

Why were the Neolithic landscapes of Bela krajina and Ljubljana Marshes regions of Slovenia so dissimilar?

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ABSTRACT – *This paper compares the development of Holocene vegetation in Bela krajina and Ljubljana Marshes (Ljubljansko barje) regions of Slovenia. The results of pollen analysis suggest that in Bela krajina the human impact on the environment (forest clearance and burning) was very intensive throughout the Holocene and led to changes in forest composition, increased biodiversity, and the formation of a mosaic landscape. In the Ljubljana Marshes, forest burning and clearance seem less intensive, although changes in forest composition and ‘anthropogenic indicator’ pollen types were detected. These differences between study regions are presumably a consequence of various climates, hydrology, bedrock and land-use in the past.*

IZVLEČEK – *V članku je predstavljena primerjava razvoja holocenske vegetacije v Beli krajini in na Ljubljanskem barju. Rezultati pelodne analize kažejo, da je bil človekov vpliv na okolje (sekanje in požiganje gozda) v Beli krajini zelo intenziven, kar je povzročilo povečanje biodiverzitete in spremembe v sestavi gozda, oblikovala se je mozaična pokrajina. Na Ljubljanskem barju je sekanje in požiganje gozda sicer res videti nekoliko manj intenzivno, kljub temu pa na pelodnem diagramu lahko opazimo spremembe v sestavi gozda in pojav ‘antropogenih indikatorjev’. Te razlike med regijama so verjetno posledica različne klime, hidrologije, geološke podlage in različne izrabe pokrajine v preteklosti.*

KEY WORDS – *palynology; Neolithic archaeology; Bela krajina; Ljubljana Marshes*

Introduction

This paper aims to address the question of the diversity of the environment of the first farming communities in the region of Bela krajina and the Ljubljana Marshes area of Slovenia (Fig. 1). Differences in the composition of vegetation detected in the pollen record will be analysed in order to estimate whether they were a consequence of specific natural characteristics of the regions studied, dissimilar land-use in the past, or the size of the study sites.

In recent decades an extensive pollen analysis of sedimentary cores and samples collected during archaeological excavations was carried out on Ljubljana Marshes, so the general development of vegetation in the area is very well known (e.g. Culiberg 1991; Šercelj 1996 and references cited there, Gardner

1999a; 1999b) and the results presented in this study (a pollen analysis of ‘Na mahu 1’ core) accord with previous research. The question of past hydrological conditions in the area was also addressed by several researchers using sedimentological, geomorphological, archaeological and multidisciplinary palaeoecological data (e.g. Melik 1946; Šercelj 1966; Šifrer 1984; Budja 1995; Velušček 2005; Gaspari and Erič 2006; Verbič 2006; Mlekuž et al. 2006; Andrič et al. in prep., and many others). This led to various interpretations of the complex hydrological conditions in the basin (most complex in the Neolithic; many researchers would probably agree that in the early Holocene the area was covered by a freshwater lake, whereas later it became a floodplain and in some parts a peat bog). In contrast to Ljubljana

Marshes palynological, research in Bela krajina was less extensive, and both palynologically investigated sites in the area (Mlaka and Griblje, *Andrič 2001; Andrič in press*) are presented in this paper. To date, no studies of past hydrology have been carried out in the area. Therefore, since hydrological conditions on Ljubljana Marshes were very complex, whereas (presumably much simpler) hydrological conditions in Bela krajina have not been investigated at all, more (detailed) research is needed in both regions in the future. Palynological research was much more intensive, and for that reason this paper will focus on only one aspect of both Neolithic landscapes: the composition of vegetation as revealed by palynological studies.

The main reasons for the variety of flora in Slovenia include its geographical position, diverse climate, relief and bedrock (*Wraber 1969; Kladnik 1996; Ogrin 1996; Perko 1998*). The distinctive vegetation of Slovenia's phyto-geographic regions became apparent after *c.* 8800 calBP, whereas the onset of an intensive, large-scale forest clearance, burning and the formation of the present-day landscape is dated between late prehistory and the medieval period (*c.* 3000 calBP – 1000 calBP). Palynological research also suggests that the human impact on the vegetation was important and contributed to increasing biodiversity (*Andrič and Willis 2003*). Neolithic/Eneolithic farming communities (*c.* 7000–5000 calBP) lived in an environment where differences between regions had already become apparent, but large-scale forest clearances had not yet occurred. In such environments it is very difficult to distinguish the natural from the anthropogenic causes of environmental change. Therefore, in order to better understand the human impact on the vegetation, the vegetation history in the vicinity of archaeological sites was studied in detail. Sedimentary cores for pollen analysis (Fig. 1) were collected at Mlaka (Bela krajina) and 'Na mahu 1' (Ljubljana Marshes) coring locations in order to estimate the similarity/dissimilarity of vegetation development during the Holocene in both study regions. In addition to this, the vegetation history at Griblje

