The ecology of Neolithic environmental impacts – re-evaluation of existing theory using case studies from Hungary & Slovenia

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ABSTRACT – *Traditional interpretations of Neolithic environmental impacts are discussed in light of new palaeoecological sequences from Slovenia and Hungary. Popular perceptions of large-scale Neolithic landscape clearance are not apparent and instead the environmental response to agricultural activity is represented as a shift in the species composition of forest following observed cycles of decline in the forest dominant. An existing archaeological model, hitherto unused by palaeoecologists, is adapted to explain the forest response to known Neolithic activity.*

IZVLEČEK – *V članku razpravljamo o tradicionalnih razlagah neolitskih vplivov na okolje v luči novih paleoekoloških sekvenc iz Slovenije in Madžarske. Priljubljene razlage, da so v neolitiku v velikem obsegu čistili pokrajino, nismo mogli potrditi. Namesto tega je odgovor okolja na kmetovanje predstavljala sprememba sestave vrst v gozdu, ki je ciklično sledila nazadovanju gozdne dominante. Da bi razložili odziv gozda na znane neolitske aktivnosti, smo prilagodili že obstoječ arheološki model, ki ga paleoekologi doslej še niso uporabili.*

KEY WORDS – *Ljubljansko barje; Mátra hills; Neolithic; palaeoecology; pollen sequence; environmental change; transition to farming; forest clearance*

INTRODUCTION

Conventional environmental research informs us that the Neolithic saw a period of intense deforestation throughout Europe which has been identified in sedimentary sequences as a decline in forest taxa and an expanse in herbaceous taxa, particularly graminids. There exist numerous records of forest clearance attributed to Neolithic activity, but many of these were either published prior to routine ^{14}C determinations or were subject to inadequate ^{14}C dating and were consequently dependent on unreliable methods of relative dating such as the Blytt-Sernander peat-based classification. Ultimately, many such records should be discounted, but the concept of a dramatic widespread environmental change is so well established in the literature that it could be considered a paradigm of archaeological research. Consequently, intellectual inertia is extensive and presents a considerable hurdle for new research to overcome.

The concept of forest clearance during the Neolithic is well established and is derived largely from analyses of sediments in northern Europe. Several models have been proposed to account for the expansion of agriculture during the early Neolithic, and palaeoecological schemes such as the *Landnám* of Iversen (*1941*), the 'leaf-foddering' model of Troels-Smith (*1954*) and the 'forest utilisation' model of Göransson (*1986; 1987*) are widely cited in both the palaeoecological and archaeological literature. The schemes of Iversen and Troels-Smith pioneered the notion of forest manipulation by humans rather than forest clearance, yet suffered problems of chronology, resolution and logistics, which became apparent with a more objective and quantitative appreciation of human activity (*e.g. Edwards 1979; 1993; Rackham 1986*). The Göransson scheme has been regarded as highly controversial (*Edwards*

1993) and suggests that pollen production *increases* as the landscape is first opened *(sensu stricto Aaby 1988; 1994)* due to greater exposure of tree crowns to sunlight, thus demanding a complete reinterpretation of Holocene palaeoecological records.

Although these models have moderated the conventions for interpreting human activity, they arise from a palaeoecological perspective and do not benefit from modern archaeological opinion regarding the onset of agriculture *(Ammerman & Cavalli-Sforza 1973; 1984; Barker 1985; Halstead 1984; 1989; Zvelebil 1988; 1990; 1994; Edwards et al. 1996)*. In addition, all of these models have been formulated with respect to the unique Scandinavian transition to agriculture, which cannot be applied to the central or south-east European situation. These interpretations fail somewhat when applied to the archaeologically and ecologically more complex situation evident in south-east Europe at the time of Neolithic settlement. Much of south-eastern Europe was covered with deciduous forest from the Early Holocene *(Bennett et al. 1991; Willis 1994; 1995a)* and the earliest Neolithic activity is presumed to have exploited natural open spaces such as river terraces and forest gaps *(van Andel & Runnels 1995; Simmons & Innes 1996)*. Such activity is difficult to detect in the palaeoenvironmental record as there is little deliberate environmental disturbance and the dominant signal is that of the 'pristine' landscape. However, the subsequent intensification of agriculture during the consolidation phase *(sensu Zvelebil & Rowley-Conwy 1984)* should be detected in the palynological record as a forest clearance event, as is evident in northern Europe *(Edwards & McDonald 1991)*. Recent research *(Willis & Bennett 1994; Willis 1995a; 1995b; Gardner 1998; 1999; Gardner & Willis 1999)* has demonstrated that the timing and magnitude of such events varies spatially and that, contrary to traditional palaeoecological interpretations, the earliest discernible forest clearance arising from the transition to agriculture in south-east Europe occurs several millenia after archaeological evidence for the earliest intensive farming.

The factors contributing to this discrepancy are complex and have been described in detail elsewhere *(Willis & Bennett 1994; Willis 1995b; Gardner 1998; 1999)*, but it is useful to introduce them here. Briefly, the contributory factors identified include spatial representation of the pollen source area, the location of palaeoecological sites in relation to archaeological sites and the temporal resolution of the palaeoecological samples.

The absence of any firm palaeoecological evidence for the early Neolithic, despite abundant archaeological evidence for agricultural settlements, suggests that either established palaeoecological methods are unsuitable for the interpretation of southeast European Neolithic impacts or that the impacts of Neolithic agriculture were so small that they remain undetected.

This paper presents results from two sites in southeast Europe which are situated in the vicinity of settlements occupied during the Neolithic. The palaeoenvironmental records from each of the sites will be discussed with reference to modern ecological studies of forest dynamics and used in a comparative analysis of Neolithic impacts. The concept of Neolithic landscape clearance will be addressed by recourse to new models which account for the shortcomings of established theories.

STUDY SITES AND METHODS

Sirok Nyírjes Tó (47° 55' 81" N, 20° 11' 14" E) is a small oligotrophic peat bog on the fringe of the Mátra hills in Heves county, north-east Hungary (Fig. 1). Situated at 200 m a.s.l., the basin is an ellipse approximately 200 m long and 100 m wide, surrounded by steep slopes supporting a gallery forest of *Quercus cerris, Carpinus betulus* and *Corylus avellana*. Podpeško Jezero (45° 58' 58" N, 14° 28' 30" E, 300 m a.s.l.) (Fig. 2) is a small circular lake of 80 m diameter at the north-western end of an elliptical basin which has an infilled with organic deposits. The surrounding steep slopes are covered by a thin rendzina soil supporting a *Picea abies* and *Fagus sylvatica* forest plantation.

