Palaeoenvironment in north-western Romania during the last 15,000 years

Angelica Feurdean

Dedicated to Ovidiu Feurdean

Avhandling i Kvartärgeologi
Thesis in Quaternary Geology
No. 3

Department of Physical Geography and Quaternary Geology,
Stockholm University
2004
This thesis is based on work carried out as Ph.D. student at the Department of Paleontology, Faculty of Biology and Geology, Babes-Bolyai University, Cluj-Napoca, Romania between Oct. 1998 and Sept. 2002 and later as Ph.D. student in Quaternary Geology at the Department of Physical Geography and Quaternary Geology, Stockholm University 2002-2004. The thesis consists of four papers and a synthesis. The four papers are listed below and presented in Appendices I-IV. Two of the papers have been published (I, II), one is in press (III) and the fourth has been submitted (IV). The thesis summary presents an account of earlier pollenstratigraphic work done in Romania and the discussion focuses on tree dynamics during the Lateglacial and Holocene, based on recent results from Romania.


Appendix IV: Feurdean A. & Bennike O. Late Quaternary palaeocological and paleoclimatological reconstruction in the Gutaiului Mountains, NW Romania. Manuscript submitted to *Journal of Quaternary Science.*

Fieldwork in Romania has been jointly performed with Barbara Wohlfarth and Leif Björkman (Preluca Tiganului, Steregoiu, Izvoare) and with Bogdan Onac (Creasta Cocosului). I am responsible for the lithostratigraphic description of all sediment and peat cores, for sub-sampling and laboratory preparation. I have done all mineral magnetic measurements and loss-on-ignition analysis (except for the lowermost part of Preluca Tiganului, which was the topic of an examination paper by Kajsa Cinthio). I have analyzed all pollen samples from Preluca Tiganului and Steregoiu, except for the uppermost part of Preluca Tiganului and Steregoiu, which was done by Leif Björkman. The macrofossil analyses were performed by Ole Bennike. As co-author of paper I and II I have been responsible for data collection, analyses, interpretation and have contributed to the text. As first author in paper IV, I have been responsible for data collection, analyses of the pollen samples, data interpretation, illustrations and text.

Palaeoenvironment in north-western Romania during the last 15,000 years

by

Angelica Feurdean

Department of Physical Geography and Quaternary Geology, Stockholm University, SE-106 91 Stockholm


IV: Feurdean A. & Bennike O. Late Quaternary palaeocological and paleoclimatological reconstruction in the Gutaiului Mountains, NW Romania. Manuscript submitted to *Journal of Quaternary Science*
Palaeoenvironment in north-western Romania during the last 15,000 years

Angelica Feurdean

ABSTRACT

The objectives of this thesis are to establish a chronological framework for environmental changes during the last 15,000 years in northwest Romania, to reconstruct the vegetation development, and to evaluate the underlying processes for forest dynamics. Furthermore, an overview of earlier and ongoing pollenstratigraphic work in Romania is provided.

Sediments from two former crater lakes, Preluca Tiganului and Stereogoiu, situated in the Gutaiului Mountains, on the western extremity of the Eastern Carpathians at 730 m and 790 m a.s.l., respectively were obtained and analysed for high-resolution pollen, macrofossils, charcoal, mineral magnetic parameters and organic matter. The chronostratigraphic framework was provided by dense AMS $^{14}$C measurements.

Cold and dry climatic conditions are indicated by the occurrence of open vegetation with shrubs and herbs, and cold lake water prior to 14,700 cal. yr BP. The climatic improvement at the beginning of the Lateglacial interstadial (around 14,700 cal. yr BP) is seen by the development of open forests. These were dominated by Pinus and Betula, but contained also new arriving tree taxa, such as Populus, Alnus and Prunus. The gradual establishment of forests may have led to a stabilization of the soils in the catchment. Between ca. 14,100 and 13,800 cal. yr BP the forest density became reduced to stands of Picea, Betula, Alnus, Larix and Populus trees and grassland expanded, suggesting colder climatic conditions. Picea arrived as a new taxon at around 13,800 cal. yr BP, and between 13,800 and 12,900 cal. yr BP, the surroundings of the sites were predominantly covered by Picea forest. This forest included Betula, Pinus, Alnus, Larix and Populus and, from 13,200 cal. yr BP onwards also Ulmus. At ca. 12,900 cal. yr BP, the forest became significantly reduced and at 12,600 cal. yr BP, a recurrence of open vegetation with stands of Larix, Pinus, Betula, Salix and Alnus is documented, lasting until 11,500 cal. yr BP. This distinct change in vegetation may by taken as a strong decline in temperature and moisture availability.

At the transition to the Holocene, at ca. 11,500 cal. yr BP, Pinus, Betula and Larix quickly expanded (from small local stands) and formed open forests, probably as a response to warmer and more humid climatic conditions. At 11,250 cal. yr BP Ulmus and Picea expanded and the landscape became completely forested. The rapid increase of Ulmus and Picea after 11,500 cal. yr BP may suggest the existence of small residual populations close to the study sites during the preceding cold interval. Ulmus was the first and most prominent deciduous taxa in the early Holocene in the Gutaiului Mountains. From ca. 10,750 cal. yr BP onwards Quercus, Tilia, Fraxinus and Acer expanded and Corylus arrived. A highly diverse, predominantly deciduous forest with Ulmus, Quercus, Tilia, Fraxinus, Acer, Corylus and Picea developed between 10,700 and 8200 cal. yr BP, which possibly signifies more continental climatic conditions. The development of a Picea-Corylus dominated forest between 8200 and 5700 cal. yr BP is likely connected to a more humid and cooler climate. The establishment of Carpinus and Fagus was dated to 5750 cal. yr BP and 5200 cal. yr BP, respectively. The dominance of Fagus during the late Holocene, from 4000 cal. yr BP onwards, may have been related to cooler and more humid climatic conditions. First signs of human activities are recorded around 2300 cal. yr BP, but only during the last 300 years did local human impact become significant.

The vegetation development recorded in the Gutaiului Mountains during the Lateglacial is very similar to reconstructions based on lowland sites, whereas higher elevation sites seem not to have always experienced visible vegetation changes. The time of tree arrival and expansion during the past 11,500 cal. yr BP seems to have occurred almost synchronously across Romania. The composition of the forests during the Holocene in the Gutaiului Mountains is consistent with that reconstructed at mid-elevation sites, but differs from the forest composition at higher elevations. Important differences between the Gutaiului Mountains and other studied sites in Romania are a low representation of Carpinus and a late and weak human impact.

The available data sets for Romania give evidence for the presence of coniferous and cold-tolerant deciduous trees before 14,700 cal. yr BP. Glacial refugia for Ulmus may have occurred in different parts of Romania, whereas the existence of Quercus, Tilia, Corylus and Fraxinus has not been corroborated.

Keywords: Northwest Romania, Gutaiului Mountains, pollenstratigraphy, macrofossil remains, Lateglacial, Holocene, tree refugia, tree dynamics, past climate, human influence.

Department of Physical Geography and Quaternary Geology, Stockholm University, SE-106 91 Stockholm
Introduction

Paleoenvironmental and palaeoclimatic research provides an insight into the extent, timing and causes of climatic and environmental changes, which have occurred in the past. Palaeo-studies have during the past years gained increasing attention, because they allow placing the contemporary environmental and climatic changes in a longer time perspective. Important archives for palaeoenvironmental and palaeoclimatic research are ice cores, marine and lacustrine sediments, peat bogs, tree rings and speleothems. An array of different methods can be applied to each of these archives to obtain as much climatic and environmental information as possible.

Pollen and plant macrofossil analyses are for terrestrial archives, such as lake sediments and peat deposits, the most common tools to reconstruct past vegetation and biogeography, past climate and human impact on the vegetation. Macrofossil analysis has been regularly employed since the 19th century, while pollen analysis was developed during the early part of the 20th century (Reid 1899; Erdtman, 1934; Iversen 1941, 1949; von Post 1916, 1946; Watts 1959; West 1977; Punt and Clarke 1984; Birks 1986, 2001; Fægri and Iversen 1989; Reille 1992, 1995; Bennett and Willis 2001; Birks 2001). Although these two techniques have been used and developed in parallel, pollen analysis is still the major tool and probably the most widely applied method to investigate past vegetation dynamics. This is due to the large production of pollen and their dispersion capability, which leads to pollen grains being relatively easy deposited in lakes and on peat. Pollen analysis has, however, some drawbacks (see Objective chapter of the thesis summary) and palaeoecologists have tried to develop and improve the method over time. Andersen (1974) made the first attempts by using the so-called “correction factor”. This approach was followed by numerical modelling to predict catchment scale and size of the sedimentary basins (Prentice 1988; Sugita 1994, 1999). More recently models of pollen dispersal have been developed based on a combination of pollen traps, vegetation surveys, climate records and fossil pollen assemblages to evaluate the relationship between pollen assemblages and the composition of the vegetation (Hicks 1994, 2001; Broström 2002). This knowledge combined with high-resolution, chronologically well-constrained pollen stratigraphy has increased the reliability of pollen analysis and allows a more objective interpretation of vegetation characteristics through time. In addition it is necessary to consider the present distribution of trees across Europe, which is limited by the following climatic parameters: the number of growing-degree days controls their northern limit, the temperature of the coldest month constrains their eastern limit and water availability their southern limit (Woodward, 1988; Prentice et al. 1993; Sykes et al. 1996).

Many studies have shown a clear spatial response of the vegetation to the distinct climatic variations during the Weichselian Lateglacial in Europe. In some regions the response was rather strong, e.g. around the North Atlantic, while it was less prominent in continental areas. These differences may have been due to the spatially varying intensity of temperature/precipitation changes, to the physiological tolerance of the species involved, to inter-species competition and migration speed. Although climatic fluctuations during the Holocene in general were not as pronounced as compared to the glacial stages, new studies have shown that even the early Holocene climate was relatively unstable and characterized by several oscillations (e.g. Bond et al. 1997, 2001), informally termed the “Preboreal Oscillation” at ca. 11,300 cal yr BP (Behre, 1966; Björck et al. 1997), the “10,300 cal yr BP” event (Björck et al. 2001) and the so-called “8200 cal yr BP” event (Bond et al. 1997). These fluctuations were initially only recorded around the North Atlantic region and on Greenland, but also appear to have occurred in continental areas, where they seem to have been relatively pronounced (von Grafenstein et al. 1998, 1999; Ralska-Jasiewiczowa et al. 1998; Tinner and Lotter, 2001; Magny et al. 2003; Wick et al. 2003). It has been shown that these short-term climatic variations must have been severe enough to have an impact on the existing vegetation (Ralska-Jasiewiczowa et al. 1998; Ammann and Birks, 2000; Tinner and Lotter, 2001; Wick et al. 2003).

During the past, palaeoenvironmental research has mainly focused on regions around the North Atlantic and in central Europe and only few records have been available for southeast Europe. Pollen stratigraphy has generally been the main tool to infer changes in vegetation composition for southeast Europe, but most of the pollen records have low stratigraphic resolution and poor chronological frameworks. Attempts to reconstruct past vegetation changes and to locate refugia during cold glacial stages had therefore often to rely on such low-resolution studies (Huntley and Birks, 1983; Bennett et al. 1991; Willis 1994). West (1977) and Huntley and Birks (1983) were among the first to compare pollen stratigraphies across Europe to decipher the immigration routes for tree taxa following the last glacial stage. Their assumption was that the locality where a tree species appeared for the first time during the postglacial would correspond to the place where the taxaon had its glacial refugia. Huntley and Birks (1983) could show that glacial refugia must have been concentrated to southern Europe and may have existed in regions such as the Balkans, the Alps, the Carpathians and the Italian mountains. Tree species survived in these areas during the cold periods of the Quaternary and spread northwards at the beginning of an interglacial. Later, Bennett et al. (1991) suggested that other factors also need to be considered, such as e.g. the modern distribution of tree spe-
cies in Europe; tree dynamics during the last cold stage and during intervening interstadials; climatic conditions during glacial stages and the physiography of southern Europe. However, for a number of areas, these discussions had to be based on old pollen stratigraphic studies and it became evident that multidisciplinary approaches with high temporal, spatial and ecological resolution were needed to address precise environmental reconstructions.

Recently published palaeoenvironmental records from south-eastern Europe now allow more accurate estimations of the palaeovegetation during periods of distinct climatic changes. (Willis 1992a, b; Willis et al. 1995, 1997, 2000; Denéfle et al. 2000; Rudner and Sümegi, 2001; Sümegi and Rudner, 2001; Tonkov et al. 2002; Stefanova and Ammann 2003). They also show that refugia for deciduous trees even existed in regions situated north of the Balkan Peninsula (e.g. Hungary). Despite the emergence of these new records, Romania has largely remained a “white spot” on the palaeoenvironmental map of Europe. Data sets from this part of Europe are, however, important to assess the spatial variability of past changes in vegetation and climate and to reconstruct tree migration routes at the beginning of the present interglacial. Only by integrating this region into a European context will it be possible to obtain a complete picture of the palaeoenvironmental development.

This thesis thus focuses on a reconstruction of the Lateglacial and Holocene vegetation development in north-western Romania. This has been done through high-resolution pollen analyses of two lake/peat bog sequences in order to get a good temporal and spatial resolution of Lateglacial and Holocene vegetation changes. Pollen analysis has been the main tool, which was complemented by macrofossil, organic matter, mineral magnetic analyses and AMS $^{14}$C measurements.

<table>
<thead>
<tr>
<th>Romania</th>
<th>Central Europe</th>
<th>Southern Scandinavia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picea-Fagus-Abies</td>
<td>X</td>
<td>Sub-Atlantic</td>
</tr>
<tr>
<td>Spruce-beech-fr</td>
<td>IX</td>
<td>Sub-Boreal</td>
</tr>
<tr>
<td>Picea-Carpinus Spruce-hornbeam</td>
<td>VIII</td>
<td>Atlantic</td>
</tr>
<tr>
<td>Picea-QM-Corylus</td>
<td>VIIa</td>
<td>VI</td>
</tr>
<tr>
<td>Spruce- mixed oak</td>
<td>VI</td>
<td>Vb</td>
</tr>
<tr>
<td>hazel</td>
<td></td>
<td>Late Boreal</td>
</tr>
<tr>
<td>Pinus-Picea</td>
<td>Va</td>
<td>Boreal</td>
</tr>
<tr>
<td>Pine - spruce</td>
<td>IV</td>
<td>Preboreal</td>
</tr>
<tr>
<td>Some spruce, birch, alder</td>
<td>III</td>
<td>Younger Dryas</td>
</tr>
<tr>
<td>Picea-Betula-Alnus</td>
<td>II</td>
<td>Older Dryas</td>
</tr>
<tr>
<td></td>
<td>Ic</td>
<td>Bölling</td>
</tr>
<tr>
<td></td>
<td>Ib</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ia</td>
<td>Oldest Dryas</td>
</tr>
</tbody>
</table>

Figure 1. Pop’s (1942) Lateglacial and Holocene forest phases and their correlation to the pollenstratigraphic schemes of Firbas (1949, 1952), Blytt (1881), Sernander (1890) and Nilsson (1961).

Figure 2. Topographic map of Romania showing the location of earlier studied lake and peat bog sites. Numbers 1-23 refer to Table 1 where more detailed site information is given.
Table 1. List of sites with pollen-stratigraphic records shown in Figure 2 and discussed in the text (Lg = Lateglacial; H = Holocene; Pb = Preboreal; B = Boreal; A = Atlantic; SB = Subboreal; QM = Quercetum mixtum.