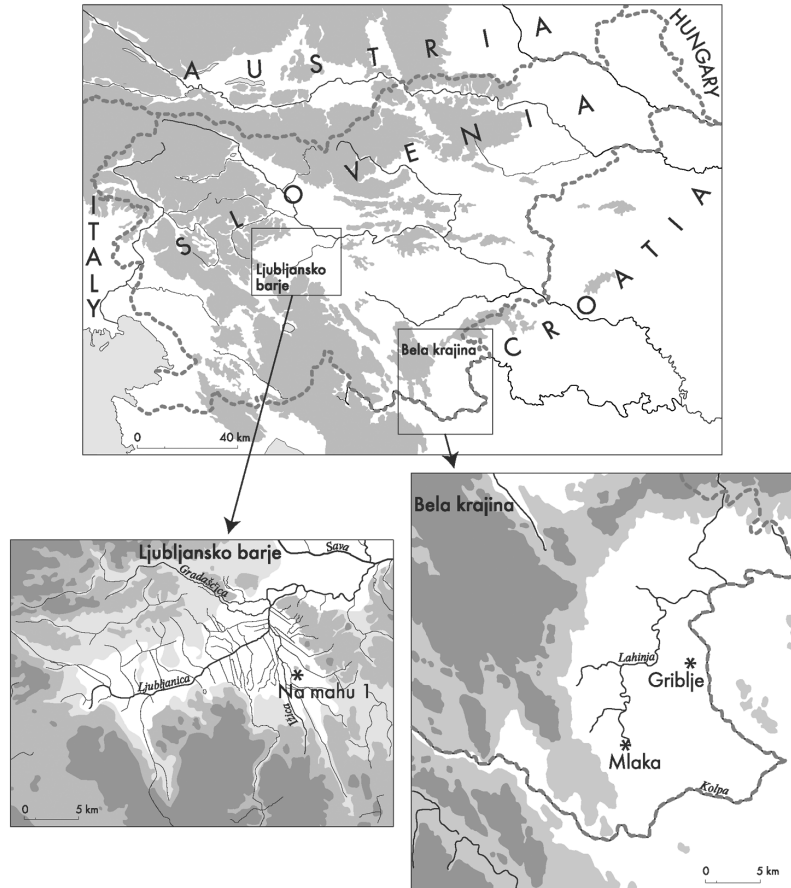


Fig. 1. Bela krajina and Ljubljana Marshes study regions and the position of palynological cores.

was investigated and compared with Mlaka to assess also the intra-regional variability of Bela krajina vegetation.

The Bela krajina study area

Bela krajina (Fig. 1) is located in south-eastern Slovenia, between high Dinaric Plateaus in the west and the Kolpa River and Pannonian Plain in the east. More than half of its territory lies below 400 m a.s.l., on predominantly Mesozoic limestone and dolomite bedrock (*Gams 1961; 1984; Buser 1984*). The climate of Bela krajina is moderate continental-sub-Pannonian, with a sub-Mediterranean precipitation regime (primary precipitation is highest in autumn), and hot, dry summers. The annual amount of precipitation is between 1200 and 1300 mm in western parts. The average temperatures of the warmest month are between 15 °C and 20 °C, and of the coldest month, between –3 °C and 0 °C (*Bernot 1984; Ogrin 1996; Plut 1985*).

The composition of Bela krajina forests varies according to altitude, land-use and soil type. Predominantly beech forests are characteristic of higher alti-

tudes, whereas patchy oak-hornbeam forests grow in the lowlands (Miklavžič 1965; Wraber 1956; Marinček and Čarni 2002; Čarni et al. 2003). Meadows, fields, pastures and human-managed birch (*Betula pendula*) forests ('steljniki'), which were originally used as spring/summer grazing areas, spread into the lowlands due to intensive human impact in the last centuries.

Both palaeo-ecological study sites presented in this study (Mlaka and Griblje) are small lowland marshy areas with diameters of c. 30 m and without inflowing/outflowing streams (Fig. 1). Numerous archaeological sites, including Neolithic/Eneolithic settlements, are located close to Mlaka and Griblje (e.g. Pusti Gradac and Griblje, *Arheološka najdišča Slovenije* 1975; Dular 1985; Mason 2001; Phil Mason, personal communication 2005).

The Ljubljana Marshes study area

Ljubljana Marshes lies in central Slovenia (Fig. 1) at about 289 m a.s.l., on predominantly carbonate bedrock, with Triassic and Jurassic limestones and dolomites in southern and western parts of the basin, whereas Palaeozoic sandstones, conglomerates, shales and limestones prevail in the north and east (Mencej 1989). The bottom of the basin is covered by thick layers of Pleistocene and Holocene alluvial and lacustrine sediments (Mencej 1989; Grimšičar and Očepek 1967; Tancik 1965; Šercelj 1965; 1967). The climate on Ljubljana Marshes is temperate-continental, with a sub-continental precipitation regime (precipitation highest in the summer) and annual precipitation between 1000 and 1300 mm. The average temperatures of the coldest month are between -3 °C and 0 °C, and in the warmest month the average is between 15 °C and 20 °C (Ogrin 1996).