All methods used are identical to those presented in Gardner (*1998*), with the exception of the coring method and age-modelling procedures adopted for
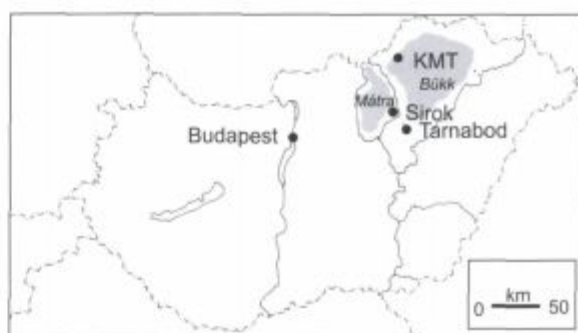

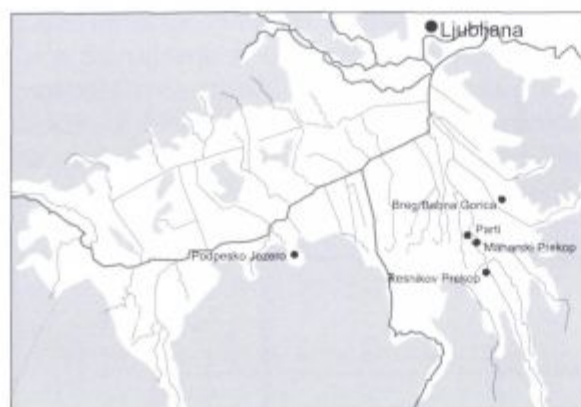*Fig. 1. Location map of Sirok Nyírjes Tó and surrounding area.*

Fig. 2. Location map of Podpeško Jezero and surrounding area.

Sirok. The peaty sediments from Sirok were collected using a hand-held Russian corer with a chamber of 50 cm length and 5 cm diameter. The Sirok age model was constructed using the Bernshtein polynomial curve (*Bennett 1997*), which was then extrapolated following the routines of Maher (*1998*) using the sequence of Willis *et al.* (*1995*) to constrain the basal date.

RESULTS AND DISCUSSION[1]

Sirok Nyírjes Tó

The pollen sequence from Sirok Nyírjes Tó (Fig. 3a–b) has been divided into 7 zones, which are summarised in table 2. The 4.5 m profile spans the last 10 000 years and is composed primarily of *Sphagnum* peat, except for the lowermost 50 cm, which comprise a unit of silty clay overlain by a 6 cm unit of clay. The resolution of the sequence is one sample

every 113 calendar years, except for a fine-interval section where one sample represents 36 calendar years.

The base of the sequence exhibits features characteristic of a change from a predominantly coniferous to a mixed deciduous forest. This type of event is typical of the Holocene after a period of total dominance by *Pinus* during the lateglacial/Holocene transition. The establishment of a mixed deciduous forest dominated by *Corylus* is complete by ca. 8300 cal BP and persists without change for ca. 600 years. This type of forest has no modern analogue (*Rackham 1988*), but is a feature apparent in several other pollen records from the region (*e.g. sites in Willis 1994; Willis et. al 1997*) and represents a distinct phase in south-east European vegetation development (*Huntley & Birks 1983*).

From ca. 6900 cal BP a series of high frequency cycles occur during which *Corylus* declines and other taxa, most notably *Carpinus betulus*, expand briefly. It is plain that the previously stable forest is being disturbed in some manner and that *Corylus* is being selectively removed, allowing minor flourishes of *C. betulus*. Furthermore, minor increases in wet-habitat field-layer taxa such as *Thelypteris palustris* and some members of the Liliaceae, in addition to expansions in *Sphagnum* and Filicales, imply a change both in hydrological conditions and light penetration to forest floor.

The removal of this disturbance is evident in the stabilisation of *Corylus* in reduced abundance and the expansion of *C. betulus* to a position of dominance within the forest, a component of the typical post-

lab code	sample code	sample material	uncalib. years bp	cal. years BP (2σ)	cal. years BC/AD (2σ)	calibration dataset used	δ¹³C PDB ± 0.1‰
AA-27177	Sir 64 cm	*Sphagnum* peat	380 ± 50	516 (467) 302	*1434 (1483)1648*	1	–27.9
AA-27178	Sir 160 cm	*Sphagnum* peat	2955 ± 55	3324 (3100) 2945	1374 (1150) 995	2	–25.14
AA-27179	Sir 240 cm	*Sphagnum* peat	4580 ± 55	5451 (5300) 5046	3501 (3350) 3096	1	–25.12
AA-27180	Sir 300 cm	*Sphagnum* peat	5135 ± 60	5989 (5910) 5738	4039 (3960) 3788	1	–29.6
AA-27185	Sir 394 cm	wood	5805 ± 55	6742 (6640) 6469	4792 (4690) 4519	1	–29.2
AA-27186	JZ 233 cm	wood	365 ± 45	509 (345) 301	*1441 (1605) 1649*	1	–27.5
AA-27187	JZ 348 cm	wood	930 ± 45	935 (829) 727	*1015 (1121) 1223*	1	–25.14
AA-27188	JZ 477 cm	wood	6110 ± 75	7176 (6970) 6786	5226 (5020) 4836	1	–31.2
AA-27189	JZ 651 cm	wood	9075 ± 70	10 279 (10 030) 9922	8329 (8080) 7972	3	–29.0

Tab. 1. ¹⁴C AMS determinations and calibration results. Calibration performed using method A of CALIB 3.0 (Stuiver & Reimer 1993).