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Site name</th>
<th>Altitude (m)</th>
<th>Sediments</th>
<th>Pollen diagram record</th>
<th>Main characteristics of the pollen assemblages</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preluca Tiganului</td>
<td>700</td>
<td>Peat</td>
<td>Pb-B</td>
<td>Early appearance of <em>Fagus</em>, high values for <em>Ulmus</em> and <em>Corylus</em></td>
<td>Lupsa (1980)</td>
</tr>
<tr>
<td>2</td>
<td>Steregoiu</td>
<td>730</td>
<td>Peat</td>
<td>Lg</td>
<td>Early appearance of <em>Fagus</em>, high values for <em>Ulmus</em> and <em>Corylus</em></td>
<td>Lupsa (1980)</td>
</tr>
<tr>
<td>3</td>
<td>Fundul Colibii</td>
<td>900</td>
<td>Peat</td>
<td>Pb</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula, Salix</em>; single grains for <em>Ulmus, Alnus, Fagus</em> in Lg</td>
<td>Pop (1932)</td>
</tr>
<tr>
<td>4</td>
<td>Taul Negru</td>
<td>1264</td>
<td>Peat</td>
<td>SB</td>
<td><em>Fagus</em> dominant; low values for <em>Carpinus</em></td>
<td>Pop (1932)</td>
</tr>
<tr>
<td>5</td>
<td>Taul Baitii</td>
<td>1450</td>
<td>Peat</td>
<td>B</td>
<td><em>QM</em> dominant</td>
<td>Pop et al. (1965b)</td>
</tr>
<tr>
<td>6</td>
<td>Dorna-Lucina</td>
<td>900</td>
<td>Peat</td>
<td>Pb</td>
<td><em>Pinus</em> dominant; high values for <em>Carpinus</em></td>
<td>Pop (1929)</td>
</tr>
<tr>
<td>7</td>
<td>Borsec</td>
<td>900</td>
<td>Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula</em></td>
<td>Pop (1958)</td>
</tr>
<tr>
<td>8</td>
<td>Mohos Tusnad</td>
<td>1040</td>
<td>Peat</td>
<td>B</td>
<td><em>QM</em> (<em>Tilia</em> dominant); high values for <em>Corylus</em> and <em>Carpinus</em></td>
<td>Pop and Diaconeasa, (1967)</td>
</tr>
<tr>
<td>9</td>
<td>Bisoca</td>
<td>900</td>
<td>Peat</td>
<td>B</td>
<td><em>QM</em> (<em>Tilia</em> dominant)</td>
<td>Pop and Ciobanu (1957)</td>
</tr>
<tr>
<td>10</td>
<td>Mangalia Herghelie</td>
<td>5</td>
<td>Clay, Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for *Picea, Betula, Salix, QM, Abies and <em>Carpinus</em> in Lg</td>
<td>Diaconeasa (1977)</td>
</tr>
<tr>
<td>11</td>
<td>Craiovita</td>
<td>110</td>
<td>Peat</td>
<td>B</td>
<td><em>QM</em> (<em>Quercus</em> dominant)</td>
<td>Pop (1957)</td>
</tr>
<tr>
<td>12</td>
<td>Balea Lac</td>
<td>2040</td>
<td>Peat</td>
<td>B</td>
<td><em>Picea</em> dominant; high values for <em>Corylus</em></td>
<td>Diaconeasa (1969)</td>
</tr>
<tr>
<td>13</td>
<td>Retezat Mts.</td>
<td>1750-1940</td>
<td>Peat</td>
<td>B</td>
<td><em>Picea</em> dominant; high values for <em>Fagus and Abies</em></td>
<td>Ciobanu (1960)</td>
</tr>
<tr>
<td>14</td>
<td>Taul Zanogutii</td>
<td>1800</td>
<td>Clay, Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for *Picea, Betula, Alnus, Salix and scattered QM</td>
<td>Pop et al. (1971)</td>
</tr>
<tr>
<td>15</td>
<td>Semenic</td>
<td>1400</td>
<td>Clay, Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Fagus and Abies</em> in Lg</td>
<td>Ciobanu (1948)</td>
</tr>
<tr>
<td>16</td>
<td>Pestera lui Vetereani</td>
<td>70</td>
<td>Clay</td>
<td>Pb</td>
<td><em>QM</em> (<em>Tilia</em> dominant)</td>
<td>Boscaniu and Lupsa (1967)</td>
</tr>
<tr>
<td>17</td>
<td>Stobor</td>
<td>356</td>
<td>Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula, Salix</em></td>
<td>Pop (1932)</td>
</tr>
<tr>
<td>18</td>
<td>Bagaau</td>
<td>290</td>
<td>Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula, Salix</em></td>
<td>Pop (1932)</td>
</tr>
<tr>
<td>19</td>
<td>Salicara</td>
<td>740</td>
<td>Peat</td>
<td>A</td>
<td><em>QM</em> (<em>Tilia</em> dominant); high values for <em>Carpinus</em>, low for <em>Fagus</em></td>
<td>Pop (1932)</td>
</tr>
<tr>
<td>21</td>
<td>Criseni</td>
<td>50</td>
<td>Clay, Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant, low values for <em>Picea, Betula Salix</em></td>
<td>Pop and Diaconeasa (1964)</td>
</tr>
<tr>
<td>22</td>
<td>Magherus</td>
<td>345 m</td>
<td>Clay</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for *Picea, Betula in Lg</td>
<td>Diaconeasa (1979)</td>
</tr>
<tr>
<td>23</td>
<td>Podu de Hartie</td>
<td>950</td>
<td>Peat</td>
<td>A</td>
<td><em>QM</em> (<em>Tilia</em> dominant); high values for <em>Carpinus</em></td>
<td>Diaconeasa and Buz (1993)</td>
</tr>
<tr>
<td>24</td>
<td>Ecedea</td>
<td>900</td>
<td>Peat</td>
<td>Pb</td>
<td>Steppe elements dominance</td>
<td>Pop (1957)</td>
</tr>
<tr>
<td>25</td>
<td>Borsec</td>
<td>910</td>
<td>Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula</em></td>
<td>Pop (1958)</td>
</tr>
<tr>
<td>26</td>
<td>Bilbor</td>
<td>910</td>
<td>Peat</td>
<td>Lg</td>
<td><em>Pinus</em> dominant; low values for <em>Picea, Betula</em></td>
<td>Pop (1958)</td>
</tr>
</tbody>
</table>
Background

Earlier pollenstratigraphic investigations in Romania

Pollenstratigraphic investigations in Romania were pioneered by Pop (1929, 1932, 1942, 1957, 1958, 1960, 1971) more than 70 years ago. Pop was also the first to establish a scheme for the Lateglacial and Holocene forest development by placing the boundaries between different forest phases where distinct changes in the composition of the pollen assemblages occurred. An age assignment for the different forest phases was obtained in comparison to the schemes established by Blytt-Sernander (1881, 1890), Firbas (1949, 1952), Nilsson (1935, 1961) and Iversen (1942). Pop’s forest phases were used to recently as the framework for the general vegetation history in Romania (Fig. 1).

1. Pop’s *Pinus* phase covered the Lateglacial and Preboreal (IV) (Fig. 1). The Lateglacial period was subdivided according to Firbas (1949, 1952) into la (Oldest Dryas), lb (Bølling), lc (Older Dryas), II (Allerød) and III (Younger Dryas). The reconstructed vegetation, which was dominated by *Pinus*, also contained *Picea, Betula, Alnus* and *Salix*. Low numbers of pollen grains of *Quercus, Ulmus, Tilia* and *Corylus* were noticed during the zone correlated to the Allerød.

2. The *Picea-Picea* phase was by Pop attributed to the late Preboreal and early Boreal, i.e. to zones IV and V of Firbas (1949, 1952) (Fig. 1). This time interval was marked by distinct forest reorganization. Pine forests spread to higher elevations in the Carpathians, spruce forest expanded at moderate elevations, and *Quercus, Ulmus, Tilia* and *Acer* pollen grains appeared in low percentages.

3. The *Picea-Quercetum mixtum* phase, which includes *Quercus, Ulmus, Tilia* and *Corylus*, was assigned to the Boreal and Atlantic, i.e. to zones V, VI and VII of Firbas (1949, 1952) (Fig. 1). Forests of *Quercetum mixtum* and *Picea* dominated in the foothill areas, whereas *Quercetum mixtum* co-dominated with *Corylus* in the lowlands. *Quercus* was abundant within the *Quercetum mixtum* communities in northern Romania, while in central and southern Romania *Tilia* was the most important forest taxa.

4. The *Picea-Carpinus* phase was correlated to the Subboreal, i.e. to zone VIII of Firbas (1949, 1952). The *Carpinus* forest belt occurred between the *Picea* and the *Quercetum mixtum* forest belts. *Fagus* became established during this time span.

5. During the *Picea-Fagus-Abies* phase, which Pop attributed to the Subatlantic or zones IX and X of Firbas (1949, 1952), *Picea, Fagus* and *Abies* were common trees in hilly and mountain areas, while *Quercetum mixtum* forest dominated the lowland areas.


The above-mentioned authors concluded that *Pinus, Picea, Betula, Salix, Alnus, Quercus, Ulmus, Tilia*, and possibly *Carpinus* survived in Romania during the cold stages of the last glacial. The establishment of *Carpinus* prior to *Fagus* is opposite as compared to the central European forest succession and was named as a particular forest phase for eastern Europe. The late appearance and expansion of *Abies* and *Fagus* was explained by the absence of refugia for these trees in Romanian (Pop 1942, 1960; Ciobanu 1958). Later, Diaconeasa and Farcas (1995, 1998), Buz (1999) and Farcas (2001) attributed the presence of thermophilous tree-pollen grains during the Lateglacial to contamination during coring procedure, to re-deposition, or to long-distance transport, and only the southern and south-eastern part of Romania was suggested as a glacial refugia for *Ulmus, Quercus, Tilia* and *Fraxinus*.

Although radiocarbon dating was increasingly used during the 1960s, 1970s and 1980s for determining the age of pollen-zone boundaries and for establishing a chronostratigraphic framework for individual sequences, pollenstratigraphic investigations in Romania continued to be carried out without any radiocarbon dates to support an age assignment (e.g., Diaconeasa 1968, 1969, 1977, 1979; Lupsa 1972, 1977, 1980; Boscaiu et al. 1983; Buz 1986, 1999; Diaconeasa and Farcas 1995-1996, 1998; Farcas 1995, 1996). Further limitations of these earlier studies were: low sampling resolution; a focus on forest pollen taxa and on the Holocene vegetation development; and, results were often only published in national Romanian journals. Consequently, the Quaternary vegetation development in Romania was poorly known outside the country, which often led to Romania being depicted with question marks, when palaeoenvironmental reconstructions for Europe were addressed (e.g., Huntley and Birks 1983, Bennett et al. 1991; Willis 1994; Renssen and Isarin 2001; Renssen et al. 2001; Ravazzi 2002). To fill this gap, a selection of the most complete and representative of the earlier investigated sites is shown in Figure 2 and Table 1.

The importance of the earlier pollenstratigraphic work in Romania should by no means be underestimated. However, the hypotheses emerging from these studies regarding age assignment of the different forest phases, location of glacial tree refugia and past forest dynamics need to be confirmed by more accurate, high-resolution pollenstratigraphic work and detailed radiocarbon dating.
The vegetation succession in the Gutaiului Mountains

In 1942 Pop performed a fairly complete investigation on the modern and fossil flora of the Oas-Gutaiului Mountains (Fig. 3) with the aim to enlarge the botanical and palaeobotanical knowledge from northern and northwestern Romania. His results showed that the vegetation succession in these mountains broadly corresponds to the rest of Romania. Nevertheless, there are some differences in the vegetation succession as compared to other areas.

1. The presence of Fagus pollen grains already in the Preboreal and rapidly increasing percentages from 2% to 10% during the Boreal let Pop (1942) to assume that Fagus may have had refugia in the Gutaiului Mountains.

2. Low Carpinus pollen percentages during the Subboreal, as compared to central and southern Romania were explained as a result of competition with Picea and a strong expansion of Fagus.

3. Abies pollen grains are only present in very low numbers.

4. The expansion of Fagus may have been favoured by more moist and cooler climatic conditions during the Subboreal, which also led to the formation of peat bogs in the area. This is well reflected in the stratigraphy by a transition from Cyperaceae peat to a peat composed of Cyperaceae and Sphagnum (Pop 1942).

Ongoing palaeoenvironmental and palaeoclimatic studies in Romania

During the last five years Romania has become the subject of an increasing number of investigations addressing the Lateglacial and Holocene environmental development. These investigations comprise pollen- and radiocarbon stratigraphies of lake-sediment and peat sequences (Farcas et al. 1999; Björkman et al. 2002, 2003; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003; Feurdean, in press), Th-U dating (Onac and Lauritzen 1996; Tamas and Causse 2000) and stable isotope analyses of speleothems (Onac et al. 2002; Tamas 2003). Many studies are still ongoing and the obtained results have not yet been published (Fig. 3).

Objectives of the doctoral thesis

At the beginning of my PhD project, no radiocarbon-dated pollen diagrams were available for Romania and very little was known about the vegetation development during the Lateglacial and Holocene (see e.g., Willis 1994). To address this gap, this thesis focused on a combination of high-resolution, pollenstratigraphic and plant-macrofossil studies of two sites in northwestern Romania. These analyses were combined with lithological parameters (loss-on-ignition, mineral magnetics) and a detailed AMS $^{14}$C chronology.
Pollen and spore analysis is an important tool for vegetation reconstructions. The vegetation is generally in equilibrium with climate. When climate changes the vegetation tends to respond according to its physiological limits (Iversen 1954; Wright 1984; Ammann et al., 2000; Wick 2000; Tinner and Lotter 2001; Williams et al. 2002). Therefore pollen and spore analyses can be used to yield specific climatic information. Caution is however advised when interpreting changes in the composition of the fossil pollen flora in terms of past vegetation and climatic changes. Firstly, the main restriction of pollen analysis is the identification of pollen at lower taxonomical levels (family and genera). Pollen can rarely be identified at species level, which makes it difficult to obtain accurate palaeocological information (Birks 1973; Watt 1978; Hannon 1999). Secondly, pollen production and the dispersion of some pollen types make the interpretation of the pollen assemblages in terms of local versus regional signals difficult. Thirdly, some of the taxa have low pollen production and/or their pollen grains are very sensitive to corrosion and are thus underrepresented or rarely found in the fossil assemblages (e.g. Larix and Populus). More recently, it has therefore been suggested that pollen analysis should always be associated with plant macrofossil analysis for a better interpretation of the fossil assemblages, hence, providing more precise information on past vegetation and climatic changes (Kullman 1998, 2002; Hannon 1999; Birks and Birks 2000; Birks 2003). However, also plant macrofossil analysis has some drawbacks. The lower dispersion capacity of plant macrofossils results in fossil remains being more closely deposited to the parental plants. Therefore, macrofossils of terrestrial taxa, particularly of those plants growing more upland e.g., Quercus, Tilia, Ulmus and Corylus are rarely found in fossil assemblages, as compared to those growing in the close proximity of the sedimentary basin e.g., Salix, Betula and Alnus (Birks 1973, 2003; Wainman and Mathewes 1990). Macrofossils of deciduous trees are also very susceptible to decay and are consequently strongly underrepresented or rarely found in fossil assemblages. The lower production rate of macrofossils and their low representation in the sediment in general, make it often difficult to perform plant macrofossil analysis with a high resolution (Tobolski and Ammann 2000). Pollen and macrofossil analysis complement each other and together they provide more reliable information on past vegetation dynamics and climatic changes.

The specific objectives of the doctoral thesis are:
1. To establish a high-resolution, radiocarbon-dated Lateglacial and Holocene pollen stratigraphy for north-western Romania (Appendix I, II, III).
2. To reconstruct the Lateglacial and Holocene vegetation development in north-western Romania, to discuss forest dynamics (arrival, expansion, reduction) and to identify which trees might have survived in Romanian refugia during the Last Glacial Maximum (Appendix I, II, III, IV).
3. To study whether changes in vegetation development can be connected to Lateglacial and Holocene climatic fluctuations and to compare the timing of these to records from around the North Atlantic region (Appendix III, IV; Thesis summary).
4. To summarize earlier pollen stratigraphic work from Romania and to present a plausible scenario for tree arrival, expansion and reduction based on recently investigated and radiocarbon-dated pollen stratigraphies (Thesis summary).
5. To discuss the impact of humans upon the landscape in north-western Romania (Appendix II, III).