Ljubljana Marsh is currently covered by meadows, fields and patchy woodlands of pine (*Pinus*), birch (*Betula*), alder (*Alnus*) and oak (*Quercus robur*). Only very small peat-bogs with ombrotrophic species have remained (Martinčič 1987). Predominantly beech (*Fagus*) forests grow on the hills surrounding the area (Čarni et al. 2003). In the 18th century it was much wetter than today, and mostly covered by peat-bogs, smaller 'puddles' and springs (Melik 1927) and drier heather lands, with spruce (*Picea*), pine, alder and birch trees. However, in the second half of the 18th century, the first drainage works in the area started, and by the end of 19th century almost all the peat had been burnt or cut in order to obtain dry land needed for agriculture (Melik 1927).

The sedimentary core presented in this study ('Na mahu 1') was collected in the eastern part of the Ljubljana Marsh basin (Fig. 1). Archaeological sites, mostly dated to the 7th and 6th millennium calBP, were discovered in the vicinity of the coring location (e.g. Resnikov prekop and Maharski prekop, Dimitrijević 1997; Budja 1995; Čufar and Korenčič 2006; Velušček 2006; Čufar and Velušček 2004; Bregant 1974; 1975)

Methodology

The pollen record of three study sites, Mlaka and Griblje (G3) in Bela krajina, and 'Na mahu 1' in Ljubljana Marshes (Fig. 1) is presented and compared in this study. The detailed methodology and results for individual study sites have been published (for Mlaka and Griblje see Andrič *in press*) or are currently in preparation ('Na mahu 1', Andrič et al. *in prep.*), therefore only selected data will be presented in this paper.

All sedimentary sequences were collected by Livingstone piston corer, and standard laboratory procedures (Bennett and Willis 2002) were used for pollen analysis. The age was determined by AMS radiocarbon dating of organic carbon extracted from the sediment. The radiocarbon dates at Mlaka and Griblje were calibrated by the BCal program (hosted by the Department of Probability and Statistics at the University of Sheffield, Buck et al. *on-line*), which incorporates the IntCal 04 calibration dataset (Reimer et al. 2004), and these results were used for age-depth modelling in PSIMPOLL (general linear line-fitting by singular value decomposition for Griblje, and a combination of general linear line-fitting by singular value decomposition and linear interpolation for Mlaka). The conventional radiocarbon dates used for age-depth modelling are marked on each diagram. The age-depth modelling for 'Na mahu 1' core was a linear interpolation between the median values of ¹⁴C dates (the lower two dates were excluded from the age-depth modelling due to an error, presumably caused by the reservoir effect). The percentage pollen diagrams of selected taxa were plotted by PSIMPOLL 3.00, 4.25 and PSCOMB 3.01, C programs (Bennett 1998; Bennett *on-line*). They were divided into zones using binary splitting by sum of squares, and the number of significant zones was determined by the broken-stick model (Bennett 1996; 1998). Dots on the pollen diagram indicate values lower than 0.5 %. Palynological richness (rarefaction analysis) was also calculated by PSIMPOLL. Microscopic charcoal (in two size classes:

<40 µm and >40 µm) was counted with the pollen ('Na mahu 1' and Griblje cores) and, in addition to this, the concentration of microscopic charcoal was determined according to Clark's (1982) point count method at both Mlaka and Griblje.

Results

The results are presented on percentage pollen diagrams of selected taxa (Fig. 2) and compared in Table 1. Landscape openness, the microcharcoal record and palynological richness of all three study sites are also compared (Fig. 3). More detailed results are being published in separate publications (Andrič *in press*, Andrič *et al. in prep.*). The mismatch of Mlaka and Griblje pollen diagrams (compare *Fagus* curves) for levels older than *c.* 6000 calBP are most probably a consequence of problematic radiocarbon dating at Griblje, where levels between 50 and 61 cm seem to be up to *c.* 900 years 'too old' (Andrič *in press*).

Early Holocene

At the beginning of the Holocene (between *c.* 11 500 and 9000–8750 calBP) an open, predominantly broad-leaved woodland with oak (*Quercus*), hazel (*Corylus*), lime (*Tilia*), elm (*Ulmus*), pine (*Pinus*), birch (*Betula*) and spruce (*Picea* mostly around Ljubljana Marshes) was growing in both study regions (Fig. 2, Tab. 1). The increased concentration of microscopic charcoal suggests that forest fires were common, probably due to the arid early Holocene climate (*e.g.* Kutzbach and Guetter 1986; COHMAP Members 1988).