1 Results from radiocarbon analyses are presented in table 1 and are incorporated in the stratigraphic diagrams (Figs. 3 & 4).
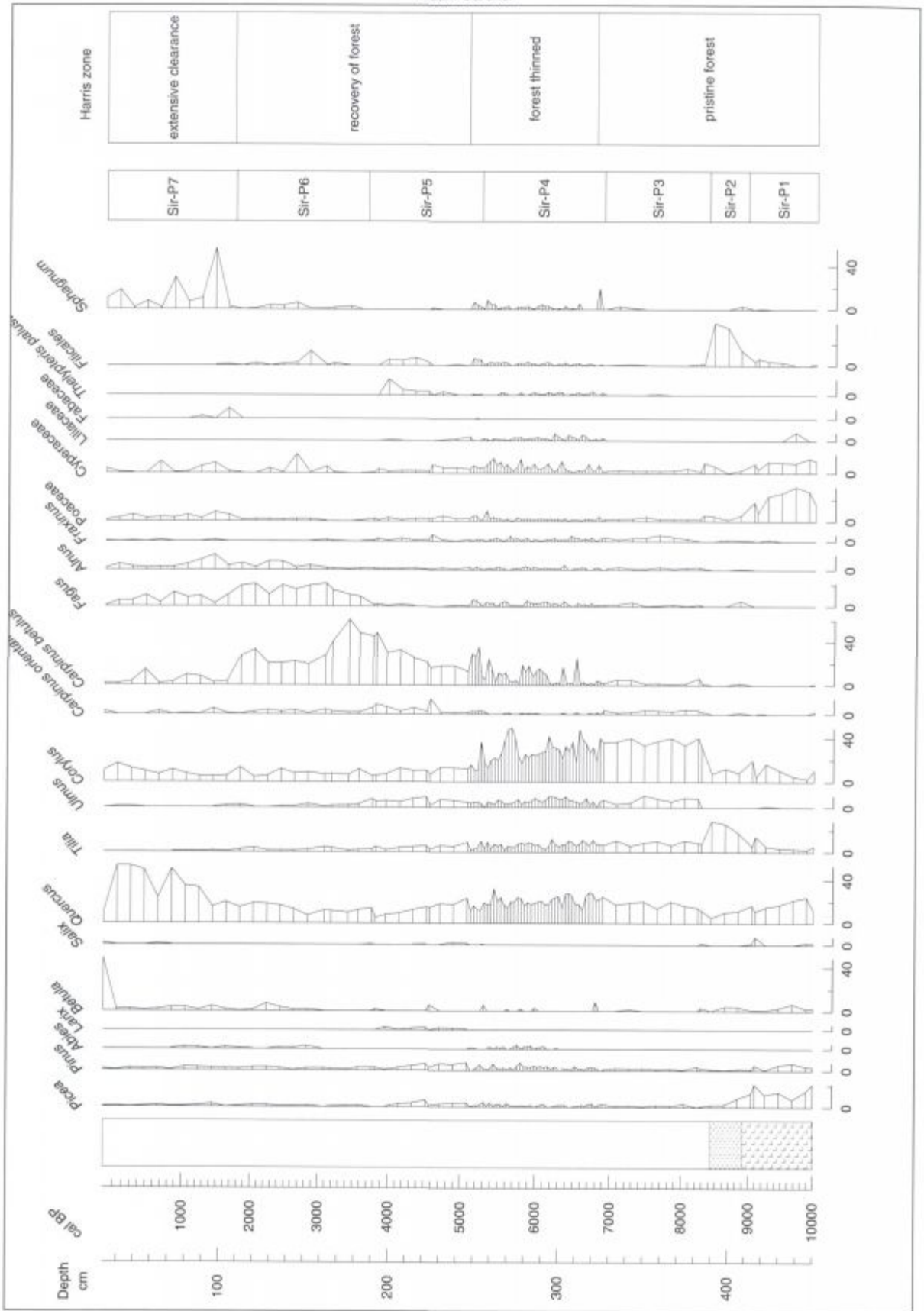
Fig. 3a

Figs. 3 a–b. Pollen percentage diagrams for Sirok Nyírjes Tó plotted against core lithology, depth and interpolated ¹⁴C timescale; 3a Percentage diagram of major taxa; 3b Summary diagram showing total pollen percentages with and without aquatics and supplementary spectra. See text for explanation of 'Harris zones'.

glacial forest succession for south-east Europe. Similarly, the subsequent expansion of *Fagus* and the continued presence of *Quercus* in abundance is indicative of a forest which is not subject to appreciable external disturbance. The summary diagram (Fig. 3b) illustrates this point well: arboreal pollen reaches maximum values ca. 3600 cal BP and there is little variation in the forest composition.

The first appreciable forest change, presumably through anthropogenic activity given the increased charcoal concentration (Fig. 3b), occurs ca. 1850 cal
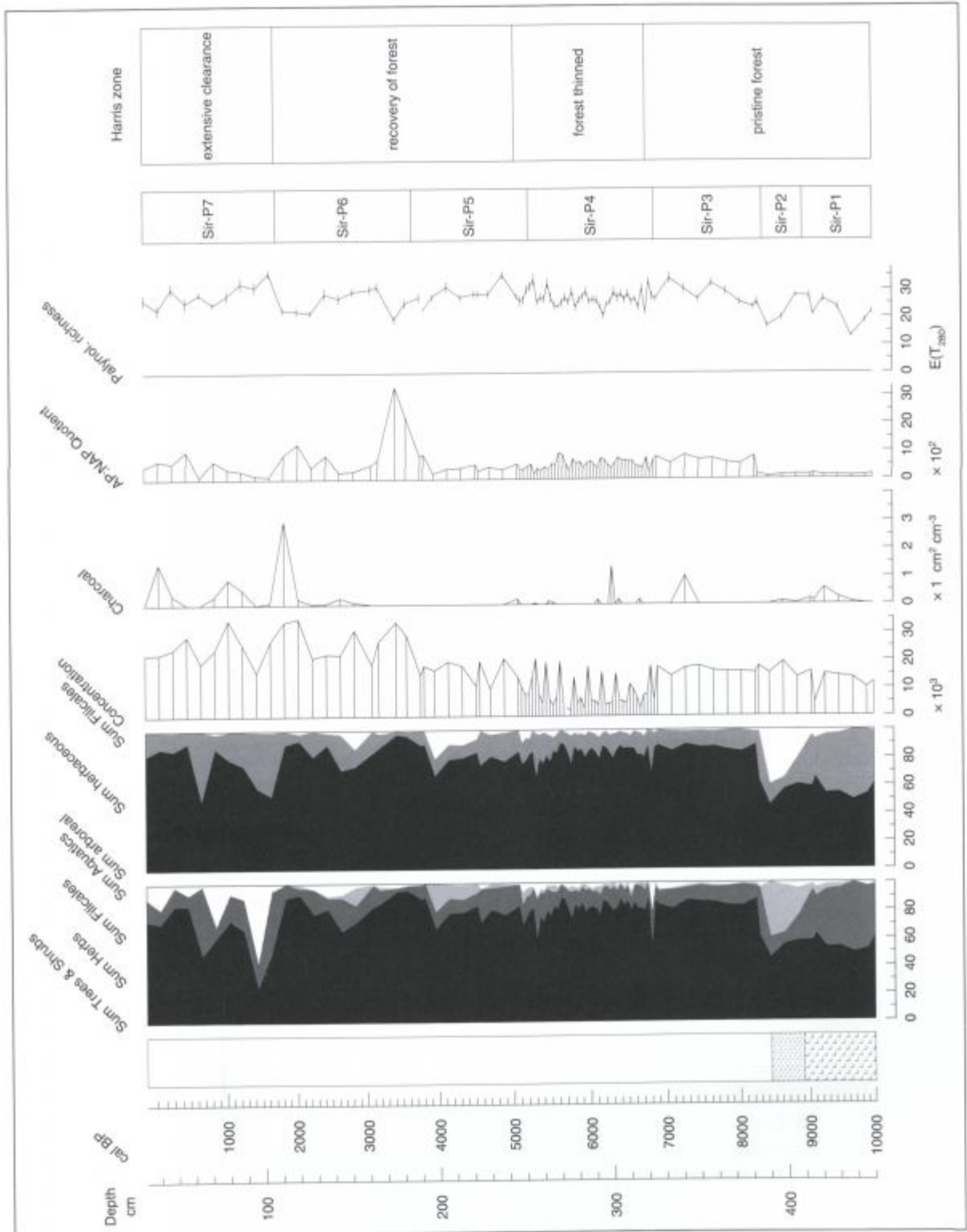

Fig. 3b

BP as *C. betulus* is reduced. The removal of the dominant forest element permits expansion in several taxa, all of which are adapted to wetter conditions. At this time the *Sphagnum* which forms the peat dramatically increases production of spores, indicating a change in surface wetness (*Barber 1981*). Subsequently, the space created by the removal of *C. betulus* is filled by an expansion of *Quercus* from ca. 1400 cal BP that persists to the present day.

