the late Holocene (Tanţău et al. 2003, 2014; Magyari et al. 2009).

A slight deforestation trend was recorded at Mohoș starting at ca. 1300 AD, probably due to an increase in the local human population during the early Middle Ages, as suggested by the rise in open herbaceous communities (grasslands), especially in grazing indicator pollen types (grasses—*Poaceae* and ribwort plantain—*Plantago lanceolata*). Interestingly, the timing of the first human deforestation around Lake Sf. Ana appears slightly earlier, around 900 AD (Fig. 11.2b) when a ca. 300 years decrease in the local beech-hornbeam forest was detected accompanied by the expansion of pastures and crops indicating the establishment of cultivated fields in the valleys of the Ciomadul Massif (Magyari et al. 2009). This timing broadly agrees with the Hungarian Conquest time. From about 1950 AD, there was a marked reduction in the proportion of beech, coinciding with the increase of light-demanding and early-successional trees (spruce, pine, birch, and oak), and of human impact indicators (cultivated plants—*Cerealia*, chenopods—*Chenopodiaceae* and ribwort plantain) in the Mohoș pollen record, signs of open-forest conditions (Fig. 11.2a). The vegetation composition shown by the pollen in the topmost part of the Mohoș sequence fits with the present day vegetation cover, where pine and birch occur on the surface of the peat bog (Fig. 11.3e), whereas spruce is found around the peat bog and on the slopes of the crater, along with beech. Also notable is that this vegetation transformation from 1950 AD with the spread of Scots pine (*Pinus sylvestris*) trees on the peat surface took place about 40 years after several channels were made on the Mohoș peat bog, an attempt that served the drainage of the peat bog and its utilization as pasture (Pop 1960).

11.3 Human Impact on Vegetation in Ciomadul

The pollen types that reflect human occupation and land-use are usually grouped as presented in Table 11.1b. The development of different agricultural practices changed the floristic composition and richness of the vegetation over the

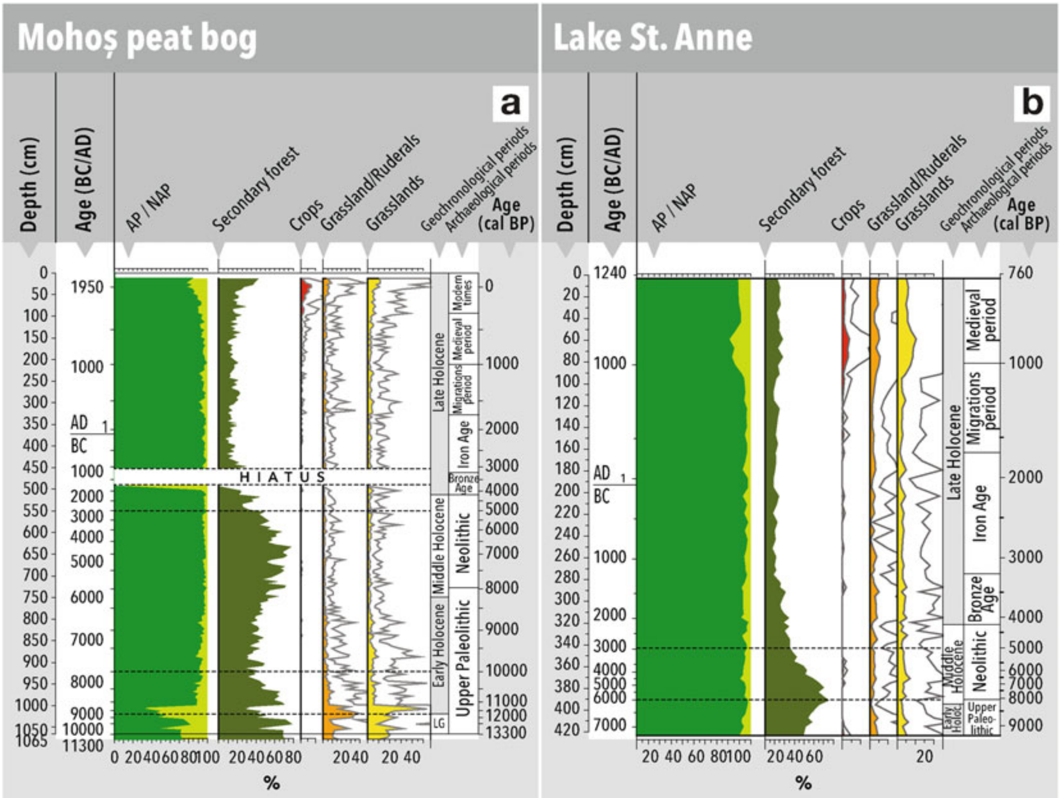

Fig. 11.4 Pollen percentages of selected plants categories according to Table 11.1b from **a** Mohoș peat bog and **b** Lake Sf. Ana; AP = arboreal pollen, NAP = non-arboreal pollen. The dashed lines are used to separate the important phases of vegetation changes described in the text at Sects. 11.2.1–11.2.4