Later (at *c.* 9000 – 8750 calBP) the forest composition suddenly changed, and thick, mostly beech (*Fagus*) forest started to grow in Bela krajina and Ljubljana Marshes (Fig. 2, Tab. 1). In Ljubljana Marshes this beech forest persisted until *c.* 6750 calBP, whereas in Bela krajina the development was much more dynamic. Slight fluctuations in beech pollen curves (some of them coincide with charcoal peaks and even with Cerealia-type pollen grain at Griblje) suggest that the forest in Bela krajina was less dense than in the Ljubljana Marshes region, and occasional small-scale landscape fires probably caused minor openings in the canopy. After *c.* 7800 calBP beech (*Fagus*) at the Mlaka site started to decline, and by *c.* 7300 calBP the percentage of tree pollen had significantly declined (with the exception of lime (*Tilia*), which increased), whereas herbs and monolet fern spores (Filicales) increased, suggesting the opening of the landscape (Fig. 2a). A similar change in vegetation was also detected at Griblje (Fig. 2b), where beech

forest was replaced by a more open landscape, with higher percentages of pine (*Pinus*) and Trilete spores than at Mlaka. In contrast to Bela krajina, the hills surrounding Ljubljana Marshes basin remained very much forested with beech (*Fagus*), and after 7600 calBP also fir (*Abies*) (Fig. 2c). No such increase in fir (*Abies*) was detected in Bela krajina, although the forest started to regenerate at the beginning of the 7th millennium calBP.

After *c.* 7000 calBP, hazel (*Corylus*) and oak (*Quercus*) at Mlaka, increased and between *c.* 6700–6100 calBP hornbeam (*Carpinus betulus*) woodland was growing around the coring location. The Griblje forest also regenerated, and beech (*Fagus*), alder (*Alnus*) and hazel (*Corylus*) started to increase again, but in contrast to Mlaka, there was no hornbeam (*Carpinus b.*) phase. The human impact on the environment around both study sites was significant and can be associated with the Neolithic/Eneolithic sites at Pusti gradac and Griblje. Small-scale forest burning (increased micro-charcoal concentration), agriculture and grazing (anthropogenic indicator taxa: Cerealia-type, *Centaurea*, *Plantago l.*, Chenopodiaceae, *Artemisia*, Compositae lig. and Compositae tub.) was most intensive at *c.* 6100 calBP (Fig. 2a, 2b).

What happened at the same time on Ljubljana Marshes? A major change in the composition of vegetation occurred between 6750 and 5600 calBP (roughly at the same time as *Carpinus b.* phase at Mlaka), when beech (*Fagus*) and fir (*Abies*) declined, whereas oak (*Quercus*), alder (*Alnus*) and hazel (*Corylus*) increased (Fig. 2c), but an increase in hornbeam (*Carpinus betulus*, best seen at Podpeško jezero, Gardner 1999b) was less significant than at Mlaka. An increased percentage of herb pollen after 6600 calBP and anthropogenic/grazing indicators (*Plantago l.*) suggest that the landscape became slightly more open, which can be associated with human activity at the Resnikov prekop settlement, located *c.* 1.5 km south of the coring location.