Podpeško Jezero

The pollen sequence from Podpeško Jezero (Fig. 4a–b) has been divided into six zones, which are summarised in table 3. The 6.25 m of sediment recovered from Podpeško Jezero span 11 350 years within a sequence of (from the base upwards) marl, silty-marl and gyttja (Figs. 4a–b). Throughout the sequence, each sample represents 108 calendar years, except for the close-interval section between 7400 and 5600 cal BP where each sample represents 64 calendar years. The base of the sequence incorporates the lateglacial-Holocene transition with a coniferous forest dominated by *Pinus*. Although its pollen is present in abundance, the *Pinus* forest at this time is not complete (*sensu Aaby 1988; Peterson 1983*) and the pollen spectra probably represent a 'coniferous parkland' type of environment with open spaces. The shift from a coniferous to a mixed-deciduous forest begins with the expansion of *Betula* in the open spaces, followed by expansion of a full range of temperate deciduous forest taxa.

From about 9000 cal BP, an expansion of *Corylus* occurs which is followed by the dramatic expansion of *Fagus*. Once established, *Fagus* persists in the forest until the present, but is subject to changes in the vegetation structure. Initially, *Fagus* dominates the

Zone	Age (cal. BP)	Dominant features	Charcoal	%AP	Conc (grains cm⁻³)	AP: NAP	Palyn. richness
Sir-P7	1750– present	Increase of *Quercus*, herbaceous elements and *Sphagnum*. Sharp increase of *Betula* in top of zone	high	>70	20 000 to 30 000	low to moderate	maximum
Sir-P6	3400– 1750	Maximum of *Carpinus betulus*; declines as *Fagus* expands	low; 1 peak	>75	20 000 to 30 000	maximum declines	high
Sir-P5	5200– 3700	Increase of *C. betulus* and *C. orientalis*.	very low	>75	ca. 20 000	moderate; increases	high; steady
Sir-P4	6900– 5200	High frequency fluctuations in *Corylus*, *Quercus* and *C. betulus*	low	>75	5000 to 15 000	moderate	high; steady
Sir-P3	8300– 6900	Mixed assemblage of *Quercus*, *Tilia* and *Ulmus* dominated by *Corylus*.	low	>80	ca. 15 000	moderate	increasing
Sir-P2	8950– 8300	Maxima in *Tilia* and Filicales, reductions in all other taxa.	low	50	ca. 20 000	low	decreasing
Sir-P1	1000– 8950	Dominance of Poaceae, high values of *Picea*, *Quercus*, *Corylus* and Cyperaceae.	moderate	50	ca. 12 000	low	increasing

Tab. 2. Summary of major palynological events by zone for Sirok. All values are approximate; for further detail see figures 3a–b.

forest until the arrival of *Abies* ca. 7000 cal BP, when an *Abies-Fagus* forest similar to those currently present in the region was formed. Soon after the establishment of the *Abies-Fagus* stage, external influences manipulate the forest structure to the extent that the dominant *Fagus* is replaced briefly by *Corylus*.

The partial removal of *Fagus* and *Abies* provided conditions suitable for a secondary expansion of *Corylus* not typically seen in Slovenian Holocene sequences (*Šercelj 1996*). *Corylus* produces little or no pollen when growing as an understorey shrub (*Rackham 1988*), therefore this event represents a real dominance by mature trees. A significant thinning of the canopy occurred locally around the basin, resulting in enhanced light levels penetrating to the field layer. From about 5000 cal BP the canopy openings contracted as *Fagus*, *Abies* and *Quercus* increased to form a forest, which although dense, nonetheless allowed sufficient light penetration for *Carpinus betulus* to establish and flourish.

From ca. 3200 cal BP the landscape surrounding the basin underwent rapid and dramatic change, during which herbaceous taxa (Poaceae, Cyperaceae, *Cannabis*) and Filicales increased and several arboreal taxa *(Fagus, Abies, C. betulus)* were reduced. Low values for the AP:NAP ratio (Fig. 4b) support this assumption and reveal that non-arboreal taxa dominated the pollen rain from ca. 3000 cal BP. This event probably represents the formation of the modern landscape of mixed (predominantly *Abies-Fagus*) forest surrounding open land which was exploited for agriculture.

DISCUSSION

Sirok Nyírjes Tó

In the early postglacial, the slopes around Sirok supported an open parkland composed of *Picea, Quercus, Tilia* and *Corylus*, with open spaces dominated by Poaceae (Fig. 3a). Moderate burning of the vegetation was occurring up to ca. 8900 cal BP. A transition from lake to peat deposits occurred in the basin from 10 000–8300 cal BP. Over the same interval distinct changes were also occurring in the vegetation, each of which corresponds to a different sedi-

Zone	Age (cal. BP)	Dominant features	Charcoal	%AP	Conc (grains cm⁻³)	AP: NAP	Palyn. richness
JZ-P6	2100– present	Expansion of Poaceae, Cyperaceae, *Cannabis* and Filicales	maximum values	ca. 50	5000– 30 000	minimum	maximum
JZ-P5	6400– 2100	Secondary (and maximum) *Corylus* peak. *Abies* declines. Appearance of *Carpinus betulus*.	virtually absent	>80	ca. 5000	low	increases
JZ-P4	7000– 6400	*Abies* maximum. *Fagus* declining sharply.	low	>90	ca. 5000	high	fluctuates; generally low
JZ-P3	8500– 7000	Total dominance by *Fagus*.	negligible	>90	ca. 5000	maximum values	declines
JZ-P2	9850– 8500	Transition from coniferous to mixed deciduous assemblage. *Corylus* rise and fall, *Fagus* rise begins.	low	80–90	ca. 12 000	increasing	fluctuates
JZ-P1	11 300– 9850	*Pinus* dominates. High values of *Picea*, *Betula*, Poaceae.	moderate	>75	ca. 7000	low	low