### Study area

#### Climate

The modern climate in Romania is continental temperate, but varies across the country. The north-western part has a rather mild and moist climate, which is influenced by western oceanic air masses, while the eastern part is influenced by cold and dry air masses from the Russian plain. The southwest receives warm air masses from sub-Mediterranean areas and the southeast is influenced by dry air masses from south-western Asia. The Gutaiului Mountains have a higher amount of precipitation as compared to other regions. The precipitation shows a significant altitudinal gradient and ranges from ca. 700 mm/yr to ca. 1200-1400 mm/yr at higher elevation. Mean annual temperature is around 8°C and mean winter and summer temperatures are -3°C and 12-13°C, respectively.

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xerophilous (4.2%)</td>
<td>Cryophilous (1.2%)</td>
</tr>
<tr>
<td>Xeromesophilous (28,22%)</td>
<td>Microthermophilous (14,36%)</td>
</tr>
<tr>
<td>Mesophilous (40%)</td>
<td>Micromezothermophilous (61,08%)</td>
</tr>
<tr>
<td>Mesohygrophilous (15,90%)</td>
<td>Moderate thermophilous (10,26%)</td>
</tr>
<tr>
<td>Hygrophilous (2,56%)</td>
<td>Thermophilous (0,51%)</td>
</tr>
</tbody>
</table>

Table 2. Percentage representation of the plant species in the Gutaiului Mountains according to their moisture and temperature requirements (Marian, 1999).
**Geology**

The Gutaiului Mountains belong to the NW Late Pliocene volcanic arc of the Romanian Carpathians (Borcos et al. 1979). The bedrock is almost entirely composed of acidic rocks such as andesites rich in pyroxene and quartz, dacites, and rhyolites. Sedimentary rocks occur only occasionally (Borcos et al. 1979) (Fig. 4). Brown earth soils dominate in the mixed-deciduous woodland. Acid brown soils are dominant in beech and spruce forests, while podzolic soils are formed under coniferous forests (Istvan et al. 1990). Numerous peat bogs are known within this mountain massif. According to Pop (1960) this area provides ideal conditions (i.e., impermeable bedrock, precipitation and springs) for the formation of peat bogs.

**Vegetation**

The modern vegetation in Romania is composed of a mixture of Eurasiatc, central European, circumpolar, Atlantic, Mediterranean and sub-Mediterranean species (Donita 1962; Csuros 1976; Cristea 1993). The vegeta-
tion is arranged in zones (latitudinal arrangement) and forest belts (altitudinal arrangement) according to climate, topographic, and edaphic conditions (Figs. 5, 6). The zones are: steppe zone, forest-steppe zone and nemoral zone; the latter is the most extensive vegetation type (Donita, 1962; Csúrós 1976; Cristea 1993). The limits of the altitudinal forest belts vary in the Carpathians with latitude, distribution of the air masses and orientation of the mountain massif. Four altitudinal belts can be distinguished:

1. The foothill forest belt (300-600 m a.s.l.) with several oak species (the most common is Quercus petraea), lime (Tilia cordata), hazel (Corylus avellana), hornbeam (Carpinus betulus) and beech (Fagus sylvatica).

2. The montane belt is subdivided into three sub-belts: beech (Fagus) between 600-1000 m; beech–spruce (Fagus-Picea) or beech–fir (Fagus-Abies) between 1000-1200 m and spruce (Picea) between 1200-1800 m.

3. The sub-alpine belt (1800-2000 m) is dominated by sessile oak (Quercus petraea). Other deciduous tree species, including common oak (Quercus robur), lime (Tilia cordata), hazel (Corylus avellana), ash (Fraxinus excelsior), hornbeam (Carpinus betulus) and beech (Fagus sylvatica) occur occasionally. This belt is affected by human activities (e.g. deforestation, forest grazing, and cultivation).

4. The alpine belt occurs above 2000 m and consists of communities of several willows (Salix spp.) and herbaceous species such as Silene acaulis, Saxifraga bryoidis, Festuca glacialis, Sesleria coerulea and Carex curvula.

The modern flora in the Gutaiului Mountains contains a mixture of Eurasian (43.9%), European (13.5%) and central European (9.69%) taxa as an expression of a continental temperate climate. Additionally, there are circumpolar (11.2%), Atlantic (2.4%), Mediterranean and sub-Mediterranean (1.5%) and Mediterranean-pontic species (2%) (Marian, 1999). The distribution of species according to their moisture and temperature requirements is shown in Table 2. Due to western oceanic influences and a northern location of the Gutaiului Mountains, the altitudinal distribution of the forest belts is as follows:

1. The lowest forest belt (below about 600 m) is dominated by sessile oak (Quercus petraea). Other deciduous tree species, including common oak (Quercus robur), lime (Tilia cordata), hazel (Corylus avellana), ash (Fraxinus excelsior), hornbeam (Carpinus betulus) and beech (Fagus sylvatica) occur occasionally. This belt is affected by human activities (e.g. deforestation, forest grazing, and cultivation).

2. The beech forest belt (Fagus sylvatica) occurs between 600 and 1000 m. Communities of hornbeam (Carpinus betulus), lime (Tilia cordata), hazel (Corylus avellana), ash (Fraxinus excelsior), elm (Ulmus minor, U. glabra), birch (Betula pendula, B. verrucosa), elder (Sambucus nigra) and oak (Quercus petraea, Q. robur) are present within the lower part and spruce (Picea abies) and pine (Pinus sylvestris) occur in the upper part.

3. Above 1000 m spruce (Picea) is only present as enclaves within the beech forest. Communities of rowan (Sorbus aucuparia), maple (Acer pseudoplatanus), grey alder (Alnus incana) and fir (Abies alba) occur sporadically within this belt.

4. The sub-alpine belt is only present on the highest peaks of the mountain massif surrounding the study area and consists of communities of dwarf pine (Pinus mugo), juniper (Juniperus communis ssp. nana), rhododendron (Rhododendron kotschyi), lingonberry and blueberry (Vaccinium vitis idea, V. myrtillus) and green alder (Alnus viridis).
Material and methods

Fieldwork and site selection strategy

The study area was chosen in accordance with the aims outlined above. There is no published data about the presence of glaciers during the Weichselian, but it is generally assumed that alpine glaciers did not reach below 1600-1800 m a.s.l. in the eastern Carpathians (Woldstedt 1958; Balteanu et al. 1998). Therefore it was expected to obtain continuous and old sediments (Late Glacial Maximum to present) in the basins located below this elevation. A more recent study by Kortarba and Baumgart-Kortarba (1999) gave evidence for the extension of glaciers during the Last Glacial Maximum at around 950 m in the Polish Carpathians, which could imply that the study area in the Gutaiului Mountains may have been subjected to periglacial processes.

Initially, several peat bogs in the Gutaiului Mountains were surveyed and cored. However, most of them turned out to be young peat deposits and did not meet our requirements. Parallel cores with 50 cm overlap were retrieved from the basal sediments of two former lake basins: Creasta Cocosului (N 47°40'; 23°50'; 900 m a.s.l.) and Izvoare (N 47°44'80''; E 23°43'35''; 900 m a.s.l. (Fig. 7). The lithostratigraphic description of the sediments is presented in Tables 3 and 4, respectively. A preliminary analysis showed a dominance of thermophilous tree pollen (Quercus, Tilia, Ulmus), characteristic of an early to mid-Holocene deciduous forest. Therefore, these sediments were regarded as too young for the purpose of the present investigation.

At the end, two sites were selected for this PhD project: the former small crater lakes Preluca Tiganului (N 47°48'83''; E 23°31'91''; 730 m a.s.l.) and Steregoiu (N 47°48'48''; E 23°32'41''; 790 m a.s.l.), situated on the western flank of the Gutaiului Mountains (Appendix I, Table 3. Lithostratigraphic description of the Creasta Cocosului sediment cores between 7.88-6.35 m below surface (The boundaries between different layers were gradual).

<table>
<thead>
<tr>
<th>Units</th>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6.35–7.72</td>
<td>Gyttja, dark brown</td>
</tr>
<tr>
<td>2</td>
<td>7.72–7.82</td>
<td>Gyttja clay with sand, dark brown</td>
</tr>
<tr>
<td>1</td>
<td>7.82–7.88</td>
<td>Silty clayey gyttja with sand, rich in diatoms, dark brown</td>
</tr>
</tbody>
</table>

Table 4. Lithostratigraphic description of Izvoare sediment cores between 3.82-2.25 m below surface (gLB, gradual lower boundary; sLB, sharp lower boundary).

<table>
<thead>
<tr>
<th>Units</th>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2.25–3.01</td>
<td>Sphagnum peat, gLB</td>
</tr>
<tr>
<td>3</td>
<td>2.82–2.88</td>
<td>Peat, gLB</td>
</tr>
<tr>
<td>2</td>
<td>2.88–2.96</td>
<td>Gyttja, dark bown, gLB</td>
</tr>
<tr>
<td>1</td>
<td>2.96–3.82</td>
<td>Sandy silt with sand layers and gravel, grey, sLB</td>
</tr>
</tbody>
</table>
II, III and IV). Cores were collected with a Russian corer (1 m length, 5 cm diameter) from the central, deepest part of each site in May 1999 (Figs. 8, 9). Overlapping cores were taken in order to obtain enough material for biostratigraphic and lithostratigraphic analyses. The cores were preliminary described in the field, wrapped in a plastic film and transported to the Department of Geology at Lund University, Sweden where sub-sampling and laboratory work were performed.

The reason for studying two neighboring sites (ca. 1 km from each other) was to see whether the vegetation development reconstructed at one site can be corroborated by the second site. Both sites are former crater lakes and their stratigraphies may be subject to hiatus, rendering a continuous reconstruction impossible. We speculated that the location of the sites at 700-800 m a.s.l. and in deep-incised valleys may have offered suitable climatic conditions for tree survival during the Last Glacial Maximum (see discussion on glacial refugia). Moreover, middle to high altitude sites are documented to have been more sensitive to vegetation changes during the cold phases of the Lateglacial, due to their possible location at an ecotone i.e. boundary zone between two different vegetation belts (Peteet 2000; Wick 2000; Ammann et al. 2000). Preluca Tiganului (surface area ca. 1 ha) and Steregoiu (surface area ca. 0.5 ha) are topographically closed basins where the hydrological balance is controlled by temperature (T), precipitation (P) and evaporation (E) changes and may therefore be used for a reconstruction of lake level fluctuations and past climatic conditions. Since the source area for pollen is related to the size of the basin, these small basins should give a local environmental signal (Jacobson and Bradshaw 1981; Sugita 1994; Broström 2002). We chose to perform a detailed multi-proxy analysis of two sites (pollen, macrofossil, mineral magnetic and organic matter analyses, radiocarbon dating), instead of analyzing several sites by one proxy method only to obtain as much detailed palaeoecological information as possible.

Laboratory methods

In the laboratory the cores were described in detail (Appendix I, II, III) and sub-sampled for pollen, macrofossil, loss-on-ignition (LOI) and mineral magnetic analyses.

Pollen and charcoal analyses

Pollen analysis was initially carried out at 2-cm intervals at Steregoiu. Later, micro-charcoal particles were counted on each second pollen slide, i.e. every 4th cm. At Preluca Tiganului the resolution between analysed samples varied between 2.5 cm in the Lateglacial and early Holocene sediments and 4 cm intervals for the mid- and late Holocene. Pollen samples (1 cm$^3$) were prepared according to the standard procedure described by Berglund and Ralska-Jaseiwiczowa (1986) and Moore et al. (1991). Lycopodium tablets with a known number of spores were added to each sample to determine fossil pollen and charcoal concentrations (Stockmarr 1971). Pollen counts were generally made at 400x magnification but for special identification a 1000x magnification and oil immersion was used. Pollen and spore identification was based on keys and illustrations of Moore et al. (1991) and Reille (1992, 1995), and by comparison to reference collections at the Department of Geology, Lund University. An average of 500 pollen grains, excluding aquatics and spores, were counted at each level, and 95 pollen taxa were indentified in total. Percentages of terrestrial pollen were calculated on the basis of their total sum, excluding spores and pollen of aquatics. Percentages of spores and aquatic pollen types were calculated on the basis of the total sum including terrestrial, spores and aquatic pollen types. The pollen diagrams were drawn using TILIA and TILIA Graph (Grimm 1992). To facilitate the description and interpretation of the pollen diagrams, the pollen spectra were divided into local pollen assemblage zones (LPAZ) using the CONISS program (Grimm 1987).
Macrofossil analysis
Contiguous (4 cm thick) samples were taken for macrofossil analyses from both sites. The samples from Preluca Tiganului have, however, only been analysed in the lowermost 6 m, comprising the time interval between 14,500 and 8000 cal. yr BP. The sub-samples were soaked in 5% NaOH and sieved through a 0.25 mm mesh under running water. All recognizable macro remains were examined under a dissecting microscope. The fossil identification was carried out using atlases and keys of Katz et al. (1965). The results are presented as volume percentages. The macrofossil diagrams were also constructed with the TILIA program (Grimm 1992) and visually subdivided into macrofossil assemblage zones (MAZ). Betula sect. Albae is referring to remains of tree birch which could not be identified to species level.

Mineral magnetic analysis
The sequences were continuously sub-sampled (2 cm$^3$) for mineral magnetic susceptibility and Saturation Isothermal Remanent Magnetization (SIRM). The analyses were used to assess input of minerogenic material and soil erosion. The samples were dried over night at 40 ºC prior to mineral magnetic analyses. Magnetic susceptibility was measured in a low magnetic field of 0.1 mT using a balanced alternating current bridge circuit. Mass specific units were calculated and expressed as mm$^3$kg$^{-1}$. SIRM was induced in a strong magnetic field of 1 Tesla by a Redcliff BSM 700 Puls Magnetic Charger. The resulting remanent magnetization was measured with a Molspin Spinner Magnetometer. Mass specific units were calculated as mA$m^2$kg$^{-1}$.

Loss on ignition (LOI)
Loss on ignition (LOI) was measured on the same samples on which we performed mineral magnetic analyses, following the methods described by Bengtsson and Enell (1986). The samples were only combusted at 550 ºC for 3 hours, because previous research has shown that carbonates are not present in the sediments (Wohlfarth et al. 2001). LOI is expressed as percentage of the weight of the dried sample and was used for estimating the organic matter content and help to characterize the sediment composition.

Radiocarbon dating
The chronology is based on seventeen AMS radiocarbon dates from Steregoiu and on fourteen AMS $^{14}$C measurements from Preluca Tiganului. All measurements were performed on terrestrial plant macrofossils and/or on peat. The obtained AMS radiocarbon ages were converted into calibrated years BP using the calibration curve of Stuiver et al. (1998) and the OxCal v3.5 program (Bronk Ramsey 1995).

Results
Summary of papers I – IV

Paper I

This is the first paper presenting the vegetation development in the Gutaiului Mountains and the response of the vegetation to Lateglacial and early Holocene climatic changes. The reconstruction is based on pollen-stratigraphic investigations of the basal sediments from the two small, overgrown crater lakes Preluca Tiganului (730 m a.s.l.) and Steregoiu (790 m a.s.l.). This study builds on work by Wohlfarth et al. (2001), which only covered the early part of the last deglaciation (15,000-13,600 cal. yr BP), but showed the potential of these sites for further investigations. The main aim was thus to provide a continuous record of the spatial and temporal vegetation development, based on high-resolution pollen studies from an area where little knowledge had previously been available. Another aim was to establish a detailed chronology for Lateglacial vegetation changes in a region, where virtually no radiocarbon dates had been obtained. This new study also aimed at advancing palaeoecological knowledge from a key area, which has been regarded as a potential glacial refugia during the last cold stage of the Quaternary.