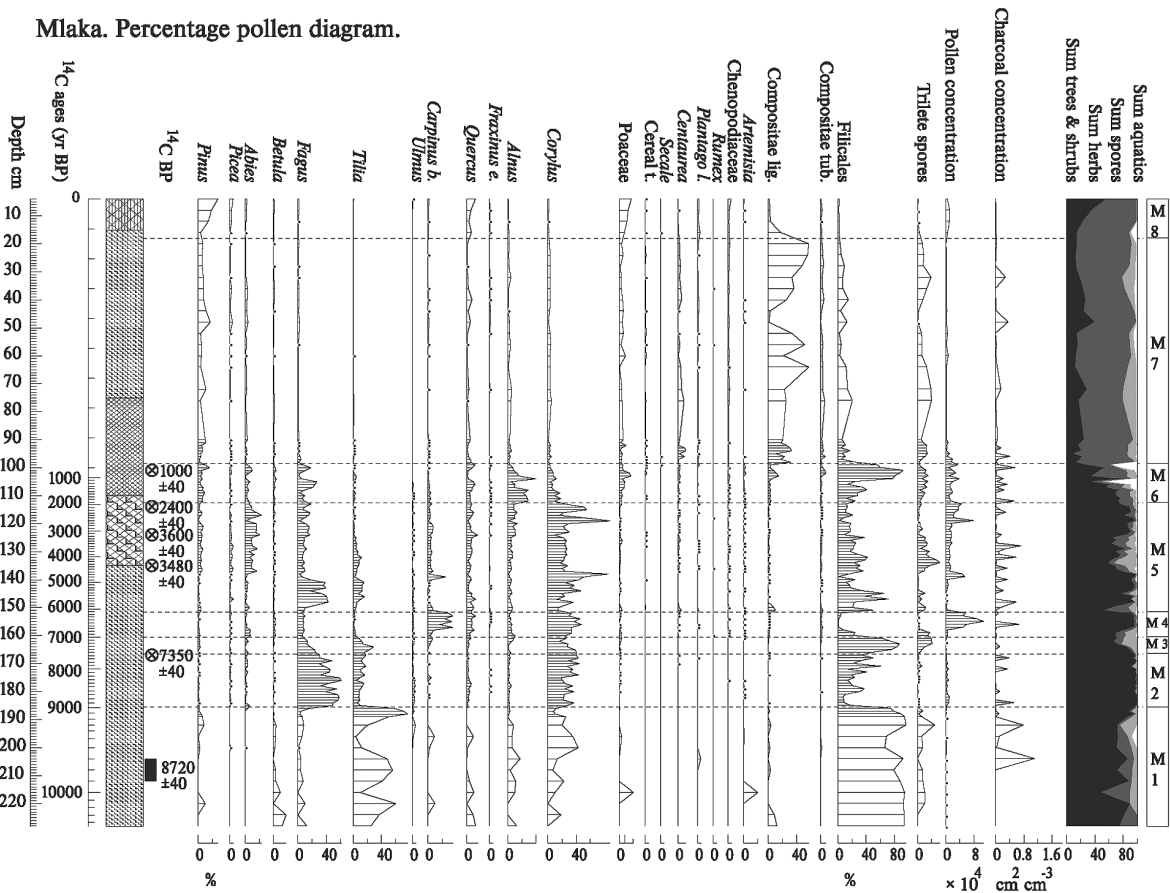
Middle Holocene

In the second half of the Holocene, shade-tolerant tree taxa started to increase in both study regions. In Bela krajina, beech (*Fagus*) forest spread again after 5700 calBP, but forest composition changed at *c.* 4800 calBP, when beech was replaced by fir (*Abies*) (Fig. 2a). Similarly, an increase in beech on Ljubljana Marshes is dated after *c.* 6000 calBP, but this was very soon replaced by fir, which remained the most important tree taxon until *c.* 4500 calBP, when spruce (*Picea*) and alder (*Alnus*) increased (Fig. 2c). The de-