Tab. 3. Summary of major palynological events by zone for Podpeško Jezero. All values are approximate; for further detail see figures 4a–b.
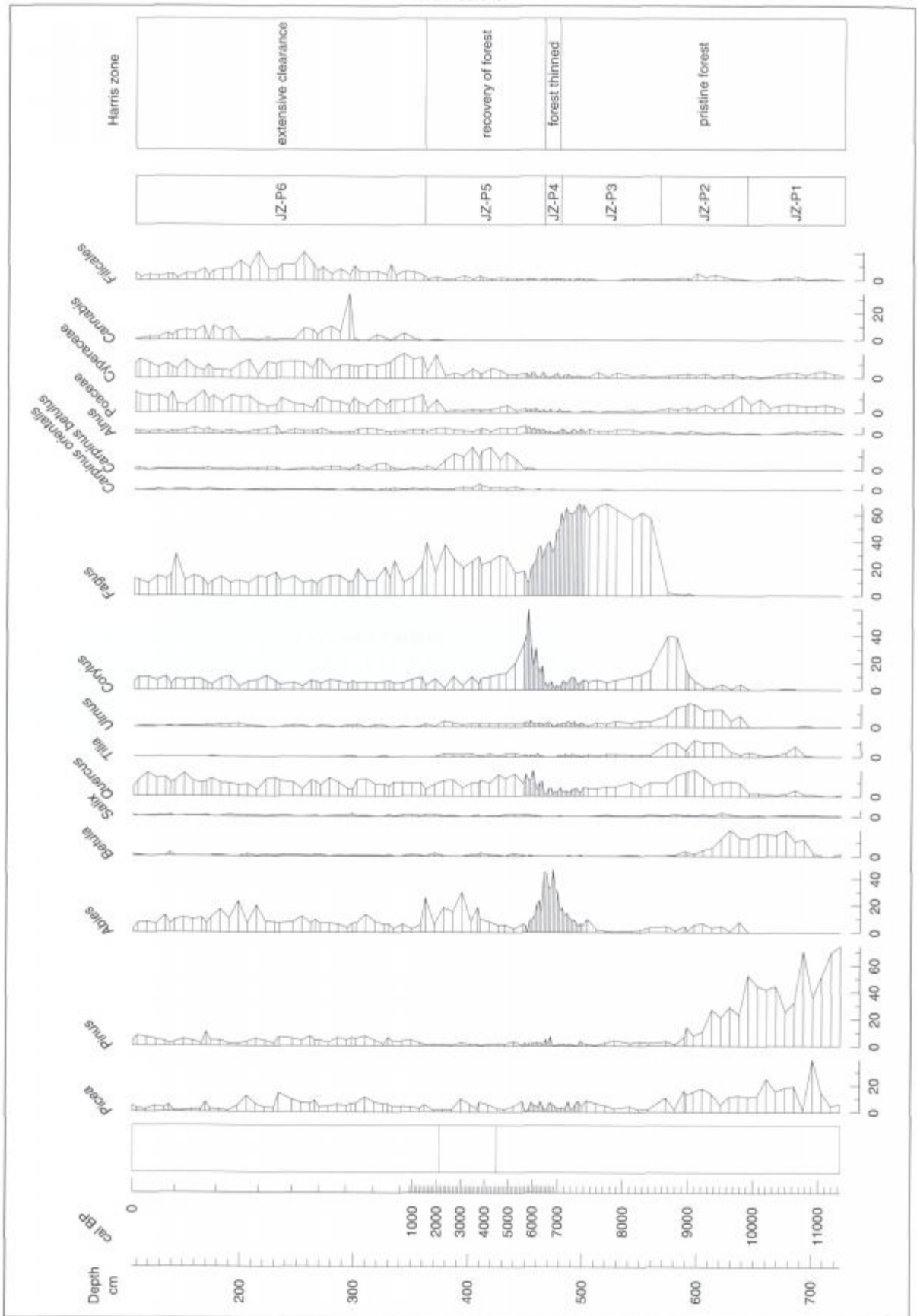
Fig. 4a

Figs. 4 a–b. Pollen percentage diagrams for Podpeško Jezero plotted against core lithology, depth and interpolated ¹⁴C timescale; 4a Percentage diagram of major taxa; 4b Summary diagram showing total pollen percentages and supplementary spectra. See text for explanation of 'Harris zones'.

mentary unit: 1. a decline of *Picea, Pinus* and *Betula* and open-ground herbaceous elements (lake sediment); 2. a dramatic increase of *Tilia* and Filicales (silt); and 3. the establishment of closed deciduous forest *(Sphagnum* peat). *Tilia* and Filicales were present at the base of the sequence, but the expansion to 25–30% of the pollen sum between 8900 and 8300 cal BP is unusual and not apparent in any other published diagram, although a sharp increase in *Tilia* at ca. 9500 BP (ca. 10 600 cal BP) has been recorded at Bátorliget, eastern Hungary *(Willis et al. 1995)*, and a peak in Filicales dated to ca. 9500 cal

BP is apparent at Kis Mohos Tó *(Willis et al. 1997)*, 50 km north of Sirok.

Given the change in the hydrological regime and the poor dispersal characteristics of *Tilia* pollen, an expansion of this sort is difficult to reconcile in terms of ecology. *Tilia* typically thrives on well-drained soils such as those of the English lowland *(Tutin et al. 1989; Rackham 1988; Packham & Harding 1992)* and is unlikely to have flourished on the waterlogged basin surface. However, dispersal of *Tilia* pollen is so poor that individual trees must have
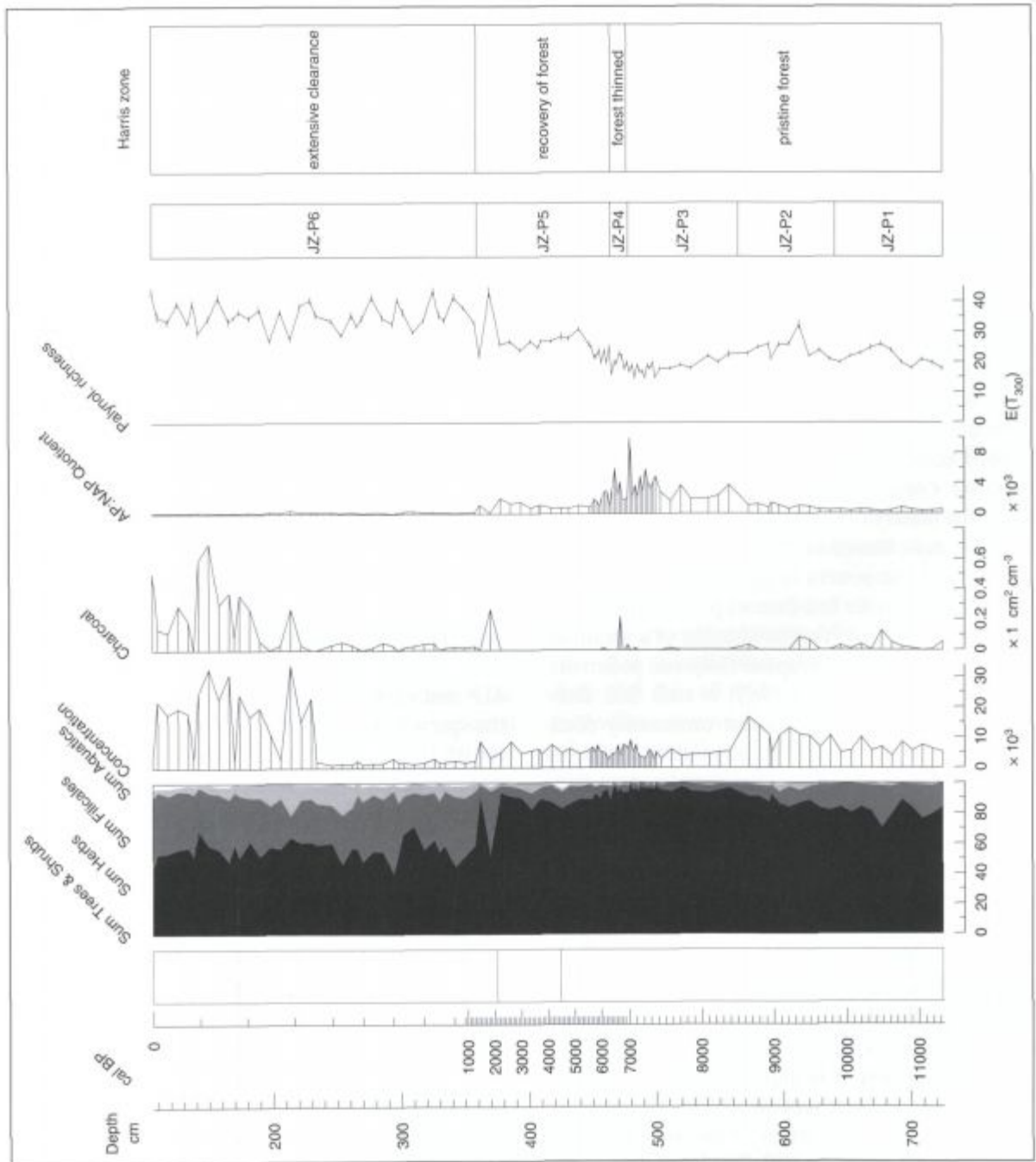