The pollen record shows that the open vegetation with herbs (Artemisia, Chenopodiaceae and Poaceae) and shrubs (Salix and Juniperus) dominated the surrounding areas prior to 14,700 cal. yr BP, corresponding to the end of the Late Glacial Maximum. Marked warmer conditions at the beginning of the Lateglacial interstadial led to a rapid expansion of an open forest dominated by Betula and Pinus. The renewed spread of open vegetation with Artemisia, Poaceae, Cyperaceae, and Chenopodiaceae between 14,050 and 13,800 cal. yr BP suggests colder climatic conditions which could correspond to GI-1d in the GRIP event stratigraphy. A further expansion of a more diverse and dense forest with Betula, Picea, Pinus, Alnus and Ulmus from 13,400 cal. yr BP onwards indicates a rise in temperature which coincides approximately with GI 1a-1c. This was followed by another episode of forest reduction between 12,900 and 11,500 cal. yr BP, implying cold climatic conditions. The expansion of Betula, Alnus and Pinus dominated, open forests at 11,500 cal. yr BP, and of Picea and Ulmus at 11,250 cal. yr BP suggests a climate warming at the beginning of the Holocene.

This study allowed for the first time a comparison between environmental changes recorded during the Lateglacial and early Holocene in Romania with those...
reconstructed from well-dated sequences in central and northwestern Europe. The reconstructed vegetation succession revealed that the climatic fluctuations recorded in the North Atlantic region had a distinct impact on areas situated in the continental part of Europe e.g., Romania. The major conclusion of this paper is that climatic fluctuations may have been the main factor controlling the forest composition during the Lateglacial in Romania, while the early Holocene forest composition was primarily determined by succession and migration processes.

**Paper II**


This article presents a detailed vegetation history, based on the sequence from Steregoiu, covering the time period from the end of Last Glacial Maximum to the present day. The objectives were to obtain a high-resolution time scale for vegetation changes and a chronology for tree dynamics. The discussion is focused on the possible survival of tree taxa in the study area, on immigration routes, tree dynamics (arrival, expansion, maximum and retraction) and human activities. The article also presents the on-site vegetation development and the sedimentary history of the basin, helping in the interpretation of the depositional environment. It is the first most complete pollen and radiocarbon-dated sequence presented so far from Romania. This facilitates comparison to other pollen stratigraphic studies from Romania and surrounding regions, allowing for a regional reconstruction of the vegetation history and climatic.

The results show that the cold periods that occurred prior to 14,700 cal. yr BP and between 12,900 and 11,500 cal. yr BP were characterized by the presence of open vegetation communities with low shrubs (*Salix* and *Juniperus*) and herbs (*Artemisia*, *Poaceae*, *Chenopodiaceae*). The forest part of the landscape was vegetated by *Pinus* and *Betula*, although high amounts of *Pinus* pollen were possibly derived from open forests, which were restricted to lowlands areas. During warmer episodes between 14,700-14,050 cal. yr BP and 13,750-12,900 cal. yr BP, the open vegetation was replaced by open forest composed of *Betula*, *Picea*, *Pinus* and *Alnus*. Small *Ulmus* populations may have existed locally between 13,200 and 12,900 cal. yr BP.

The rapid expansion of open *Betula*, *Pinus* and *Alnus* forest at the beginning of the Holocene, at 11,500 cal. yr BP is the result of the expansion from local populations. The fairly abrupt replacement (at ca. 11,250 cal. yr BP) of pine-birch forest by *Ulmus* and *Picea* indicates a temperature rise and that they had occurred in small stands in isolated habitats with sufficient warmth and humidity. The local establishment and expansion of *Quercus*, *Tilia*, *Fraxinus* and *Acer* was dated to ca. 10,750 cal yr BP. The late expansion and establishment of *Quercus*, *Tilia*, *Fraxinus* and *Acer* may imply that these trees survived in glacial refugia in areas located further away e.g. south of Romania and in the Hungarian plain. At ca. 10,200 cal. yr BP *Corylus* started its expansion and replaced *Ulmus* as a dominant forest constituent. A forest composed of *Corylus*, *Ulmus*, *Quercus*, *Tilia*, *Fraxinus*, *Acer* and *Picea* was maintained in the surrounding landscape until ca. 4800 cal. yr BP. It was succeeded by a simultaneous establishment and expansion of *Fagus* and *Carpinus* at around 4800 cal. yr BP. From about 4000 cal. yr BP onwards *Fagus* dominated and the forest diversity became strongly reduced, with only *Quercus* and *Carpinus* present. The late *Fagus* and *Carpinus* expansion was probably connected to climatic changes, rather than human activities. Human activities are represented by grazing and forest grazing. Scattered pollen indicators of arable field and grazing are recorded during the last 300 years. These pollen grains were probably blown from the Oas Depression, which is located at an elevation of 200 m above sea level.

**Paper III**


The aim of this study was to document the postglacial forest development based on a pollen-stratigraphic analysis of the sediment sequence obtained from Preluca Tiganului, north-west Romania. The terrestrial pollen data was used to describe the history of the upland vegetation. Aquatic and wetland pollen types were used to reconstruct past peat surface conditions, which in turn may provide an estimate of climatic conditions. Furthermore, results obtained at Preluca Tiganului were correlated to those obtained at Steregoiu in order to infer regional forest and climate history. Apart from the timing of the postglacial tree succession, ecological requirements e.g. tolerance limits, length of the growing season, regeneration, shade tolerance, colonization ability, modern distribution of the trees and inter-specific competition of different taxa, as well as factors that may have influenced the Holocene tree succession, are discussed.

The first step in the Holocene vegetation succession was the rapid expansion of birch and pine, which survived in the area during the Lateglacial. During the first 200-300 years of the Holocene, the forest had an open character and large areas of the landscape were still occupied by an open shrub and herb vegetation. The slightly delayed expansion of *Ulmus* and *Picea* (at ca. 11,250 cal. yr BP) was connected to a strong reduction during the cold Younger Dryas episode. The arrival of *Quercus*, *Tilia*, and *Fraxinus* probably occurred around 11,250 cal. yr BP, however, they did not expand until
around 10,700 cal. yr BP. Their delayed expansion was primarily connected to the immigration lag from more distant localities as compared to the other tree taxa. The demand of higher temperatures during the growing season and high growing degree days have played an important role in their spreading from 10,700 cal. yr BP. In contrast, competition with the already established Ulmus, Picea, Pinus and Betula may have limited their expansion.

Temperature reconstructions based on a variety of proxies show general warming trends during the early Holocene, which were interrupted by short, colder episodes. The changes in temperature and precipitation were significant enough to trigger changes in forest composition. This study presents for the first time a correlation between changes in forest composition in Romania and short-lasting climatic cooling episodes recorded in the Northern Hemisphere. For instance the pollen investigations show that the permanent decline of Ulmus along with the expansion of Corylus at ca. 10,300 cal. yr BP, the reduction of Ulmus, Tilia and Quercus together with the dominance of Corylus at ca. 9300 cal. yr BP, and a clear decline of all thermophilous trees taxa at 8600 cal. yr BP may possibly be synchronous with the short climatic cooling recorded around 10,300 cal. yr BP, 9300 cal. yr BP and 8600 cal. yr BP in regions around the North Atlantic. Once Ulmus started to decline (around 10,300 cal. yr BP), it never regained its dominance in the forest. Instead, Quercus, Tilia and Fraxinus re-expanded around 8200 cal. yr BP, although except for Quercus, the latter two taxa never reached their previous proportion in the forest again.

At Preluca Tiganului we have for the first time dated the local establishment of Carpinus and Fagus. Thus, the expansion of Carpinus at ca. 5750 cal. yr BP, coincident with a regression of Picea and Corylus was documented to be induced by warmer and possibly drier climate. The expansion and dominance of Fagus at 5200 cal. yr BP and 4800 cal. yr BP, respectively is interpreted as a response to cooler summers, warm winters and moist conditions. An alternative cause for the late expansion of Carpinus and Fagus is human impact, although evidence of human-induced deforestation is not clearly documented. Only during the last 300 years is human activity clearly recognized by a strong reduction of forest diversity and density. Other evidence of human activities upon the landscape are grazing, forest grazing and agriculture, the latter only evidenced in the Oas Depression.

This paper combines results from high-resolution macrofossil, pollen, mineral magnetic and loss-on-ignition analyses from two sites in north-western Romania. The aim of this study is to complement previous pollen results by focusing on the reconstruction of the local vegetation and on climatic conditions. Terrestrial plant macrofossils were used for a reconstruction of the local vegetation and telmatic and limnic macrofossils, including faunal and flora remains, were used to document past lake level fluctuations and to improve the knowledge about climatic changes. Lithostratigraphy and mineral magnetic parameters (magnetic susceptibility and SIRM) can give information about water-level fluctuations and erosion of sediments from the surrounding slopes. The organic matter content and the composition of the aquatic remains were used as an approximate indicator of aquatic productivity and of changes in the depositional environment.

The cold water lake with low trophic status was colonized by pioneer communities prior to 14,700 cal. yr BP. The prevalence of a cold and dry climate is indicated by the presence of a tree-less vegetation and by the development of open communities including shrubs and herbs with steppe and montane taxa. Relative stable environmental conditions characterized the beginning of the Lateglacial as revealed by the formation of open forests with Pinus and Betula, and changes in sediment composition (reduction of the mineral magnetic material and rise in organic matter content). The increase in number of limnic animals could reflect some rise in lake productivity. This succession was interrupted by a short episode of climate cooling and drier conditions inferred from macrofossils, which led to a forest reduction with single stands of Pinus and Betula between 14,100 and 13,800 cal. yr BP. Plant macrofossils provide evidence of a rapid expansion and dominance of Picea abies forests mixed with Pinus sp., Larix decidua, Betula sp., and Salix sp. from about 13,800 cal. yr BP, while pollen data indicates a possible occurrence of Ulmus. Warm and moist climatic conditions were inferred between 13,800 and 13,400 cal. yr BP, followed by a decrease in humidity from ca. 13,400 cal. yr BP. Cooler and drier conditions between 12,900 and 11,500 cal. yr BP are inferred from the recurrence of an open landscape where only Betula, Larix, Salix, and possibly Pinus were present.

An increase in diversity and abundance of limnic plant and animal remains around 11,800 cal. yr BP (most pronounced at 11,500 cal. yr BP) reflects higher water temperatures and increased aquatic productivity. At 11,500 cal. yr BP, terrestrial macrofossils show a rapid reforestation with Pinus, Betula, Larix, Populus and Picea. This is taken to mark the rapid warming at the beginning of the Holocene, but is 300 years later than the signal observed in the aquatic community. Reconstructed climatic conditions for the early Holocene were warm and wet, but were followed by a drier climate from about 10,600

---

**Paper IV**

Feurdean A. and Bennike O. Late Quaternary palaeoecological and palaeoclimatological reconstruction in the Gutaiului Mountains, NW Romania. Manuscript submitted to *Journal of Quaternary Science.*
cal. yr BP onwards. This observation is also supported by the dominance of trees with more continental affinities such as *Quercus*, *Tilia*, *Ulmus* and *Fraxinus* between 10,700-8600 cal. yr BP, which indicate higher summer temperatures and lower precipitation as compared to the present day. Dry summers (inferred from aquatic macrofossils) could have been responsible for the late expansion and maximum of *Corylus* at 10,300 cal. yr BP and 9300 cal. yr BP, respectively. Very dry conditions may have occurred between 8600 and 8200 cal. yr BP. The clear reduction of *Tilia*, *Quercus*, and *Fraxinus* around 8600 cal. yr BP may have been caused by increased water stress and possibly cooler conditions. Moisture availability increased again after 8200 cal. yr BP, documented by the expansion of *Picea* and by the re-expansion of *Quercus*, *Tilia*, and *Fraxinus* and by wetter peat surface conditions.

**Unpublished results**

Additional results to those presented in Appendix I-IV are variations in micro-charcoal content along the whole sediment sequence at Steregoiu (Fig. 10) and a mid- to late Holocene macrofossil record for Steregoiu (Fig. 11). Micro-charcoal was analysed to obtain additional parameters on forest fires and past climatic conditions and the late Holocene macrofossil analysis contributes to a reconstruction of the terrestrial local vegetation and allows extending the reconstructed peat surface status from 8000 cal. yr BP to the present.

**Fire history**

Prior to 14,700 cal. yr BP, micro-charcoal concentrations are generally low, indicating that fires have not been common around the site (Fig. 10). The slight increase of micro-charcoal fragments between 14,700 and 13,400 cal. yr BP could possibly indicate dry climatic conditions, which could have facilitated vegetation inflammability. The distinct rise in charcoal concentrations from about 13,400 cal. yr BP onwards is associated with a decrease in pollen values for *Picea*. The charcoal particles could not be identified, but it could be speculated whether intense forest fires could have destroyed parts of the *Picea* stands around the site. A clear correlation between high numbers of macro-charcoal and a reduction of *Picea* pollen and macro-remains could e.g., be demonstrated by Wohlfarth et al. (2001) at Preluca Tiganului for the time interval 13,900-13,700 cal yr BP and was interpreted as having been caused by dry summer conditions. High micro-charcoal percentages and increasing pollen values of xerophytic herbs (e.g. *Artemisia*, Chenopodiaceae, Poaceae) between 12,900 and 12,500 cal. yr BP could point to dry summers, which could have caused forest fires. Herb pollen values remain high between 12,500 and 11,700 cal. yr BP, but charcoal particles decrease in numbers. This could indicate that forest fires decreased and that summers were less dry. On the other hand, low charcoal numbers could also indicate that the open vegetation communities, which became established between 12,500 and 11,700 cal yr BP, were less susceptible to ignition.

The increase in micro-charcoal particles between 11,700 and 11,000 cal. yr BP occurs at a time when dense forest became gradually established around the site. The pollen records show no marked changes in the arboreal pollen percentage values, which may imply that the charcoal fragments were possibly derived from ground fires close to the site, which did, however, not affect the forest. The distinct peak in micro-charcoal concentration between 10,600 and 10,400 cal. yr BP follows after *Quercus*, *Tilia* and *Fraxinus* had become established and predates the forest reorganization, (expansion of
Corlylus) by ca. 100-200 years. Although no decline in arboreal pollen percentages and thus in the proportion of forest taxa can be observed, small, local fires may have occurred on or close to the site, but they did not affect the forest composition. Charcoal concentration decreases gradually until ca. 10,000 cal. yr BP, indicating only occasional forest fires. Two isolated charcoal peaks can be seen at ca. 9300 cal. yr BP and at ca. 8700 cal. yr BP, which may point to small local fires. From 8600 cal yr BP onwards, charcoal concentrations are generally low, except for between 5700 and 4800 cal. yr BP, 3200 and 2700 cal. yr BP, 1300 and 800 cal yr BP and during the last 300 years. This could be interpreted as several small local fires, which occurred in the surroundings or on the site.

**Macrofossil results**

The macrofossil assemblage zones (MAZ) from Steregoiu are shortly presented below. The zone numbers follow the MAZ S1-S8 presented in Appendix IV and their age assignment is according to Appendix II.

MAZ-S9 (2.30-1.90 m; 8000-7500 cal. yr BP). Macrofossils of *Picea abies* macro remains are abundant, coinciding with high pollen percentages for *Picea*. This indicates that the surrounding landscape was predominantly forested by *Picea*, but also that this tree likely grew on the peat surface. Radicells are scarce and *Cenococcum geophilus* sclerotia appear only as two isolated spikes. The telmatic flora is scarce and comprises *Carex* ssp., *Cyperus* sp. and *Urtica dioeca* remains (Fig. 11).

MAZ-S10 (1.90-1.50 m; 7500-5500 cal. yr BP). Macrofossils of *Picea abies* disappear, although pollen values remain constant. Radicells increase and a few isolated remains of *Carex* sp. are recorded. Wetter conditions on the surface of the peat bog could have caused a retraction of *Picea*, but most probably it was still abundant in the surrounded landscape.