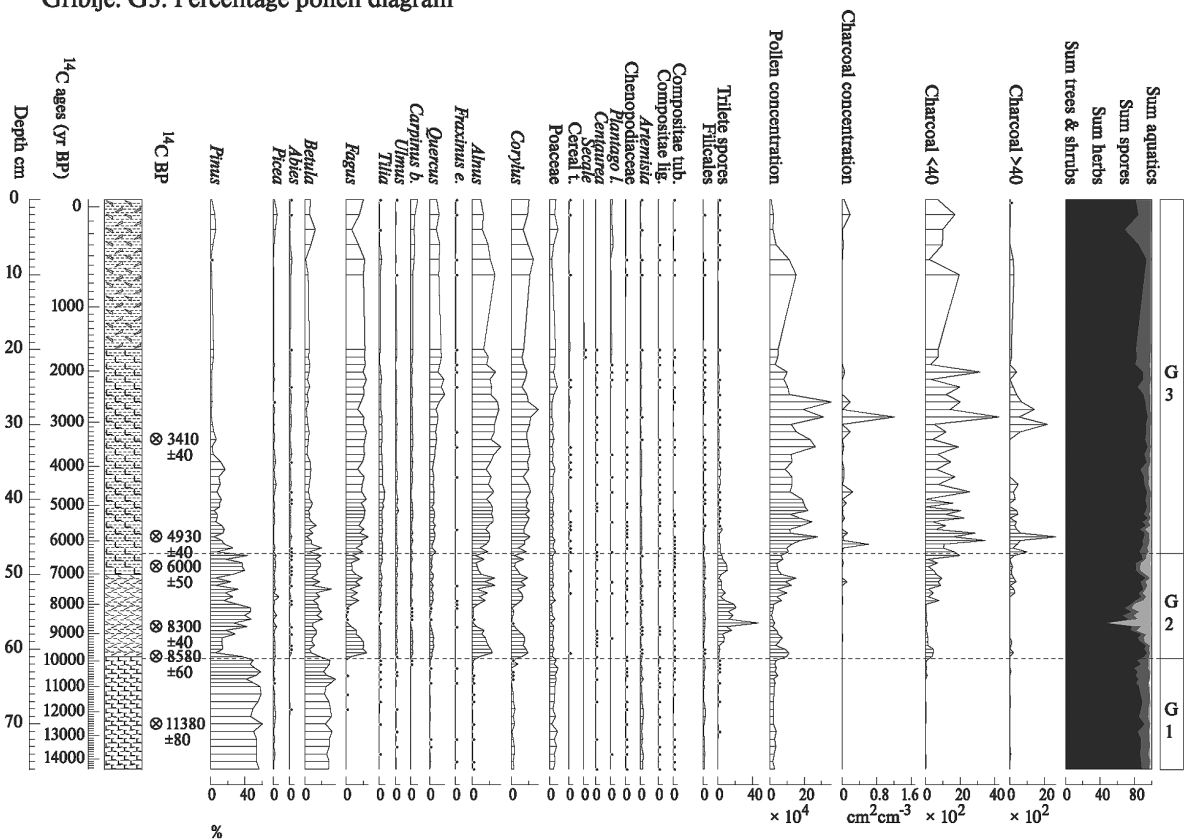
Age (calBP) Bela krajina (Ljubljansko barje)	Vegetation development in Bela krajina (Mlaka, Griblje)	Vegetation development in Ljubljansko barje ('na mahu 1')	Archaeological sites in the vicinity of coring locations and their impact on the vegetation
Middle Holocene c. 4800-4500 calBP	Forest composition changes: beech (<i>Fagus</i>) declines and fir (<i>Abies</i>) increases at Mlaka	Fir (<i>Abies</i>) remains high and only declines after c. 4500 calBP, when spruce (<i>Picea</i>) and alder (<i>Alnus</i>) increase	?
c. 5700-4800 calBP	Beech (<i>Fagus</i>) forest and decreased human impact on the environment	Fir (<i>Abies</i>) increases Human impact continues, but without large-scale forest clearance	Bela krajina: Neolithic/Eneolithic sites near Mlaka (Pusti Gradac) and Griblje ? small scale forest clearance/burning, agriculture and grazing Ljubljansko barje: Maharski prekop (c. 5500-5000 calBP?) small-scale forest clearance, agriculture and grazing
Early Holocene c. 6700-5700 calBP	Hornbeam (<i>Carpinus betulus</i>) phase at Mlaka Human impact on environment (small-scale forest burning, agriculture and grazing), most intensive at c. 6100 calBP, when hornbeam woodland was burnt/cut.	Fir (<i>Abies</i>) and beech (<i>Fagus</i>) decline, whereas oak (<i>Quercus</i>), alder (<i>Alnus</i>) and hazel (<i>Corylus</i>) increase at 6750 calBP, Human impact (agriculture and grazing) Beech (<i>Fagus</i>) increases again after c. 6000 calBP	Bela krajina: Neolithic/Eneolithic sites near Mlaka (Pusti Gradac) and Griblje, small scale forest clearance/burning, coppicing, agriculture and grazing Ljubljansko barje: Resnikov prekop (c. 6600-6500 calBP), small-scale forest clearance, agriculture and grazing
c. 7000-6700 calBP	Forest regrowth through a phase of hazel (<i>Corylus</i>) and oak (<i>Quercus</i>)	Beech-fir (<i>Fagus-Abies</i>) forest	Bela krajina: Neolithic/Eneolithic sites near Mlaka (Pusti Gradac) and Griblje? ?
c. 7500-7000 calBP	Beech (<i>Fagus</i>) decline and more open landscape at Mlaka and Griblje (with slight differences between study sites)	Beech (<i>Fagus</i>) forest, fir (<i>Abies</i>) starts to increase after 7600 calBP	?
c. 9000 (8750) - 7500 (7600) calBP	Predominantly beech (<i>Fagus</i>) forest (with occasional small-scale openings of the canopy due to burning), gradually opening up, first 'Ceraealia-type' pollen grain occurs at Griblje	Woodland with spruce (<i>Picea</i>), elm (<i>Ulmus</i>), lime (<i>Tilia</i>), oak (<i>Quercus</i>) and hazel (<i>Corylus</i>), increased microcharcoal concentration	?
before c. 9000 (8750) calBP	Woodland with lime (<i>Tilia</i>), oak (<i>Quercus</i>), elm (<i>Ulmus</i>), hazel (<i>Corylus</i>), spruce (<i>Picea</i>), increased microcharcoal concentration, more pine (<i>Pinus</i>) and birch (<i>Betula</i>) at Griblje than at Mlaka		

Tab. 1. Comparison of vegetation development in Bela krajina and Ljubljana Marshes regions of Slovenia.

Mlaka. Percentage pollen diagram.