Fig. 4b

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been within a few metres of the basin (*Nilsson & Praglowski 1992*) and the possibility exists that a dense gallery forest (which is composed of *Corylus avellana, Carpinus betulus* and *Quercus cerris* at present), of which *Tilia* was a dominant component, developed on the well-drained slopes at the periphery of the basin (*cf. Ellenberg 1988*).

The order Filicales includes taxa which characteristically thrive on burnt or nutrient-poor soils, but specifically certain taxa (such as *Thelypteris palustris* and *Athyrium* sp.) which grow on wet ground (*Tutin et al. 1989*). The charcoal concentration for this section of the core decreases prior to the expansion of Filicales (Fig. 3b), therefore fire would appear to be an unlikely factor to account for this event. However, the gradual infilling of the lake revealed newly exposed land which could have been colonised by advantageous taxa such as Filicales. Therefore, the abundance of Filicales spores at this time can probably be explained in terms of colonisation of newly exposed land.

From 8300 to 5200 cal BP the forest around the site became dominated by *Corylus* with *Quercus, Tilia* and *Ulmus*. The expansion of *Corylus* to values >40% is a common feature of European Holocene pollen diagrams (*Huntley & Birks 1983*) and is conventionally taken to represent a shrub layer in a forest. However, *Corylus* produces little pollen when growing in the understorey (*Rackham 1988*) and the population must therefore have either been a dominant canopy component or growing on the fringe of the basin. The latter is a distinct possibility in small basins such as Sirok, yet the ubiquity of a pronounced *Corylus* phase in European Holocene pollen diagrams (*Huntley & Birks 1983*) is such that there may once have existed a forest community dominated by *Corylus* which has no modern analogue. By extension, this implies that *Corylus* may have existed as a canopy tree. Three palynologically indistinguishable species of *Corylus* exist in Europe, of which two (*C. avellana* and *C. maxima*) are shrubs and one *(C. colurna)* is a canopy tree reaching 22 m (*Huntley & Birks 1983; Tutin et al. 1989*). All are currently distributed throughout the Balkans (*Tutin et al. 1989*) and are presumed to have been present throughout the Holocene (*Huntley & Birks 1983*). Given the possibility of two alternative species for the Balkan region, it is impossible to say whether the *Corylus* spectrum represented in this sequence is a shrub layer on the fringe of the basin or a now extinct forest assemblage with *Corylus* in the canopy.

From 6900 to 5200 cal BP, there were several forest cycles in which the dominance of *Corylus* in the sequence was periodically reduced and in which *Carpinus betulus* rapidly expanded. These cycles occurred over various timescales, the shortest being ca. 36 years and the longest ca. 288 years. This selective removal of *Corylus* and the subsequent expansion of *Carpinus betulus* (Fig. 3a) may be due to anthropogenic intervention on the landscape, given the respective ecology of the two taxa. However, the climate of this period was significantly different to that of today (*Kutzbach & Guetter 1986; Huntley & Prentice 1988; 1993; Kutzbach et al. 1993; Cheddadi et al. 1997*) and underlying climatic factors which could account for these events must also be examined.

Between approximately 7800 and 5700 cal BP the climate of Europe experienced conditions which have traditionally been described as 'optimal' and which were designated as 'Atlantic' under the Blytt-Sernander classification (*Roberts 1998*). These optimal climatic conditions were considered to be uniformly warmer and moister than present across Europe, yet recent research has shown this not to be the case. Cheddadi *et al.* (*1997*) demonstrated that although the idea of a 'climatic optimum' is acceptable for northern Europe, conditions in south-east Europe at 6ka BP (6800 cal BP) were up to 4°C cooler than present and precipitation was up to 200 mm year^{-1} greater. Given that *Corylus* is more tolerant of cool summers and of wetter conditions than *Carpinus betulus* (*Huntley & Prentice 1993*), there is no apparent climatic reason for the onset of the periodic declines observed in the *Corylus* curve.

ALP and early copper-using cultures flourished on the sparsely wooded plains between 7300 and 5800 cal BP (*Sherratt 1982a; 1982b; Willis et al. 1998*) and the forests of the Mátra and Bükk mountains represented the only reliable source of wood for raw materials and fuel, in particular for the nearby Tarnabod (Fig. 1) settlements which were occupied from 7240 cal BP. The possibility exists that forest grazing and browsing by livestock from the ALP settlements gradually introduced a change in the forest composition, but this is unlikely, as the *Alföld* provided vast expanses of grassland suitable for both arable and pastoral use (*Kosse 1979*). Therefore, the coincident timing of these events in the pollen record and of the occupation of the Tarnabod tells suggests that the changes to the forest could be attributed to human activity.