MAZ-S11 (1.50-1.20 m; 5500-3700 cal. yr BP). *Picea abies* remains re-appear and increase gradually; *Carex* sp. remains are rare. *Cenococcum geophilum* sclerotia increase distinctly in the lower part of the unit, whereas radicells are only present in low numbers. This development, together with the increase in pollen values for *Picea*, *Alnus* and *Betula*, could indicate that woody species expanded over the bog surface, which in turn could point to a change towards drier peat surface conditions.

MAZ-S12 (1.20-0.30 m; 3700-800 cal. yr BP). The disappearance of *Picea abies* remains and the presence of abundant *Cenococcum geophilum* sclerotia coincide with the appearance of radicells and a marked increase of *Carex* ssp. and *Cyperus* sp.

MAZ-S13 (0.30-0.00 m; 800 cal. yr BP to present). *Potentilla erecta* macrofossils increase in numbers, coinciding with high pollen values for *Potentilla*. Finds of *Cyperus* sp. are recorded in the lower part of S13, where also radicells decrease markedly. The macrofossil remains of MAZ-S12 and MAZ-S13 show that fen communities dominated the surface of the bog.


Discussion

Glacial refugia

The term glacial refugia is used to denote areas with favorable micro-environmental conditions, where trees could survive in small populations during glacial periods (Faegri 1963; Lang 1970; West 1977; Huntley and Birks 1983; Bennett et al. 1991; Willis 1992a, 1992b, 1996, 1994). The information about the location of refugia was based on the assumption that the first tree taxa, which responded to climate warming, were those that had been locally present earlier (West 1977; Huntley and Birks 1983; Bennett et al. 1991). Refugial areas offered specific local conditions (i.e., moister, warmer) for trees to survive and acted as a repopulation centre for temperate trees, which had become extinct in regions, where full glacial and/or periglacial conditions prevailed. Once a tree species also became extinct in its refugia at any time of the Quaternary period, it became extinct everywhere in Europe (Bennett et al. 1991).

It has been proposed that tree refugia may have been located in southern Europe, particularly in the Balkans, Alps, Carpathians and the Italian mountains (van der Hammen et al. 1971; Huntley and Birks 1983; Bennett et al. 1991; Willis 1994). The Iberian Peninsula was often excluded due to extreme dry condition during glacial periods. The Balkan region was situated south of the major ice sheets and outside the region of continuous permafrost during the Weichselian glaciations and local glaciers may only have occurred at high elevation sites in the Carpathians. Nevertheless this region had one major drawback: moisture availability. Therefore, if refugia existed on the Balkans, they would have been restricted to mid-elevation sites, where adequate habitats may have been available and where potential glacial refugia may have existed (Willis 1994).

High pollen values for coniferous (Picea, Pinus, Abies, Larix) and temperate trees (Betula, Alnus and Salix) are often associated with macro-remains during last Glacial Maximum and the Lateglacial confirming their local presence. In contrast, sporadic finds or low amounts of pollen of thermophilous trees (Ulmus, Quercus, Tilia, Fraxinus and Corylus) are difficult to interpret in terms of local presence or absence. If it is assumed that these trees only survived in small populations or as single trees, it cannot be expected to find a high amount of pollen grains and macro remains in the sediments. Moreover, pollen trap studies show that the pollen production, especially Pinus is controlled by changes in climate (Hicks 2001; Autio and Hicks 2004). Colder climatic conditions could therefore have contributed to a weaker representation of thermophilous pollen in the fossil assemblages.

Forest development in the study area during last ca. 18,000 cal. yr BP and comparison to other sites in Romania

Last Glacial Maximum (LGM)

Pollen and plant macrofossil remains in the oldest sediments at Steregoiu, which were dated to >14,700 cal yr BP, i.e. to the end of the LGM, suggest predominantly tree-less vegetation with herbs and shrubs of montane and steppe character at mid-altitude sites in the Gutaiului Mountains. However, it cannot be excluded that scattered Pinus and Betula individuals were present (Appendix IV). Two other pollen-stratigraphic records from Romania, Iezerul Calimani in the eastern Carpathians (Farcas et al. 1999; Farcas 2001) and Avrig in central Romania (Tantau 2003), show LGM sediments in the basal part of the sequence (Figs. 3, 12). One AMS 14C date of 14,800±1100 yr BP (ca. 18,000 cal. yr BP) from Iezerul Calimani may give indications for a LGM age of the sediments, which contained relatively high frequencies of Pinus pollen, together with some Betula and Picea (Farcas et al., 1999, Farcas, 2001). However, due to uncertainties in the radiocarbon chronology, it has been suggested to attribute this part of the sequence to the Lateglacial interstadial (Farcas et al., 1999). The lowermost sediments at Avrig are dated to 13,880±90 14C yr BP (ca. 17,000 cal. yr BP) and contained pollen of Pinus, Betula, Juniperus and Salix (Tantau, 2003). Recently, a pine log was found at Magherus, a site situated in the lowland area, ca. 200 km south of the Gutaiului Mountains (Fig. 3) and was dated to ca. 14,500 14C yr BP (corresponding to ca. 17,000 cal yr BP) (Wohlfarth et al. unpublished; Lascu, 2003), demonstrating the existence of pine in this area.

No published palaeotemperature reconstructions for Romania exist, but simulated climatic conditions for Europe during the LGM show that mean January temperatures may have been around -15 to -20°C and mean July temperatures at around 13-15°C (Renssen and Isarin, 2001). Permafrost conditions existed in areas north of 47°N (Renssen and Isarin, 2001). Another paleoclimatic simulation for central Europe shows similar low temperatures and implies dry climate conditions (Kutzbach et al. 1993). Pinus and Betula trees could survive these low temperatures, but must have been exposed to water stress, caused by drought (less precipitation) or by frozen soils.

The pollen and plant macrofossil studies described above suggest a possible occurrence of Pinus, Juniperus, Betula and Salix at the end of the LGM in different regions of Romania, such as the Gutaiului Mountains, Calimani Mountains and Avrig (Fig. 12). Based on findings of pine megafossils it can, however, be concluded that pine forests have been common in lowland areas in Romania (Wohlfarth et al. unpublished). Picea pollen (ca. 4%) has only been found at Iezerul Calimani and is absent in the lowermost sediments at Steregoiu.
Figure 12. Map showing the tree taxa, which were present in Romania during the Last Glacial Maximum, according to pollen and mega-fossil evidence (Appendix I, II, IV; Wohlfarth et al. 2001; Wohlfarth unpublished; Lascu 2003) or only pollen (Farcas et al. 1999; Tantau 2003).

Figure 13. Map showing the tree taxa, which were present in Romania between 14,700 and 14,100 cal. yr BP. Their occurrence is based on pollen and macrofossil remains (in the Gutauiului Mountains) (Appendix I, II, IV; Wohlfarth et al. 2001), on charcoal at Magherus (Wohlfarth unpublished; Lascu 2003) and on pollen (Tantau 2003; Farcas et al. 1999).
Pinus cembra coal analyses could confirm that trees of relatively homogenous. On the other hand, pollen and charcoal analyses could suggest a relatively wide expansion of Picea during the LGM over central and south-eastern Europe, including the Romanian Carpathians. Charcoal fragments of Picea sp., Pinus cembra and Salix sp. have also been found in Moldavia (Haessaerts et al. 1998).

**Lateglacial forest development**

At the beginning of the Lateglacial interstadial Pinus and Betula started to form open forests at mid-altitude sites in the Gutaiului Mountains, coincident with a decline of open vegetation communities. The Pinus-Betula forests also contained Alnus, Populus and Prunus (Wohlfarth et al., 2001; Appendix I, II, IV), while shrubs (Juniperus and Salix) herbs (predominant Artemisia), grasses (Poaceae) and sedges (Cyperaceae) dominated the open vegetation communities. Our record is in agreement with pollenstratigraphic results from Avrig (Tantau 2003) and is rather similar to the vegetation pattern reconstructed at Taul Zanoguti and Iezerul Calimani (Farcas et al. 1999) (Fig. 13).

Around 14,100 cal. yr BP a short-lived re-expansion of open vegetation communities and a decline in forest components can be observed in the Gutaiului Mountains. The arrival of Larix decidua is confirmed by macrofossil remains. This episode, which lasted ca. 300-400 years, can also be seen at Avrig, which is situated at a lower elevation (Tantau, 2003), but could not be recognized at higher elevation sites (Farcas et al. 1999) (Fig. 14).

Marked changes in vegetation occurred at around 13,800 cal. yr BP in the Gutaiului Mountains. Trees, which had already been present, re-expanded, Picea abies arrived and the surrounding slopes became covered by rather dense forest (Appendix I, II, IV). While the pollen records show high pollen values for Betula, Pinus and Alnus and comparatively high percentages for Picea, the macrofossil records indicate that Picea likely became the dominant forest taxon (Appendix IV). It is probable that the pollen values for Picea are suppressed by those of Pinus and Betula, which both are higher pollen-producing taxa and that the macrofossil record more accurately illustrates the former forest composition. The forest vegetation reconstructed for the Gutaiului Moun-
tains differs slightly from other sites in Romania (Fig. 15), where high pollen values of Pinus and increasing percentages for Betula and Picea were interpreted as Pinus-Betula dominated forests, which included some Picea and Salix (Farcas et al. 1999; Tantau 2003). Modern studies on Picea pollen productivity, dispersion, transport and representation have, however, shown that Picea pollen have low values even in Picea-dominated forests and that long-distance transported Picea pollen do not exceed 5% (Huntley and Birks 1983; Hicks 1994). For boreal forests it has been demonstrated that Picea pollen are suppressed by pollen of Pinus (Hicks 1994). These lines of evidence give support for a wide spread of Picea-dominated forests between 13,800 and 12,900 cal. yr BP in the Gutaiului Mountains and possibly also in other low and mid-altitude areas in Romania (Fig. 15). Larix and Populus pollen have never been identified in Romanian pollenstratigraphic records, but macro-remains of these taxa, found in the Gutaiului Mountains (Wohlfarth et al. 2001; Appendix IV), may support the suggestion that Larix and Populus were also present in other parts of Romania during the Lateglacial. Low pollen production and preservation, poor dispersal capacity and difficulties in identification usually lead to Larix pollen being strongly underestimated in fossil pollen records (e.g., Lang 1994). The occurrence of pollen and macrofossils of Larix along with Pinus sylvestris, Pinus cembra, Pinus mugo and few Picea abies and Betula sp. was also noted in the eastern Polish Carpathians (Ralska-Jasiewiczowa and Latalowa 1996). Larix pollen have also been recorded at Kis-Mohos-To in northeastern Hungary, but were absent from other pollenstratigraphic records in Hungary (Willis 1995, 1997, 2000). The presence of Pinus, Picea, Betula, Salix, Juniperus and some thermophilous trees on the Hungarian plain during the Lateglacial is suggested based on pollenstratigraphic records (Willis et al. 1995, 1997).

Increasing Ulmus pollen values from single grains to around 1% at Preluca Tiganului and around 5% at Stereogoi were interpreted as a local establishment of Ulmus (Appendix I, II, IV). Since Ulmus pollen have low dispersal capability and the size of the studied sedimentary basins is rather small, Ulmus pollen percentages of 5% could be explained by its local establishment. This, however, leads to the questions whether these Ulmus pollen percentages represent small Ulmus populations on the surrounding slopes or whether they represent a signal from lowland areas or protected valleys (located close to the sites) with favorable local conditions? When using pollen analysis alone it is difficult to distinguish between a local versus a regional signal when taxa are only present in low numbers. Plant macrofossil analysis on the same sequence could not confirm the hypothesis of a local presence of Ulmus (Appendix IV). Similarly, although few pollen grains of Quercus, Tilia, and Fraxinus could be recorded in the sequences from the
Figure 14. Map showing the tree taxa, which were present in Romania between 14,100 and 13,800 cal. yr BP, based on pollen and macrofossils (Appendix I, II, I; Wohlfarth et al. 2001) or only on pollen (Farcas et al. 1999; Tantau 2003).

Figure 15. Map showing the tree taxa, which were present in Romania between 13,800 and 12,900 cal. yr BP, based on pollen, macrofossil and charcoal evidence (Appendix I, II, IV, Wohlfarth et al. 2001; Lascu 2003) or only on pollen (Farcas et al. 1999; Tantau 2003).
Figure 16. Map showing the tree taxa, which were present in Romania between 12,900 and 11,500 cal. yr BP, based on pollen and macrofossil records (Appendix I, II, IV) or only on pollen (Farcas et al. 1999; Tantau et al. 2003; Tantau 2003).

Figure 17. Map showing the tree taxa, which were present in Romania between 11,500 and 11,250 cal. yr BP, based on pollen and macrofossils (Appendix I, II, III, IV) or only pollen (Farcas et al. 1999; Tantau et al. 2003; Tantau 2003).
Gutauiului Mountains, no corresponding macrofossils were found to clearly demonstrate their presence during the Lateglacial. In earlier studies conducted in Romania, single pollen grains of these deciduous trees have been interpreted as long-distance transported, possibly from an area located in southern Romania or even further south (Farcas et al. 1999; Diaconeasa and Farcas 2002; Tantau et al. 2003). Pollen of cold-tolerant deciduous trees, such as Betula, Salix and Populus in Lateglacial deposits in Europe and North America are often associated with macrofossils of these taxa. However, pollen grains of ther- 
omorphic trees have never been confirmed by macro- 
remain (Birks 2003). Based on the composition of today’s boreal forests, Birks (2003) argued that thermophilous trees could not have been present in a Picea-Larix forest, due to unfavourable climatic conditions. In contrast, Willis (1994) and Willis et al. (1995, 1997, 2000) suggested that thermophilous trees (Ulmus, Quercus, Tilia and Fraxinus) may have survived in small populations within suitable micro-environmental habitats in southeastern and central Europe during the LGM and the Lateglacial.

At 12,900 cal. yr BP the boreal forest started to open up and from ca. 12,600 cal. yr BP onwards only scattered Betula, Larix, Salix and Pinus trees occurred in the Gutauiului Mountains (Fig. 16). Picea pollen percentages decline and Picea macro remains disappear. Based on the good correspondence between the pollen and macrofossil records of Picea during the previous time inter- vals and during the Holocene, we should expect to find at least some Picea macrofossils, if Picea would have occurred locally during the Younger Dryas stadial. An explanation for the presence of Picea pollen, but absence of its macrofossils could be that the local forest was strongly depressed during Younger Dryas and that the opening of the vegetation may have facilitated increased pollen transport and deposition from lowland areas or protected valleys, located close to the study sites. A reduction of arboreal pollen percentages and a maximum development of Betula forests is also inferred from the study at Avrig in the lowland (Tantau 2003). At the sites Taul Zanogutii, Iezerul Calimani (Farcas et al. 1999) and Mohos (Tantau 2003) (with some uncertain- 
dies due to a hiatus), the reduction of pollen percentages of Pinus and Betula along with increasing values of non-arboreal pollen was interpreted as a distinct decrease in forest cover (Fig. 16). Scattered or low pollen percentage of Picea of around 1% at Avrig, Taul Zanogutii, Iezerul Calimani and Mohos were attributed to their local pres- ence (Farcas et al. 1999; Tantau 2003). Overall, the forest composition shows significant changes in all investigat- ed sequences. However, there is some variation between 

tees, such as that Betula became the dominant taxon at low and middle altitudes, whereas Pinus domi- 
nated at higher elevations. Although local climatic con- 

tion could explain these dissimilarities, the large amount of Pinus pollen found at high-elevation sites may have been long-transported from lowlands and these differ- ences could thus just be artificial. The vegetation suc- cession in the Polish Carpathians is similar to that recon- 
structed for the Gutauiului Mountains for this time interval. Betula expanded at the expense of coniferous for- 
est (Ralska-Jasiwieczowa and Latalowa 1996). In the Czech Carpathians, Pinus, Juniperus, and Larix were the dominant species during the Lateglacial (Rybnickova and Rybníček 1996). However, on the Hungarian plain, the forest composition seemed to have remained fairly homogenous during the whole Lateglacial interval (Willis et al. 1995; Willis 1997).