Griblje. G3. Percentage pollen diagram



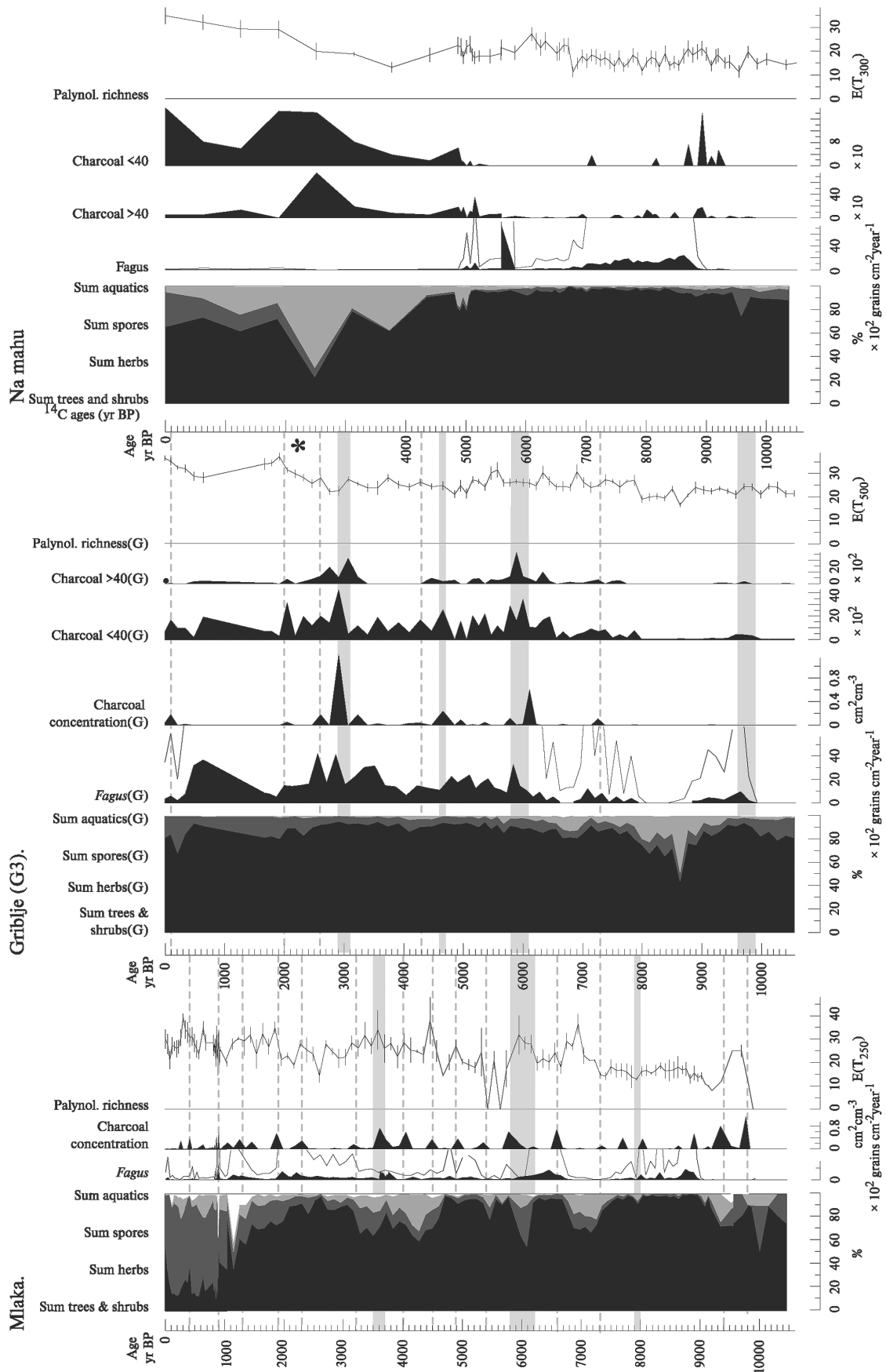


Fig. 3. Landscape openness, microcharcoal record and palynological richness at Mlaka, Griblje (G3) and 'Na mahu 1' study sites. * hiatus due to peat cutting/burning on Ljubljana Marshes.

in biodiversity (palynological richness, Fig. 3) at the beginning of the 7th millennium calBP (*c.* 7000 calBP at Mlaka and 6700 calBP at 'Na mahu 1' core), although no major landscape forest clearance has been detected on pollen diagrams. This could probably be associated with small-scale forest clearance and the activities of early farming communities.

Human impact versus climate

Changes in forest composition and differences between the study regions can be a consequence of climatic fluctuations and/or human impact. Today, summers in Bela krajina are warmer and drier than on Ljubljana Marshes, and it is possible that a similar contrast existed in the past. Therefore, less fir (*Abies*), which needs a humid climate (Ellenberg 1988) was growing in Bela krajina than on Ljubljana Marshes. However, fir is susceptible to fire (Tinner *et al.* 1999), and it is possible that in Bela krajina it was suppressed by anthropogenic burning of the landscape. The charcoal record suggests that the vegetation around Ljubljana Marshes was not burnt so often. Why not – because the lake/marshy landscape of Ljubljana Marshes was more difficult to burn, and this landscape was used instead for hunting, fishing and gathering? Due to the complex hydrological conditions, more open land probably already existed (or was regularly formed) near the edge of the lake and/or along floodplains, and very extensive forest clearance for agriculture was not needed (Willis 1995)?

Palynological research also demonstrated that differences in the composition of vegetation occurred not only between the phytogeographic regions of Slovenia, but also within each individual region. This can best be demonstrated by the differences between Mlaka and Griblje, where, although the study sites are located only *c.* 10 km apart, the vegetation history was very dissimilar. While at Mlaka (located on predominantly limestone bedrock) human pressure on the environment was intensive throughout the Holocene, and the present-day open landscape had formed by the medieval period at *c.* 1000 calBP, the landscape at Griblje (on sand and clay) remained predominantly forested up to the present. This suggests that areas more suitable for agriculture were probably most intensively used.