Coppicing of *Corylus* is an effective land-use strategy which would have ensured a continuous supply of raw material (*Evans 1992*) from the Sirok area. *Carpinus betulus* was present as a minor element of the stable *Corylus* dominated forest for ca. 600 years, and selective removal of *Corylus* through coppicing created the conditions into which *C. betulus* had the opportunity to expand. *C. betulus* seedlings are light-demanding and severe disturbance or coppicing allows the establishment of new specimens (*Rackham 1980*) which, if left undisturbed, will grow and cast dense shade. Therefore, there must have been an external influence between 7000 and 5200 cal BP which prevented the expansion of *C. betulus* into the forest canopy. *C. betulus* also coppices extremely well (*Rackham 1980; Evans & Barkham 1992*) and although it has virtually no uses as timber, burns at an extremely high temperature (*Evans 1992; Mabberley 1997*) and is hence valuable as fuel. It is therefore reasonable to suggest that two coppice cycles were operative; *Corylus* coppice with a short rotation of 6–10 years and *C. betulus* coppice with a longer rotation of 15–35 years (*Evans 1992*). Clearly these cycles are too brief to register within the limits of the available temporal resolution (1 sample = ca. 36 years), but the varied timescales of these cycles (36–288 years) suggests that there may be a threshold level at which the signal of coppicing activity is recorded.

The recovery of the woodland from ca. 5200 cal BP coincides with the abandonment of the settlements at Tarnabod (*Kalicz & Makkay 1977*) and a gradual eastward shift in settlement pattern during the Copper Age (*Sherratt 1982a*). It is highly probable, therefore, that woodland recovery is linked to abandonment of coppicing. This would have lead to the inevitable closure of the canopy and the gradual accession of *C. betulus* to a position of dominance within the forest. Figures 3a–b shows that this process occurred over more than a millennium. More significant, however, is the apparent lack of any sedimentological influx through erosive disturbance during the entire period of coppicing and *C. betulus* expansion, indicating the validity of coppicing as a sustainable land-use strategy.

The removal of human influence allowed natural forest processes to resume at Sirok and the expansion of *Fagus* occurred at the expense of the *C. betulus* canopy. Recent ecological studies (*Peters 1997*) have demonstrated that the deep shade cast by *Fagus* restricts growth in all the forest taxa present, and the decline in *C. betulus* appears to be directly associated with the expansion of *Fagus*. However, *Fagus* does not achieve total dominance in the forest and merely restricts *C. betulus* to a position within a mixed deciduous assemblage containing *Quercus, Corylus, Tilia, Ulmus* and *C. orientalis*. Thus, the expansion of *Fagus* from ca. 3500 cal BP appears to have coincided with a reduction in total forest cover.

From ca. 1700 cal BP to the present day, the vegetation around the basin changed once again and became dominated by *Quercus* with a greater proportion of non-arboreal taxa. Taxa tolerant of wetter conditions (e.g. *Alnus* and *Sphagnum)* expanded and charcoal concentrations increased (Fig. 3b), suggesting burning of the landscape. The most striking feature of these events is the expansion of *Quercus* to a position of dominance in the pollen assemblage. Clearly, the combination of increased burning, the removal of the deciduous tree cover and the apparent shift in the water table are related to increased impacts from anthropogenic activity, perhaps as a result of increased populations, lack of effective controls (e.g. coppicing) to mitigate against landscape degradation, or a combination of both.

The period from 1700 BP to the present represents a turbulent period in the cultural history of Hungary. The early Middle Ages (2000–1625 BP; AD 0–375) saw the colonisation of the Mátra region by Barbarian groups of Celts, Dacs, Vandals and Sarmatians, followed by migration groups of Huns, Avars and Slavons between 1625 and 1105 BP (AD 375–895) and the Hungarian conquest of 1105–1045 BP (AD 895–955) (*Trogmayer 1980; Willis et al. 1997*). Not until the evolution of the Hungarian Kingdom from 995 BP (AD 955) did the population resettle into village communities and return to managed use of woodland (*Fügedi 1986*), by which time the forest composition had totally changed. The response evident between 7000 and 5200 cal BP is therefore not apparent over the past millennium. In addition, *Quercus*, the dominant taxon present from ca. 995 BP (ca. 920 cal BP), does not coppice well and is a highly valued timber tree (*Rackham 1980; 1986; Mabberley 1997*). Furthermore, *Quercus* mast provides good fodder for livestock (*Newbold 1983*) and the forests may therefore have been subject to an alternative form of managed use.

Podpeško Jezero

The Holocene pollen stratigraphy of Podpeško Jezero is similar to the regional pollen record estab-

lished for Slovenia (*Culiberg 1991; Šercelj 1996*). The characteristic lateglacial assemblage of predominantly coniferous types with Poaceae and Cyperaceae is evident up to ca. 9800 cal BP. From 9800 cal BP the vegetation changed rapidly and became dominated by a mixed deciduous forest composed of *Quercus, Tilia, Ulmus* and *Corylus,* and the open areas decreased in size. This persisted for approximately 600 years until the expansion of *Corylus* at ca. 9000 cal BP. The basin at this time was occupied by a diverse, dominantly deciduous forest into which *Corylus* expanded rapidly. The forest was dominated by *Corylus* for ca. 300 years until the expansion of *Fagus* at ca. 8500 cal BP. An almost pure *Fagus* forest existed in the basin until the expansion of *Abies* at ca. 7000 cal BP when a mixed *Abies-Fagus* occupied the slopes surrounding the lake.

From ca. 7000 cal BP a series of changes to the forest occurred which does not follow the sequence of Šercelj (*1996*) or the general trends suggested for south-east Europe (*Huntley & Birks 1983; Huntley & Prentice 1993*). The decline of *Fagus* and *Abies* and the subsequent expansion of *Corylus, Quercus* and *Carpinus betulus* from ca. 6400 cal BP (Fig. 4a) is an unusual event in forest development. The characteristic internal dynamics of *Fagus* forest are driven by its canopy dominance and tolerance of extremely low light levels, particularly during the juvenile stage of growth (*Newbold 1983; Peters 1997*). Shade tolerance whilst juvenile is especially important to maintain *Fagus* dominance. Furthermore, Huntley and Prentice (*1993*) show that elsewhere in south-east Europe, *Fagus* and *Abies* were expanding at this time and the eastern range of *Corylus* was in decline. Thus, there is no readily apparent reason for a *Fagus-Abies* population to become reduced by *Corylus* through competition alone.

A possible explanation for the retraction of *Fagus* is a change to an unfavourable climate more suitable for other deciduous forest taxa. However, this does not account for the initial expansion of *Fagus* at 8500 cal BP during conditions which were less favourable for growth than those of ca. 6400 cal BP (*Huntley & Prentice 1993*). The microclimate of the Ljubljana Moor region is modulated by the constant temperature of inflowing karstic streams from the southern highlands. Consequently, local climatic conditions throughout the Holocene have been warmer and moister than elsewhere (*Šercelj 1996*), favouring the growth of temperate deciduous forest. Coupled with the close proximity of refugial populations (*Willis 1994*), this explains the early expansion

of *Fagus* at 8500 cal BP during climatic conditions described by Huntley and Prentice (*1993*) as unfavourable. However, given this constant microclimate, there is no apparent climatic explanation for the decline of *Fagus* at 6400 cal BP.