**Holocene forest development**

Several external and internal factors, such as competi- tion processes, climate change, migration patterns, soil development, anthropogenic impact and physical barri- ers are generally considered responsible for the Holocene forest successions (Bennett and Willis 1995). Which of these factors played the main role in the Holocene forest history is, however, still a matter of debate. Below I dis- cuss the forest dynamics in the Gutauiului Mountains with the emphasis to evaluate which of these factors may have played the major role in the forest history of Romania.

The vegetation development at 11,500 cal yr BP, at the onset of the Holocene, was a response to the abrupt climate warming reconstructed from many palaeo-archives around the Northern Hemisphere and was prima- rily triggered by two factors: (i) the Lateglacial forest composition and (ii) migration processes. At ca. 11,500 cal yr BP, Betula, Larix and Pinus were the first trees, which were present and formed open forests in the Gutauiului Mountains (Fig. 17). Their immediate response to the hemispheric warming implies that they had sur- vived locally during the Younger Dryas. During the first 200-300 years of the Holocene, the forests were still open and large areas were likely covered by open vegetation communities (Appendix I, II, III, IV). The large number of Larix decidua macro remains suggests that a Larix for- est was present at mid-altitudes in the Gutauiului Moun- tains and most probably also in other parts of the Roma- nian Carpathians, although Larix has only been noted as isolated pollen grains in other records (Farcas et al. 1999). Picea, Populus, Alnus and Salix were part of these pioneer forests, but their expansion and occurrence was more restricted (see discussion below). Pollen diagrams from mid-elevation areas in the Carpathians show in- 
creasing values for Pinus and Betula, which was inter- 
preted as a Pinus-dominated forest with Betula abun- 
dant in sheltered areas (Tantau 2003). The beginning of the Holocene at higher elevation sites was, however, charac- 
ized by an expansion of Pinus (possibly Pinus mugo), Betula and Alnus viridis (Farcas et al. 1999; Farcas 2001) (Fig. 17).
At ca. 11,250 cal. yr BP, the landscape became completely covered by forest as new tree species arrived and expanded (Fig. 18). A lower presence of *Picea* at the onset of the Holocene and its late expansion, some 200-300 years later as compared to *Betula, Pinus* and *Larix* is seen in all sites in Romania (Farcas *et al.* 1999; Björkman *et al.* 2002, 2003; Tantau *et al.* 2003; Tantau 2003). The very similar shape of the pollen percentage curves for *Picea* in Romanian pollen diagrams may indicate that *Picea* started to spread from small local residual populations, located in different areas in the Romanian Carpathians, which acted as an important repopulation centre for *Picea*. The delayed expansion of *Picea* could represent the time it needed to build up populations from local individual trees or, could be due to a migration lag from nearby areas, where *Picea* survived the Younger Dryas cold episode.

*Ulmus* pollen grains occur sporadically at the onset of the Holocene, but increase rapidly from ca. 11,300 cal. yr BP onwards (especially between 10,000 and 9600 cal yr BP), which shows a local establishment of *Ulmus* at all recently investigated localities in the Romanian Carpathians i.e. Stereogiu, Preluca Tiganului, Iezerul Calimani, Avrig and Taul Zanogutii (Fig. 18). Although pollen studies are now available from several key areas in the Romanian Carpathians, no investigations have yet been carried out in southern and south-eastern Romania, where potential glacial refugia for thermophilous trees may have been located. The establishment of *Ulmus* occurred almost simultaneously across Romania and the slight difference in timing was probably determined by a migration lag from lower elevation sites (where *Ulmus* populations survived in suitable microhabitats during the Late-glacial) to higher elevation sites of each massif. If *Ulmus* would have migrated from areas situated to the south of Romania, then a distinct time-transgressive pattern should be visible during the early Holocene. Indirect evidence, supporting the hypothesis of a survival of *Ulmus* in the proximity of the studied sites, could also be obtained from the fact that *Ulmus* started to expand 300-500 years earlier as compared to *Quercus, Tilia, Fraxinus* and *Acer*. Comparisons to regions around Romania show a different early Holocene forest succession. In Poland and Slovakia *Ulmus* was the first deciduous tree to expand (Ralska-Jasiewiczowa and Latalowa 1996; Rybnickova and Rybnicek 1996). In Hungary the forest composition varied across the country: *Tilia* expanded first in eastern Hungary, *Quercus* and *Corylus* in the northern part and *Ulmus* and *Quercus* in the central part (Willis *et al.* 1995, 1997). The early Holocene forest of Bulgaria was composed of *Ulmus* and *Quercus* (Bozilova *et al.* 1996; Bozilova and Tonkov 2000; Tonkov *et al.* 2002; Stefanova and Ammann 2003). Although the vegetation development in the Polish Carpathians generally corresponds to that reconstructed for the Gutaiului Mountains, the timing of tree establishment and expansion (*Betula, Picea, Ulmus Quercus, Tilia, Fraxinus* and *Corylus*) was delayed by several hundred years (Ralska-Jasiewiczowa and Latalowa 1996; Ralska-Jasiewiczowa *et al.* 1998) as compared to our area. This delay may indicate that the trees had to migrate from areas located on the Balkan Peninsula, in Hungary or even along the Black Sea coast.

The next step in the forest succession was the establishment of *Quercus, Tilia, Fraxinus* and *Acer* throughout Romania (Fig. 19). Scattered pollen grains of *Quercus, Tilia* and *Fraxinus* were continuously noted since the beginning of the Holocene, which may show that these trees were present in the region. Their local establishment is shown by increasing pollen values, documented from ca. 10,700 cal. yr BP onwards (~9500 14C yr BP) at Steregoiu, Preluca Tiganului, Taul Zanogutii and Avrig. High pollen percentages recorded in the basal sediments of sites in the Apuseni Mountains and at Mohos at 10,200 cal. yr BP (9000 14C yr BP) show that *Quercus, Tilia* and *Fraxinus* must have arrived already earlier. In contrast, at Iezerul Calimani these trees were possibly only rarely present during the whole Holocene period (Farcas *et al.* 1999). The establishment of *Quercus, Tilia* and *Fraxinus* seems to have occurred synchronously, since no or only a small time difference is observed between sites located throughout Romania (Fig. 19). This pattern suggests that these trees entered Romania from different source areas e.g., from southern, south-western and western Europe. If they would only have had one single southern refuge centre, then a distinct, time transgressive south-north succession would be seen. Coinciding with their local establishment, these trees had to compete with already established forest constituents, which resulted in the formation of altitudinal forest belts. From this time onwards, dissimilarities in the forest composition can be observed between sites, depending on which of these tree species first reached its maximum and on the proportion of tree types already present within the forest canopy. For instance, *Tilia* and *Fraxinus* reached their maximum 300 years before *Quercus* in the Gutaiului Mountains. At Mohos, *Fraxinus* expanded first and was better represented. At Taul Zanogutii, *Quercus* was most important and dominated over *Tilia* and *Fraxinus*. In the Apuseni Mountains *Fraxinus* pollen percentages were slightly higher than those of *Quercus* and *Tilia*. These differences could be the result of the altitudinal position of the studied sites and of local climatic and edaphic conditions, rather than having been caused by different immigration patterns for each forest species.

The first regular occurrence of *Corylus* pollen grains is observed in all investigated sites at the beginning of the Holocene. Increasing pollen values for *Corylus* are noted from 10,300 cal. yr BP (9200 14C yr BP) at Preluca Tiganului, Stereogiu, Avrig and Taul Zanogutii. At ca. 10,190 cal. yr BP (8990 14C yr BP) *Corylus* pollen was already abundant in the lowermost part of the sediment
Figure 18. Map showing the tree taxa, which were present in Romania between 11,250 and 10,700 cal. yr BP according to pollen and macrofossil evidence (Appendix I, II, III, IV) or pollen evidence only (Farcas et al. 1999; Rösch and Fischer 2000; Tantau et al. 2003; Tantau 2003).

Figure 19. Map showing the tree taxa, which were present in Romania between 10,700 and 9300 cal. yr BP, based on pollen and macrofossil evidence (Appendix I, II, III, IV) or pollen evidence only (Rösch and Fischer 2000; Farcas et al. 1999; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003).
Figure 20. Map showing the tree taxa, which were present in Romania between 9300 and 6500 cal. yr BP, based on pollen evidence (Appendix II, III, IV; Farcas et al. 1999; Rösch and Fischer 2000; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003). Only Picea is recorded as macrofossil remains (Appendix IV).

Figure 21. Map showing the tree taxa, which were present in Romania between 6500 and 4500 cal. yr BP, based on pollen evidence (Appendix II, III; Farcas et al. 1999; Rösch and Fischer 2000; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003). Only Picea is recorded as macrofossil remains (Appendix IV).
Around 8000 cal. yr BP \( (\text{Appendix III, IV}) \). The initial slow expansion of late aquatic plant macrofossil record, it seems that the Quercus, Tilia, Ulmus \( \text{Corylus} \) available in the forest. Climatic change could possibly have caused this forest reorganization, during which likely that forest had diminished. Following these two lines, is seems to be claimed. However, sequences from the Apuseni Mountains, at ca. 9800 cal. yr BP \( (8720 \text{Cyr BP}) \) at Preluca Tiganului and Steregoiu, at ca. 8700 cal. yr BP \( (7790 \text{Cyr BP}) \) with the expansion of \( \text{Corylus} \) became the dominant tree species at ca. 9600 cal. yr BP in the Apuseni Mountains, around 9300 cal. yr BP \( (8200 \text{Cyr BP}) \) \( \text{Corylus} \) gary, the expansion of \( \text{Corylus} \) components \( (\text{Tonkov et al. 1999, 2000}) \). In Bulgaria the expansion of \( \text{Corylus} \) is recorded already at the beginning of the Holocene \( (\text{Willis et al. 1995, 2000}) \). In Romania, the arrival and expansion of \( \text{Corylus} \) is similar to that recorded in Romania and followed the decline of \( \text{Quercetum mixtum} \) \( \text{Fagus} \) \( \text{Carpinus} \) \( \text{Picea} \) \( \text{Ulmus, Quercus, Tilia} \) as compared to \( \text{Corylus} \). The \( \text{Carpinus} \) did not expand and reach its maximum until the density of the \( \text{Quercetum mixtum} \) \( \text{Fagus} \) \( \text{Carpinus} \) was already abundant in Romanian forests, forming a distinct forest belt, which was only interrupted by the expansion of \( \text{Carpinus} \). The proportion of \( \text{Fagus} \) \( \text{Carpinus} \) \( \text{Picea} \) \( \text{Ulmus, Quercus, Tilia} \) regularly occurred from the beginning of the Holocene in all pollen profiles, a late arrival as a consequence of migration delay can not be recognized. Results obtained from neighbouring countries suggest the existence of glacial refugia for \( \text{Carpinus} \). The proportion of \( \text{Fagus} \) \( \text{Carpinus} \) \( \text{Picea} \) \( \text{Ulmus, Quercus, Tilia} \) nicely corresponds to results obtained from other investigations in Romania \( (\text{Farcas et al. 1998; Farcas 2001; Tantau 2003}) \). More regular, but still low values are noted in all sites from ca. 8500 cal. yr BP \( (\text{Willis et al. 2003; Tantau 2003}) \). More recent scattered occurrences of \( \text{Carpinus} \) have hampered the spread of \( \text{Carpinus} \) forests was probably larger in southern and south-western Romania than in the northern or north-western part. The late development of \( \text{Fagus} \) \( \text{Carpinus} \) shows a different pattern even within western Romania. It simultaneously expanded in the Gutaiului Mountains, \( \text{Carpinus} \) occurred, however, at ca. 7700 cal. yr BP \( (6800 \text{Cyr BP}) \) in the Apuseni Mountains, at ca. 7500 cal. BP \( (6700 \text{Cyr BP}) \) at Taul Zanogutii and in the Semenic Mountains, at ca. 6700 cal. yr BP \( (5700 \text{Cyr BP}) \) at Avrig and Mohos, at 5700 cal. yr BP \( (5000 \text{Cyr BP}) \) in the Apuseni Mountains, at ca. 5000 cal. yr BP \( (4500 \text{Cyr BP}) \) at Iezerul Calimani (Fig. 19).
Figure 22. Map showing the tree taxa, which were present in Romania between 4500 and 35000 cal. yr BP, based on pollenevidence (Appendix II, III; Farcas et al. 1999; Rösch and Fischer 2000; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003). Only Picea is recorded as macrofossil remains (Appendix IV).

Figure 23. Map showing the tree taxa, which were present in Romania between 3500 - 300 cal. yr BP, based on pollenevidence (Appendix II, III; Farcas et al. 1999; Rösch and Fischer 2000; Bodnariuc et al. 2002; Tantau et al. 2003; Tantau 2003).
(around 6600 cal. years BP), may be an evidence for its presence in the local forest (Appendix II, III). At ca. 4800 cal. yr BP, *Fagus* shows a strong increasing trend and from about 4000 cal. yr BP to the present *Fagus* became the dominant forest tree in all investigated sites in Romania (Figs. 22-24). The highest proportion of past and present *Fagus* woodlands is evidenced at sites situated at mid elevations. The late expansion of *Fagus* in Romania was connected to forest clearance by humans (Rösch and Fischer 2000; Tantau et al. 2003), while it was correlated to a change towards a more humid climate in the Gutaiului Mountains, although human influence was not excluded (Appendix III). Around ca. 3500 cal. yr BP coinciding with the dominance of the *Fagus* forest, a significant decline in forest diversity, except for *Quercus* is recorded. This feature is also seen in other pollen profiles within Romania (Fig. 22). *Quercus* pollen peaks coinciding with a decline in *Fagus* pollen values have been found in the Swiss Alps during the late Holocene (Ammann 1989) and were explained by a reduction of *Fagus* forest density when *Quercus* flowered more plentifully. My pollen diagrams do not show any *Quercus-* *Fagus* antiphases during the late Holocene, although it may be possible that higher pollen values for *Quercus* are related to increased flowering in a less dense forest, rather than to a marked increase in the proportion of *Quercus* in the forest.

*Abies* pollen are recorded regularly between 3000 and 300 cal. yr BP, although in very low percentages (Fig. 23, 24). This may indicate that this taxon was present in the region, but not in the close vicinity of the study sites (Appendix III). This is a particular situation for the Gutaiului Mountains, which differs from other Romanian sites, where *Abies* was well represented during this period (Rösch and Fischer 2000; Farcas et al. 1999; Farcas 2001; Bodnariuc et al. 2002; Tantau et al. 2003).

**Human indicators in study area**

The first indication of anthropogenic disturbance is often a reduction of forest density, evidenced by a decline in arboreal pollen percentages along with a rise in non-arboreal pollen types (Iversen 1949, 1960; Behre 1981, 1988; Ammann 1989; Berglund 2000, 2003). In the Gutaiului Mountains the increase in non-arboreal pollen percentages during the last 4000 years is mainly caused by increasing values of wetland species such as *Cyperaceae*, *Ranunculaceae*, *Filipendula* and *Potentilla*. Changes in the composition of the forest (i.e. replacement of existing forest taxa by pioneer forest constituents such as *Betula*, *Pinus*, *Alnus*, *Picea*, and *Corylus*) are good indicators of forest clearance. In the study area high pollen values for *Fagus* at ca. 3500 cal. yr BP and significant values for *Carpinus* and *Quercus* coincided with a strong decline of *Ulmus*, *Tilia*, *Fraxinus* and *Acer* pollen percentages. This was interpreted as a natural forest succession driven by a change to drier climatic conditions, since human disturbance indicators were almost absent (Appendix II, III). The parallel increase in pollen percentages for *Betula* and *Alnus* was interpreted...
sively exploited as pasture land. The vegetation of the mires is dominated by Poaceae (mainly Holocene, which would indicate the occurrence of major forest fires. In summary, the signs of human impact on the landscape are especially clear between 14,700 and 11,500 cal yr BP, and are mainly represented by an expansion of pasture land and forest grazing. During the last 300 years grazing and forest grazing pressure became more intense, as inferred from the rise of the pollen indicators mentioned above, plus the occurrence of new taxa such as Glyceria and in the area around the studied site. An increase of charcoal particles could also point to human-induced fires. However, no particular rise in charcoal concentrations was noted during the late Holocene (Karocsanyi 1995). Another sign for human influences are some herbaceous taxa indicating grazing and forest grazing (e.g., Plantago lanceolata, Plantago major, Plantago media/major).