Climate

To date no studies of local (regional) climate have been carried out, therefore changes in vegetation (*e.g.* forest composition) can be only compared with the global (Northern Hemisphere) climate. In both study regions beech (*Fagus*) establishment at the be-

ginning of the 9th millennium calBP was presumably associated with climatic change – an increase in precipitation. A similar increase in shade-tolerant tree taxa also occurred in other regions of Slovenia (Andrič and Willis 2003) and neighbouring countries (*Abies* expansion in the lowlands of the southern Alps, Tinner *et al.* 1999; Gobet *et al.* 2000; Tinner and Lotter 2006; and *Fagus* increase in Dalmatia, Schmidt *et al.* 2000) and it seems that this palaeo-environmental change was of regional extent. It was limited to the areas south of the Alps, where a continental climate regime had already been replaced by an Atlantic climate regime at about 9100 calBP, whereas north of the Alps, the Atlantic climate is associated with the 8.2 ky BP event (Tinner and Ammann 2001).

At the beginning of the 8th millennium calBP, beech (*Fagus*) in Bela krajina started to decline, and by *c.* 7300 calBP, the beech forest had been replaced by a more open landscape. *Fagus* decline is limited only to Bela krajina (the Ljubljana Marshes region remained very much forested), so it seems unlikely that it would have been triggered by cold global climatic fluctuations, such as the 8.2 ky BP event (Alley *et al.* 1993; Meese *et al.* 1994; Stager and Mayewski 1997; Haas *et al.* 1998; Alley and Ágústsdóttir 2005). However, the impact of precipitation fluctuations might have been more important than the temperature, especially since the 8.2 ky event is assumed to have been dry in the lowlands (Haas *et al.* 1998), with lower lake levels north and south of 50°N and 43°N respectively (Magny and Begeot 2004). It is possible that in the 8th millennium calBP climatic differences between Bela krajina and the Ljubljana Marshes were more pronounced than today, and forest composition in Bela krajina was affected by warm and dry summers, whereas at the same time no major change in forest composition took place on the Ljubljana Marshes.

Is it possible that *Fagus* decline was caused by the impact of hunter-gatherers and/or farmers on the landscape? Yes. Admittedly, no archaeological sites reliably dated before *c.* 7000 calBP have been discovered in Bela krajina, but this option cannot be completely ruled out, and further archaeological and multi-proxy palaeo-ecological research of the regional climate is needed.

After *c.* 6700 calBP, the percentage of beech (*Fagus*) and fir (*Abies*) was low in both study regions. This is most probably a consequence of significant human impact (forest clearance and burning), and coincides

with a major climatic reversal after 8.2 ka calBP (*Stager and Mayewski 1997; Alley and Ágústsdóttir 2005*), when the oceanic early Holocene climate with enhanced westerly airflow was presumably replaced by a more meridional flow pattern, with anti-cyclonic summer conditions, and thus a dry climate and lower lake levels in the period between c. 6800–5700 calBP (*Seppä and Birks 2001*).

After c. 6000–5700 calBP, beech (*Fagus*), and later also fir (*Abies*), increase in both regions, with a slightly decreased human impact on the environment. This could have been associated with the cold and wet climate in the 6th millennium calBP (*Mayewski et al. 2004; Haas et al. 1998; Magny 2004; Magny and Haas 2004; Denton and Karlén 1973; Seppä and Birks 2001; O'Brien et al. 1995; Bond et al. 1997*).

Conclusions

The above described differences between Bela krajina and the Ljubljana Marshes are presumably a consequence of different climates (wetter/colder in the Ljubljana Marshes region?), hydrology, topography and bedrock, as well as archaeological settlement patterns and land-use (more frequent landscape burning in Bela krajina) in the past. However, different natural characteristics and thus the pollen source area of individual study sites should not be ignored.

While at Bela krajina, where all the study sites are small marshes without inflowing/outflowing streams, the local Neolithic impact on the landscape is very visible, the Ljubljana Marshes study site is much bigger and has a more complex and changeable hydrology, which affected the pollen source area. Here, a weak local human impact on the vegetation is more difficult to detect.

How to proceed: more archaeological research is needed in both regions in order to better understand the economy of past societies and their impact on the vegetation. Especially in Bela krajina, where natural conditions are not very favourable for the preservation of archaeological sites or animal and plant remains, more information about archaeological settlement patterns and the economy during the transition from hunting-gathering to the first farming communities would be very valuable. More multi-proxy palaeo-ecological (palaeo-climatological and palaeo-hydrological) research is also needed, since the impact of climate fluctuations on the vegetation and hydrology was significant.

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