Holocene (from ca. 9700 BC to present). The pollen analyses from the Mohoș peat bog and Lake Sf. Ana encompass a history of vegetation dynamics since the upper Palaeolithic (since c. 11,300 BC) (Fig. 11.4a, b). Although major changes in the land cover during the Paleolithic are mainly associated with natural driving forces (e.g., climate, wildfire, inter-specific competition), the first occurrences of cereals (*Cerealia*) and hemp (*Cannabis sativa*) pollen grains at ca. 7000 BC likely indicate a change in the lifestyle of the prehistoric communities towards the end of the period; from nomadic hunter-gatherer to semi-nomadic and settled farming. The extent to which this change can also be associated with deforestation (for creating arable fields) cannot be clearly derived, as arboreal pollen percentage values (AP) do not visibly decline (Fig. 11.4a) suggesting that the area was poorly populated and human impact was likely far-distance.

During the Neolithic (ca. 6000–2200 BC), the landscape dynamic was mainly characterized by the development of dense and extensive thickets of hazel alongside increasing proportions of spruce in the area (Fig. 11.2a, b). Although widely believed to have natural causes (i.e., climate, wildfires), these changes could also be somewhat related to human exploitation of the natural resources. Coppicing of hazel for example might have contributed to its high abundance, while it was also an important food source for both humans (hazelnuts) and livestock (fodder for cattle). The occurrence of pollen grains from cultivated plants (cereals and hemp), ruderal weeds (e.g., nettle—*Urtica* and mullein—*Verbascum*) and pasturage-related herbs (e.g., ribwort plantain—*Plantago lanceolata*) support the presence of settled farming communities in the surrounding lowlands, using a primitive ploughing system and herding practices (Fig. 11.4a, b).

In the Bronze Age (ca. 2200–1200 BC) the fallow system of farming (primitive crop rotation system) was introduced, which favoured the diversification of ruderal weeds and grassland taxa. Both climate changes and land clearing by man could have been factors in the forest vegetation changes, which mainly favoured the rapid expansion of hornbeam below the spruce vegetation zone (Fig. 11.2a, b). Large quantities of timber (mainly mixed oaks) could have also been harvested for developing large defensive systems characteristic of the time (hillforts). However, the local surroundings of the mire and lake were still covered by closed forest at this time, and only a small scale opening of the forest is inferable with distant crop fields on the basis of the Lake Sf. Ana pollen record (Fig. 11.4b).

In the Iron Age period (ca. 1200 BC–271 AD) the forests were dominated by spruce and beech (Fig. 11.2a, b). The initial low percentages of cereals pollen suggest that local communities temporarily reverted from crop farming, as a method of subsistence, to a pasturage approach as their primary means of food production (Fig. 11.4a, b). However, by the end of the period, both farming methods appear to have been in an equilibrium following the development of the iron plough. Our pollen study does not record important deforestation phases (no decline in the arboreal pollen), although elm, ash, and lime pollen percentages are significantly reduced (Fig. 11.2a, b).

The second half of the Migrations Period (ca. 271–900 AD) is generally associated with deforestations on a large scale and high fire abundance (Feurdean et al. 2013). The noticeable pollen percentage decline of the main tree taxa (beech and spruce) and the increase of those of alder and birch indicate deforestation followed by colonization of early successional taxa (Figs. 11.2a, b and 11.4a, b). Moreover, continuous occurrences of pollen indicators for crops, ruderals and grassland suggest the expansion of agricultural land (arable terrain, managed pastures) (Fig. 11.4a, b).

The Medieval Period (ca. 900–1700 AD) marked the beginning of the decline of trees pollen and increasing pollen percentages of taxa associated with human impact on the landscape (crops, ruderals and grasslands) (Fig. 11.4a, b). Most affected forest species were hornbeam, oak, elm, and ash (Fig. 11.2a, b). All these changes indicate the establishment of large agricultural fields and open landscape to accommodate the growing population. Rye (*Secale cereale*) became an important addition to crop farming. Human impact on the vegetation as recorded in the Mohoş peat bog seems to have been more intense during the Migrations Period (higher abundance of ruderals and grasses) than during the Medieval Period (Fig. 11.4a).

Over the last several centuries, the proportion of forest tree taxa has become visibly reduced (mainly beech) in favour of early successional trees (pine and birch) and herbaceous taxa linked to human impact (Figs. 11.2a, b and 11.4a, b). Current protective management measures for this biodiversity-rich area include the interdiction of deforestation, pastoral activities and artificial draining channels on the Mohoş peat bog.