Today the forest below 800m has an open character and the openings are intense. The late and only weak human signal in the study area could also be due to the small size of the investigated basin and a rather closed forest canopy, which reduces the pollen source area. In a mainly forested landscape and a sedimentary basin with a radius of less than 1000 m there is a considerable underestimation of non-arboreal taxa (Appendix I, IV). This is the result of reforestation by plantation, which took place in the middle of the last century (Karocsanyi 1995). Another sign for human influences are some herbaceous taxa indicating grazing and forest grazing (e.g., Plantago lanceolata, Plantago major, Plantago media/major).

The rapid warming trend at ca. 14,700 cal yr BP (start of the Lateglacial) is seen in various records from north-western and central Europe (e.g., Björck et al. 1991; Broström, 2002). This temperature rise is clearly registered in the sedimentary records from Romania and also to western European lake records and to the GRIP ice core from Greenland. The late and only weak human signal in the study area could also be due to the small size of the investigated basin and a rather closed forest canopy, which reduces the pollen source area. In a mainly forested landscape and a sedimentary basin with a radius of less than 1000 m there is a considerable underestimation of non-arboreal taxa (Appendix I, IV). This is the result of reforestation by plantation, which took place in the middle of the last century (Karocsanyi 1995). Another sign for human influences are some herbaceous taxa indicating grazing and forest grazing (e.g., Plantago lanceolata, Plantago major, Plantago media/major).
lated at low, mid- and high altitudes, is remarkable. The tree limit must have been located above 800 m a.s.l., as indicated by macrofossil finds in the Gutaiului Mountains. Overall, the interval between ca. 13,800 and 12,900 cal. yr BP, which corresponds approximately to the Allerød pollen zone of Scandinavia and to the Greenland interstadial GI-1c, 1b and 1a (Björck et al. 2000). The low pollen representation of the other trees (Picea, Alnus, Betula) at higher altitude sites could be explained by lower pollen production and transport capacity (e.g. Wick 1996; Ammann et al. 2000). Although this period is clearly recorded around the North Atlantic region, its amplitude was probably less pronounced in the eastern, continental part of Europe. It has been shown that the vegetation may reflect a strong depression of the tree limit and a lowering of the ecotone. Therefore, the pollen signal may represent a migration lag. Trees, which survived during the Last Glacial Maximum in lowland areas, gradually colonized higher elevations. The initial rise in arboreal pollen percentages at Avrig (Tantau 2003) and of Pinus may thus represent an increase in pollen productivity of locally existing open stands or, of scattered trees in response to higher temperatures and can only later be regarded as a reflection of rising temperatures and increasing soil moisture content from around 13,800 cal yr BP onwards (Appendix I, IV). A similar phase, with lower arboreal pollen percentages has also been observed at Avrig (Tantau 2003), whereas no changes are recorded at higher elevation sites (Farcas et al. 1999). The response of the vegetation in the Gutaiului Mountains and in Avrig is consistent with recent stable isotope results on speleothems from the Apuseni Mountains, NW Romania, which imply cooler and drier climatic conditions during the Lateglacial in Romania. None of the Romanian pollen stratigraphies records, however, a short-term cooling phase, such as the so-called intra-Allerød cold event or GI-1b, which has been recognised in lakesediments from central Europe (Brooks et al. 1999). The distinct response of the forest vegetation in Romania, which is seen at sites situated between the pollen and macrofossil signals may be explained by a regional pollen source. An analogous, strong vegetation response, with the re-occurrence of open vegetation communities, is recorded at Avrig (Tantau 2003). In speleothems from the Bihor Mountains there are also indications for cooler and drier climatic conditions (Tamas 2003). A less prominent, but still distinct signal is revealed at Taul Zanogutii and Iezerul Calimani, which are higher elevation sites (Farcas et al. 1997). Around 13,800 cal. yr BP mixed forests re-expanded in the Gutaiului Mountains, soon followed by the establishment of Ulmus. A 300 year long interval, marked by a re-expansion of open vegetation communities, is observed between 14,100 and 13,800 cal. yr BP and is interpreted as a short episode of cooler and drier climatic conditions. A marked increase in arboreal pollen percentages at Avrig (Tantau 2003) and of Larix and, at 13,200 cal yr BP by Picea, Alnus, Betula. Around 13,800 cal. yr BP mixed Picea, Alnus, Betula forests re-expanded in the Gutaiului Mountains, soon followed by the establishment of Ulmus. A possible explanation for this might be that the temperature decrease was only minor in northwest Romania and did not hamper the forest development, whereas only minor vegetation changes seem to have occurred at Taul Zanogutii and Iezerul Calimani (Farcas et al. 1998). A ca. 300 year long interval, marked by a re-expansion of open vegetation communities, is recorded at Avrig (Tantau 2003). In speleothems from the Bihor Mountains there are also indications for cooler and drier climatic conditions (Tamas 2003). A less prominent, but still distinct signal is revealed at Taul Zanogutii and Iezerul Calimani, which are higher elevation sites (Farcas et al. 1999). Altogether this time interval was the most pronounced cold phase or GI-1, which has been recognised in lakesediments from central Europe (Brooks et al. 1999). The response of the vegetation in the Gutaiului Mountains and in Avrig is consistent with recent stable isotope results on speleothems from the Apuseni Mountains, NW Romania, which imply cooler and drier climatic conditions during the Lateglacial in Romania. None of the Romanian pollen stratigraphies records, however, a short-term cooling phase, such as the so-called intra-Allerød cold event or GI-1b, which has been recognised in lakesediments from central Europe (Brooks et al. 1999). The distinct response of the forest vegetation in Romania, which is seen at sites situated between the pollen and macrofossil signals may be explained by a regional pollen source. An analogous, strong vegetation response, with the re-occurrence of open vegetation communities, is recorded at Avrig (Tantau 2003). In speleothems from the Bihor Mountains there are also indications for cooler and drier climatic conditions (Tamas 2003). A less prominent, but still distinct signal is revealed at Taul Zanogutii and Iezerul Calimani, which are higher elevation sites (Farcas et al. 1997). Around 13,800 cal. yr BP mixed Picea, Alnus, Betula forests re-expanded in the Gutaiului Mountains, soon followed by the establishment of Ulmus. A 300 year long interval, marked by a re-expansion of open vegetation communities, is observed between 14,100 and 13,800 cal. yr BP and is interpreted as a short episode of cooler and drier climatic conditions. A marked increase in arboreal pollen percentages at Avrig (Tantau 2003) and of Larix and, at 13,200 cal yr BP by Picea, Alnus, Betula. Around 13,800 cal. yr BP mixed Picea, Alnus, Betula forests re-expanded in the Gutaiului Mountains, soon followed by the establishment of Ulmus. A possible explanation for this might be that the temperature decrease was only minor in northwest Romania and did not hamper the forest development, whereas only minor vegetation changes seem to have occurred at Taul Zanogutii and Iezerul Calimani (Farcas et al. 1998).
Figure 25. Summary chart of the Lateglacial and Holocene environmental and climatic development in the Gutaiului Mountains inferred from Preluca Tiganului and Steregoiu, based on pollen, macrofossils, lithology and sediment parameters. The ... LPAZ = local pollenassemblages zones. For a detailed description of the lithology see Tables 1 and 2 in Appendix IV.
**Holocene**

Distinct climatic oscillations during the Holocene were recorded in speleothems in northwestern Romania and are well correlated to those evidenced in the North Atlantic region (Onac et al. 2002; Tamas 2003). In contrast such distinct climate shifts are hard to distinguish based on pollenstratigraphy and inferred vegetation changes (Appendix III and IV). Pollenstratigraphic records for Romania were usually analysed with respect to the time of arrival, expansion and regression of Holocene forest taxa and less attention was given to climate as a driving force for forest dynamics. A lower resolution of the pollen stratigraphy and sometimes poor dating control may have prevented the recognition of the short-lived cooling phases seen in speleothem records.

The diversity and abundance of macrofossils and pollen of aquatic plants increased around 11,800 cal. yr BP, coinciding approximately with the later part of the Younger Dryas stadial (Appendix IV). More pronounced changes in aquatic pollen and macrofossils are observed at 11,500 cal. yr BP, simultaneously with the response of the terrestrial vegetation to the significant warming at the beginning of the Holocene. The macrofossil and pollen records from Preluca Tiganului indicate moist conditions already at 11,500 cal. yr BP. The rise in temperature and probably also in moisture availability were the triggering mechanisms, which initiated the vegetation succession, development and migration at the start of the Holocene (Appendix I, II, III, IV). Although *Betula* and *Pinus* expanded rapidly, a time lag of ca. 300 years as compared to the response of the aquatics is observed. This time lag most probably represents the period needed by these trees to enlarge their populations and to develop extensive forests (Figs. 17, 25). A rapid and fairly similar response of the vegetation to the rapid warming at the start of the Holocene is reconstructed from other pollen diagrams in Romania (Farcas et al. 1999; Tantau et al. 2003; Tantau 2003).

The abrupt response of *Ulmus* (200 years after the start of the Holocene) implies a distinct temperature and moisture increase (Fig. 25). The expansion and dominance of *Quercus*, *Tilia*, *Ulmus*, and *Fraxinus* between 10,700 and 8600 cal. yr BP may point to a more continental climate with higher summer temperatures and lower precipitation as compared to the present (Appendix III, IV). Furthermore, the remarkable high concentration of micro-charcoal between 10,600 and 10,400 cal. yr BP could be connected to increased fire frequencies, which may have been the result of drier summers. The subsequent, continuous decrease in moisture from about 10,300 cal. yr BP onwards is documented in the aquatic plant record (Appendix IV). High temperatures between 10,750 and 8600 cal. yr BP may have triggered the spread of thermophilous forests to their widest and highest distribution during the Holocene. Higher temperatures during the first part of the Holocene (11,500-8200 cal. yr BP) are documented by oxygen isotope records from northwestern Romania (Tamas 2003) and show the same pattern as in the North Atlantic region. In contrast, isotope records on stalagmites from southwestern Romania indicate a gradual temperature rise and a climatic optimum much later, at around 5000 cal. yr BP (Constantin 2003).

The studies in the Gutaiului Mountains allow detecting some changes in the forest structure during the early and middle Holocene, which could not have been related to migration processes (Fig. 25). At ca. 10,300 cal. yr BP, *Ulmus* declined permanently and *Corylus* expanded and achieved dominance around 9300 cal. yr BP. This was interpreted to be climatically induced, i.e. connected with a dry and possibly cold period (Appendix III, IV). These climatic conditions may have affected the forest structure and density and the gaps left by *Ulmus* were then occupied by *Corylus*. Two isolated charcoal peaks are noted at 9030 and 8700 cal. yr BP, but these could indicate local fires. In Appendix III and IV, the vegetation changes around 10,200 and 9300 cal. yr BP, respectively were linked to two distinct climatic cooling events centred around 10,300 and 9500 cal. yr BP in North Atlantic records (Bond et al. 1997, 2001; Björck et al. 1998, 2001; von Graevenitz et al. 1999; Nesje et al. 2001; Seppä et al. 2002; Hannon et al. 2003). Shorter, colder phases during the early and middle Holocene have also been registered in speleothems from northwestern and southwestern Romania (Tamas 2003; Constantin 2003). Increasing forest fires and a forest reorganization recorded between 10,200 and 9650 cal. yr BP may also be a consequence of dry climatic conditions (Bodnar et al. 2002; pers. comm.). These climate oscillations compare well to changes in the forest composition and to the climatic reconstructions obtained in the Gutaiului Mountains (Appendix IV). A distinct decline in *Quercus*, *Tilia*, *Fraxinus* and a re-expansion of *Picea* over the peat surface and on the surrounding slopes between 8600 and 8200 cal. yr BP coincides with maximum dry conditions (Appendix III, IV). A cool and dry episode centred around 8000 cal. yr BP is seen in stable isotope analyses of speleothems in the Apuseni Mountains and in southwestern Romania (Constantin 2003; Tamas 2003). All these changes have been connected to the 8200 cal. yr BP climatic reversal (Appendix III, IV; Constantin 2003; Tamas 2003), which is documented by several proxies (including pollen and macrofossil records) in the North Atlantic region (Nesje and Dahl 2001; Seppä and Birks 2002; Baldini et al. 2002), in central Europe (von Graevenitz et al. 1998; Tinner and Lotter 2001; Wagner et al. 2002; Magny et al. 2003; Ralska-Jasiewiczowa et al. 1998), in southern Europe (Wick et al. 2003) and in the Mediterranean Sea (Ariztegui et al. 2000). In contrast, other authors in Romania have attributed the maximum occurrence of *Corylus* to the Holocene thermal optimum (8000-5000 °C yr BP or ca. 9000-5000 cal. yr BP), which was the warmest and most humid interval during
the Holocene in Romania (Diaconeasa and Farcas 1995-1996, 2002; Farcas et al. 1999; Tantau et al. 2003; Tantau 2003).

The pronounced Picea recurrence around 8200 cal. yr BP (confirmed by abundant macrofossils) is contemporaneous with a slight re-expansion of mesophilous trees (Appendix III, IV) and low frequencies of charcoal (Fig. 25). This and the association of Corylus and Picea between 8000 and 5700 cal. yr BP could imply less natural fires, lower summer temperatures and moister climate. Geographically contrasting climatic conditions are shown by oxygen isotope from stalagmites between 8200 and 5000 cal. yr BP: stalagmite records from northwestern Romania indicate a cool and possible dry climate (Tamás, 2003) or, similar conditions as at present (Onac et al. 2002), whereas higher temperatures are inferred for south-western Romania (Constantin 2003). These reconstructions compare well with present climatic conditions, i.e. the south-western part is influenced by warm air masses from the Sub-Mediterranean region, while the north-western part receives oceanic air masses from the North Atlantic. Altogether, pollen and stable isotope data indicate that the north-western part of Romania may have experienced more humid conditions between 8000 and 5000 cal yr BP, as compared to the south-western part. The expansion of Carpinus at ca. 5500 cal. yr BP, which coincided with a regression of Picea and Corylus and a rise of Tilia and Quercus, may have been favored by a change to warmer and drier climatic conditions (Appendix III). This is supported by high pollen concentrations, low peat accumulation rate and a reduction of wetland indicators (Appendix III). Also the increase of micro-charcoal particles could indicate drier conditions. The expansion of Fagus at 4800 cal. yr BP may have been related to possibly higher humidity, i.e. milder winters, and to more acidic soils, although human activities cannot be ruled out (Appendix III). The dominance of Fagus from 4000 cal. yr BP onwards was most likely climatically induced, favoured by more humid and possibly cooler summers. The present distribution of the Fagus forest in Romania is related to a moist and cooler climate. A dry period may have occurred around 3500 cal. yr BP, indicated by a strong re-expansion of Quercus on the slopes surrounding the basins, a reduction of wetland taxa, by exceptionally high pollen concentrations (Appendix III) and an increase in charcoal particles. A warm and dry period is also documented by speleothems records in both north-western and south-western Romania (Onac et al. 2002, Constantin 2003), which implies a broad amplitude of this event.