11.4 Summary

Pollen analysis is a powerful tool not only to demonstrate changes in plant communities through time but also to investigate changes in past climate and human exploitation of the landscape. Our palynological-based study from two sequences (Mohoş peat bog and Lake Sf. Ana) has provided important features of the vegetation history from the Ciomadul massif. Thus, at the end of the Pleistocene, the vegetation was strongly affected by the cold and dry Younger Dryas period, when a strong decrease in arboreal pollen was observed, hinting at the withdrawal of mainly coniferous forests. Following this period, pollen records indicate a marked vegetation response to the temperature and precipitation increase at the YD/Holocene transition (ca. 9700 BC). This was manifested as a retreat of the steppe vegetation and a rapid expansion of forests. Initially the open woodlands were primary composed of cold deciduous trees (alder, birch, and willow). This was followed by the expansion of temperate deciduous forests dominated by elm, and from ca. 8700 BC included oak, lime, maple, ash and hazel. Spruce was a significant taxon in the Holocene forests indicating the strong competitive abilities of this tree compared to all other tree species at this altitude. Elm, lime, oak and ash were the main components of the mountain mixed deciduous forests until 6000 BC, and began to decline from about 3000 BC, being largely replaced by hornbeam. The expansion of hornbeam is recorded between ca. 5600 and 3500 BC, followed by that of beech between ca. 1700-1000 BC. Traces of human impact on the natural land cover from the Ciomadul massif were mainly recorded through shifts of the AP/NAP (trees/herbs) ratio and the occurrence of cultivated plants and weeds, and grassland species. Although noted since the Palaeolithic (since ca. 11,300 BC), anthropogenic influence on the environment was more apparent starting with the Bronze Age (expansion of arable fields through deforestation and fire) and intensified considerably over the last several centuries.

Glossary of Terms. AD – Anno Domini (after the birth of Christ). 1 AD = 2000 years Before Present.

BC—Before Christ; indicating years numbered back from the supposed year of the birth of Christ. In this paper BC years are based on radiocarbon dating and expressed as calibrated years BC.

Boreal forest—Large area in the northern hemisphere that is covered with coniferous forests consisting mostly of pines, spruces, and larches.

^{14}C chronologies (radiocarbon dating)—The age of organic material determined by the amounts of isotope carbon-14. Radiocarbon dating is a method that provides objective age estimates (for the last 40,000 years) for carbon-based materials that originated from living organisms. An age could be estimated by measuring the amount of carbon-14 present in the sample and comparing this against an internationally used reference standard. Carbon 14 (^{14}C) is an isotope of the element carbon that is unstable and weakly radioactive. The stable isotopes are carbon-12 and carbon-13 (also see Chap. 3).

Glacial refugia—A geographic region which made possible the survival of flora and fauna in times of ice ages and allowed for post-glacial re-colonization.

Holocene—An epoch of the Quaternary Period beginning 11,700 years ago and continuing today.

Mixed oaks—A deciduous forest or woodland community dominated by species of tree oak and other mesothermophilous (warmth-loving) trees (elm, ash, lime).

Palynology—The study of pollen and spores produced by plants.

Paleoclimatology—The study of climate changes from the past.

Paleoecology—A branch of ecology that studies the characteristics of past environments and their relationships with ancient plants and animals.

Peat bog—A swamp in which a compact brownish deposit of partially decomposed vegetable matter has accumulated.

Pollen—Microscopic body that contains the male reproductive cell of flowering plants/ the fertilizing element of flowering plants, consisting of fine, powdery, yellowish grains.

Primeval forests—A forest unaffected by humans, typically containing large live trees, large dead trees, and large logs.

Quaternary—The most recent Period of the most recent Era (Cenozoic) on the geologic time scale that spans from 2.588 million years ago to the present and is divided into two epochs: the Pleistocene (2.588 million years ago to 11,700 years ago) and the Holocene (11,700 years ago to today).

Short-term cooling events—Abrupt climate changes which occur when the climate system is forced to transition to a new climate state at a rate that is determined by the climate system energy-balance, and which is more rapid than the rate of change of the external forcing.

Spore—Reproductive cell capable of giving rise to a new individual without sexual fusion, characteristic of lower plants, fungi, and protozoans.

Vegetation belts—Vegetation zone with specific characteristics, determined by the changes of the thermal and water regime in altitude.

Xerophyte—Plant adapted to survive in dry environments.

Younger Dryas—Cold and short period between ca. 12,900 and 11,700 years ago that disrupted the prevailing warming trend occurring at the end of the Pleistocene.