Conclusions

§ The vegetation and climate development during the past 15,000 years in the Gutaiului Mountains of north-western Romania has been inferred from high-resolution pollenstratigraphy, complemented by studies of macrofossil remains, mineral magnetic parameters and organic matter analyses, as well as AMS 14C measurements. The combination of pollenstratigraphy and plant macrofossil analysis was important for the interpretation of vegetation changes in terms of local presence/absence of some trees during the Lateglacial.

§ During the Lateglacial period vegetation dynamics were likely driven by climatic fluctuations and by physiological requirements and tolerances of the different taxa. Prior to 14,700 cal. yr BP, open vegetation communities and possibly scattered stands of Pinus and Betula colonized the surrounding landscape. Unstable slopes, which were highly susceptible to erosion, may have existed around the basin as indicated by the minerogenic bottom sediments. Open Pinus-Betula forests and more stable soil conditions developed between 14,700 and 14,100 cal. yr BP and were followed by a return to open vegetation with stands of Pinus and Betula. Around 13,800 cal. yr BP Picea became established and soon dominated the landscape, together with Pinus, Betula, Alnus and Larix. Ulmus may have existed locally in small populations. Forest fires may have been common between 13,400 and 12,500 cal. yr BP, possibly indicating dry climatic conditions. Open vegetation with stands of Pinus, Betula, Larix, Alnus and Salix occurred between 12,900 and 11,500 cal. yr BP. The phases with open vegetation were correlated to events GS-2, GI-1d and GS-1 and the phases with tree expansion to event GI-1e and GI-1a to c of the GRIP event stratigraphy. If this correlation is correct, it shows that Lateglacial climatic variations were driving factors for the vegetation dynamics in north-western Romania.

§ Although distinct changes in forest density can be recognized at 11,500 cal. yr BP, i.e. at the Lateglacial/Holocene transition, the aquatic macrofossil record gives indications for increasing temperatures already at 11,800 cal. yr BP.

§ Forest dynamics during the Holocene were driven by complex processes probably caused by the interaction of several factors, such as forest succession, immigration lag, inter-specific competition, changing climatic conditions, soils and - during the late Holocene also human influence. The vegetation response at 11,500 cal. yr BP (expansion of Betula, Pinus, Larix and Alnus) can be interpreted as a succession process, because these trees were already present in the area. The expansion of Picea and Ulmus at 11,250 cal. yr BP was likely due to a migration process from closely located residual
populations and the later expansion of Quercus, Tilia, Fraxinus and Corylus at 10,700 cal. yr BP shows a migration from more distant localities. As the forest became denser, competition between new arriving taxa and already existing forest constituents played an important role in the forest structure and may have been triggered by changing climatic conditions. It is speculated that the late establishment of Carpinus at ca. 5700 cal. yr BP and of Fagus at ca. 5200 cal. yr BP could have been caused by climatic changes. Human influence can, however, not be excluded for a delayed expansion of Fagus, although evidences for this are not clear. A distinct human influence is evident in the pollen stratigraphy around 2300 cal. yr BP and is related to the extension of pasture land and forest grazing in proximity to the sites. During the last 300 years human activity is reflected by an abrupt reduction in forest diversity, and an increase in forest grazing and pastureland.

§ The present study gives evidence for the existence of the following trees during the Lateglacial at a mid-altitude area in the Gutaiului Mountains: Pinus, Betula, Picea, Larix, Populus, Salix and Alnus. Significant pollen percentages for Ulmus indicate that this tree could have been present in this area between 13,200 and 12,900 cal. yr BP. However, isolated pollen grains of Quercus, Tilia, Fraxinus and Corylus are attributed to long-distance transport.

§ Coniferous and cold-tolerant deciduous trees have probably been present in Romania already before 14,700 cal. yr BP and may have survived the Last Glacial Maximum. Since Ulmus seems to have expanded rapidly in Romania shortly after the beginning of the Holocene, it is assumed that it at least survived during the Younger Dryas stadial. It remains, however, uncertain whether Ulmus was present before 13,200 cal. yr BP. No evidence exists so far from Romania to prove the survival of Quercus, Tilia, Fraxinus and Corylus before and during the Lateglacial.

Acknowledgments

First, I would like to thank my head supervisor, Barbara Wohlarth, who initiated the project and gave me the opportunity to work in this fascinating field of science. I am very appreciative for her enormous support and guidance in the Quaternary world, of which I had little knowledge before I started this work. In addition, I would like to thank Barbara for her hospitality while I was visiting Lund University. I am very grateful to my co-supervisor in Lund, Leif Björkman, for his help and patience in introducing me to pollen techniques and the Tilia program, correcting my manuscripts, and advice while I was in Romania and Stockholm. I am profoundly grateful to Ann-Marie Robertsson, my co-supervisor, for her patience, kindness, and suggestions for improvements of the manuscripts, especially the synthesis of the thesis. Thanks are also due to Prof. Iustinian Petrescu my supervisor at the Department of Geology, Cluj University, Romania.

Thanks to Bogdan Onac for including me in this interesting research project, for help during the fieldwork, for always being positive about my work, and giving stimulating comments on the manuscripts.

Thomas Persson and Sven Karlsson gave kindly assistance with the tricky and sometimes annoying Tilia program. Mats Rundgren introduced me to pollen preparation techniques. I thank Kajsa Cinthio, Per Sandgren, and Oana Stan for helping me with magnetic measurements. I am thankful to Tudor Tamas for his constructive criticism on the manuscripts and for the enormous help with the drawing program to produce the maps. I would like to extend my thanks to Siwan Davies and Joe Kearns for correcting the language. I am greatful to Helena Alexanderson for her kindly help with the layout of the thesis.

I would also like to thank all my colleagues and PhD students at the Department of Physical Geography and Quaternary Geology, Stockholm University for the stimulating environment and their friendship. Also, I give thanks to the following friends who made my time easier while I have been in Stockholm: Siwan, Dani, Teodora, Amélie, Yoshi, and Veronica.

The Stockholm University financed my doctoral position at the Department of Physical Geography and Quaternary Geology. Fieldwork in Romania was financed by the Swedish Research Council and Kungliga Fysiografiska Sällskapet Lund (grants to Barbara Wohlfarth and Leif Björkman). Financial support for scholarship was also provided from the Erasmus program, the Swedish Institute and the Royal Swedish Academy of Science.

I am thankful to all my dear friends, especially to Sanda, for their moral support and good thoughts.

My warmest thoughts and thanks to my family (mama, tata, Renata, Ovidiu) and in-laws (Lucian, Adrian, mother and father inlaws) for their enormous support, for always caring and being there for me. I am thankful to Markus for being a special part of my life.

Svensk sammanfattning

Klimat- och vegetationsförändringar under de senaste 15 000 åren är väl kända från området kring Nordatlansten, medan enbart ett fåtal studier belyser utvecklingen i sydöstra Europa i detalj. Rumänien har en lång tradition
när det gäller pollenstratigrafiska undersökningar och rekonstruktion av skogs- och vegetationsutvecklingen, men kronologin för de förändringarna som skedde är ännu mycket osäker. Många av de äldre undersökningarna är översiktliga och uppbygger därför inte kraven på moderna paleoekologiska undersökningar. Huvudsyftet med avhandlingen är därför att

- upprätta en mycket detaljerad tidsskala för de klimat- och miljöförändringar som skett under de senaste 15 000 åren i nordvästra Rumänien,
- klarlägga skogens historia
- diskutera de processer som kan ha styrt och påverkat skogens dynamiska förändringar.

Undersökningarna baseras på sedimentkärnor från två små före detta kratersjöar, Preluca Tiganului och Undersökningarna baseras på sedimentkärnor från två små före detta kratersjöar, Preluca Tiganului och Steregoiu, belägna 730 och 800 m ö h i Gutaiuluibergen i Rumänien. Analys av pollen, växtmakrofossil, kolpartiklar, organism kol och mineralmagnetiska parametrar, samt en detaljerad tidsskala (AMS 14C date-ringar av terrestriska växtmakrofossil) möjliggör en noggrann rekonstruktion av miljöförändringarna under slutfasen av sista istiden och under den nuvarande mellanistiden (Holocene).


En jämförelse med de få pollenstratigrafiska studier som gjorts i Rumänien under senare år visar att vegetationsutvecklingen i Gutaiuluibergen var likartad i låglandsområden, medan högre liggande lokaler inte uppvisar lika stora förändringar under slutfasen av sista istiden. Trädslagens invandring och spridning under de senaste 11 500 åren verkar ha skett samtidigt över stora delar av Rumänien. Däremot skiljer sig den låga representationen av avenbok och den svaga mänskliga påverkan inom det undersökta området tydligt från andra områden.

Under de kallaste faserna av sista istiden har björk, asp, tall och gran funnits i låglandsområden i Rumänien. Alm växte troligen i mer skyddade områden (refugier) i olika delar av Rumänien, medan refugierena för ek, lind, hassel och al ännu inte är kända. Fördelning och förändringar (invandring, expansion, regression) mellan olika trädslag var troligen klimatisk betingade under slutfasen av sista istiden. Skogsutvecklingen under de sista 11 500 åren har däremot mer styrt av konkurrens mellan arterna, olika spridningshastighet, jordmänsförhållanden och till viss grad också växlande klimatförhållanden.

Rezumat în limba română

Cu toate că "coala palinologică are o veche tradiție în România, neajunsuri ca rezoluția stratigrafică și coeziunea ecológică scăzută, precum și lipsa totală a datelor de cronologie absolută, a făcut dificilă interpretarea profilurilor polenice în sensul stabilirii compoziției vegetale de-a lungul timpului

Studiul de fața îi propune reconstituirea vegetației "a climatului din ultimii 15.000 de ani, ceea ce ar corespunde ultimei părți a glaciarului Weichsel (Würm), tranzităia Pleistocen-Holocen încai cu seamă Holocenul, accentuându-se următoarele aspecte:

- Evidențierea existenței unor refugii glaciare pentru diferiți arbori în România, în particular , în Munții Gutăului.
- Dinamica "i factorii care au controlat dinamica arborilor de la sfârșitul glaciăriunii "i până în prezent.
- Fluctuațiile climatice reflectate în schimbările apărute în comunitatea vegetală.

Reconstituiriile de paleomediu s-au efectuat pe flancul vestic al Munților Gutău, pe baza sedimentelor acumulate în două vechi cratere vulcanice, Stereogiu (790 m alt.) și Preluca Tiganului (730 m alt.). Investigațiile au făcut uz de analiza polinică ca metodă de bază, fiind pentru prima dată completată cu analize de macro-resturi vegetale "i animale, micro-particle de cărbune, litostratigrafie, material magnetic mineral "i studii privind cantitatea de carbon organic. Cronologia a fost stabilită pe baza numeroaselor datări 14C AMS. Analizele s-au efectuat la
o rezoluție temporală și spatială ridicată, fapt ce a permis detectarea unor schimbări de vegetație, precum și fluctuațiile climatice de scurtă durată.

În urmărirea dinamicea vegetației de-a lungul Tardiglaciarului, putem concluziona că fluctuațiile climatice din această perioadă, precum și toleranța fiziologică a diverșilor taxoni au avut un rol esențial. Astfel, ansamblul polenic “i cel al macroplantelor prezintă în sedimentele depuse înainte de 14.700 ani BP indică o vegetație lipsită de arbori, dominată în schimb de ierburi și arbuști rezistenți la condiții de climat rece și aridă. Creșterea temperaturilor și a precipitațiilor de acum ~14.700 de ani corespunde cu începutul Tardiglaciarului "i a determinat apariția "i expansiunea gradată a vegetației forestiere dominantă de Pinus "i Betula, "i la stabilizarea versanților. Între 14.100–13.800 ani BP vegetația dominată de arbuști "i ierburi s-a extins din nou, în timp ce covorul forestier s-a redus la exemplare răzlețe Pinus, Betula "i Larix, indicând reinstalarea unor condiții climatice mai reci. Un nou episod cald desfășurat între 13.800–12.900 ani BP este evidențiat de expansiunea semnificativă a pădurilor dominate de Picea, la care se adaugă Betula, Larix, Pinus "i Alnus. Ulmus, probabil forma populată mici pe versanții din împrejurimile siturilor studiate. Perioada cuprinsă între 12.950–11.500 ani BP este caracterizată de retragerea taxonilor forestieri - începând cu Ulmus, urmat apoi de Picea, Betula "i Pinus -, în paralel cu expansiunea rapidă a ierburilor "i arbuștilor, constituind un indiciu al instalării unui nou episod rece "i mai puțin umed.

Tranzitia Tardiglaciar/Holocen are loc acum 11.500 ani BP, iar evoluția vegetației postglaciares a fost un proces complex, rezultat al interferenței unor factori precum, clima, procesele de succesiune vegetală, migrația arborilor, competiția interspecifică, solurile sau impactul antropic. Astfel, expunerea următorilor taxoni lenno"i": Betula, Larix, Pinus "i Alnus de acum 11.500 ani BP poate fi interpretat ca fiind un proces succesional, întrucât aceștia arbori au fost prezenți în împrejurimile de-a lungul Tardiglaciarului. În timp foarte scurt (250 ani BP) a urmat expansiunea taxonilor Ulmus "i Picea, care, probabil au supraviețuit în habitat favorabil destin de aproape de bazinele de sedimente. Apariția regională a fioasaelor mezo-termofile Quercus, Tilia, Fraxinus "i Corylus s-a produs probabil acum 11.250 de ani BP, pentru ca expunerea locală să înceapă în urmă cu 10.700 de ani BP când covorul forestier devine diversificat. Cinci sute de ani mai târziu (~10.200 de ani BP) Corylus se stabilește în Munții Gutăi, pentru ca în jur de 9.300 ani BP să devină taxonul dominant. Competiția interspecifică dintre taxonii prezenți deja în regiune "i noi sosși, la care se adaugă noi condiții climatice, au jucat un rol important în reorganizarea forestieră "i în formarea etajelor de vegetație.

Carpinus "i Fagus apar "i dezvoltă păduri mult mai târziu, în jur de 5.700, respectiv 4.800 ani BP, cel mai probabil ca urmare a schimbărilor climatice "i a păturii de sol. Influенța antropică nu este totuși exclusă, de"i informațiile de care dispunem nu sunt suficiente de sugestive. Influencia antropică este semnalată acum 2.300 de ani, pentru ca în ultimii 300 de ani să devină foarte pronunțată. Acest impact se reflectă în extinderea pășilor "i, a păzurii în pădure, existând dovezi privind activității de defrișare, ceea ce a contribuit la reducerea diversității "i densității covorului silvestru.


References


Baldeanu, D., Ielenicz, M., Popescu, N. 1998. Geomorphology of...


Birks HH, Ammann B. 2000. Two terrestrial records of rapid climatic changes during the glacial-Holocene transition (14,000-9,000 calendar years B.P.) from Europe. *Proceedings of the National Academy of Science of USA* 97, 4: 1390-1394.


SILVESTRIA 106, Swedish University of Agricultural Science.


Jacobson GI, Bradshaw RJW. 1981. The selection of sites for denning Medd. 10, Copenhagen .


Pop E. 1929. Analize de polen in turba Carpatilor Orientali (Dorna-Lucina). *Buletinul Gradinii Botanice si al Muzeului*

Pop E, Diaconeasa B, Boscaiu N. 1965b. Analiza polinica a turbe noastra cuaternara. Progrese in palinologia romaneasca


Pop E, Diaconeasa B, Boscaiu N. 1965a. Analiza polinica a turbei din tinovul Mohos (Tusnad).


Tamas T, Causse C. 2000. U-Th TIMS chronology of two
stalagmites from V11 Cave (Bihor Mountains, Romania). *Theoretical and Applied Karstology* 13: 25-32.


Walker MJC. 2001. Rapid climatic change during the last glacial-interglacial transition; implications for stratigraphic sub-


Wohlfarth B, Hannon G, Feurdean A, Ghergari L, Onac BP. 2001. Reconstruction of climatic and environmental changes in NW Romania during the early part of the last deglaciation (15,000–13,600 cal years BP). *Quaternary Science Reviews* 20: 1897-1914.