Recent research (*M. Budja, unpublished data: personal communication, 1999*) has produced the earliest reliable radiocarbon date for human settlement on Ljubljana Moor. New excavations at Breg have revealed Mesolithic artefacts and occupation layers dated to 9180 cal BP, whilst at Babna Gorica early Neolithic occupation layers containing monochrome pottery have been dated to 6290 cal BP. The early Neolithic has hitherto been considered absent from the region and these excavations provide a cultural framework in which to view the forest changes at Podpeško Jezero.

Forest grazing by livestock has been shown to reduce deciduous forest by limiting the regeneration of seedlings (*Pigott 1983*) with the effect that forest stands gradually decline. The immature shoots of deciduous taxa, especially *Fagus*, are exceptionally palatable to grazing animals (*Rackham 1980*) and consumption of seedlings drastically reduces the success rate of regeneration (*Newbold 1983*). Furthermore, consumption of beechnuts by herbivores (*Newbold 1983*) places an additional strain on the marginal success of *Fagus* replacement. Grazing and browsing by animals could therefore account for the decline in *Fagus* apparent from 6400 cal BP, but this would not have operated in isolation and additional agencies must have contributed to the selective removal of forest elements.

The selective removal of *Fagus* and *Abies* could be regarded as the result of repeated small-scale clearances within the catchment with the intention of creating useful pockets of land for cultivation or grazing. The opening of the forest canopy would have promoted the establishment of a rich field-layer and advantageous fast-growth arboreal taxa such as *Corylus* respond rapidly and soon dominate the canopy gap. In addition, present day ecological studies have demonstrated that *Fagus* will not regenerate if gaps are large (*Peters 1997*). However, these findings have not been incorporated into any of the popular models proposed to characterise the environmental response to Neolithic agriculture.

Carugati *et al.* (*1996*) present a model for small-scale agricultural activity in the forest of Neolithic Sammardenchia on the Friuli Plain of north-east

Italy. In this example, a small gap is created in *Quercus-Fraxinus* forest by felling or ring-barking, and the cleared land is used for the growth of cereals. The stumps of felled trees remain in position and after removal of any undergrowth, cereals are sown in the sheltered glade surrounded by mature forest. After several years of use for crops, the perimeter of the clearance is encroached by shrubs such as *Corylus* which subsequently close the abandoned plot as the forest recolonises.

Although relatively simple, this model serves as a useful example for the nature of early human impacts upon dense forest and demonstrates the manner in which small-scale activity may produce a localised shift in forest composition. Repeated openings of this type within a small forest are palynologically invisible (*Sugita et al. 1999*), yet over an extended period of time may result in a shift in the forest composition.

The expansion of *Corylus* from 6400 cal BP reached a peak ca. 5800 cal BP, but was rapidly reduced by the expansion of *Carpinus betulus, C. orientalis* and by the partial recovery of *Fagus* (Fig. 4a). Small increases in Poaceae and Cyperaceae are apparent, indicating greater availability of light in an increasingly open landscape. In addition, the summary diagram (Fig. 3b) shows a reduction in arboreal pollen to ca. 80%, which suggests the existence of openings in the canopy (*sensu Aaby 1988; 1994*). Large-scale landscape clearance is apparent from 2300 cal BP and herbaceous types increase. Accumulation of organic deposits began at 2300 cal BP with the onset of eutrophication and the transition to the gyttja phase of sedimentation. At this time, the forest in the catchment was composed of *Abies-Fagus* forest with *Picea, Pinus* and *Quercus* and a greater (ca. 40%) non-arboreal component dominated by Poaceae and Cyperaceae.

The forest clearance at 2300 cal BP represents the first large-scale landscape disturbance and the first reliable appearance of 'anthropogenic indicators' (*Behre 1981; 1986*). Increases in Poaceae, Cyperaceae and Filicales palynomorphs reflect the expansion of non-arboreal vegetation within the catchment which, nonetheless, was floristically poor. The expansion of *Cannabis* -type pollen in the sequence includes *Humulus lupulus* and *Cannabis sativa*, which are palynologically indistinguishable. Both types are used for fibre production (*Polunin 1980; Mabberley 1997*), although the primary use of *Humulus* is in brewing.

However, Godwin (*1967*) suggests that as only the female infructescence of *Humulus* is used for brewing, female plants are selectively cultivated and the pollen is scarce. Therefore pollen of *Cannabis*-type is more likely to represent *Cannabis sativa* than *Humulus lupulus*. An expansion of this magnitude can be taken to represent either pollen deposition from a large stand growing nearby or retting of fibres in the lake (*Bradshaw et al. 1981; Willis et al. 1998*). *Cannabis* will not grow in large stands unless cultivated (*Polunin 1980; Clapham et al. 1987*) so it is reasonable to assume that both processes were active.

The range of economically important taxa present in the pollen assemblage from 2300 cal BP is surprisingly poor in consideration of the number and density of archaeological settlements in the region (*Bregant et al. 1980*). Other than those taxa mentioned above, the only crops present in more than trace abundance are represented by pollen of cereal-type, *Fagopyrum, Apiaceae* and *Brassicaceae*, and of those, none reach 5% of the total terrestrial pollen. In addition, arboreal pollen remains at ca. 50% from 2300 cal BP to the present day. Surface samples taken from the sediment-water interface (*Gardner 1998*) display a similar pollen assemblage, with low values of crop pollen and a total arboreal pollen value of 48%. The only marked difference is a higher proportion of *Fagopyrum* and the total absence of *Cannabis*-type pollen. Thus the present day landscape was formed ca. 2300 cal BP.

DYNAMICS OF HOLOCENE ENVIRONMENTS IN SOUTH EAST EUROPE

Theoretical Framework

In the Holocene palaeoecological record of southeast Europe there appear three dominant phases of environmental change (*Gardner 1999*):

1. Early Holocene   'primary' forest development; recolonisation of the landscape by forest upon climatic improvement; rapid change characterised by high species turnover.

2. Mid Holocene   'secondary' forest development; maturation of the forest soils and canopy structure; expansion of the dominant forest taxon.

3. Late Holocene large-scale forest clearance by human populations; high species diversity, essentially static equilibrium achieved.

Each of these three phases is characterised by regional differences in floral composition and timing of events, but the broad explanation for the mechanisms of change is simple. In the early Holocene, the magnitude of climatic events exerted a greater influence upon the environment than did any aspect of human activity. Thus, the rapid environmental change recorded for the early Holocene in southeast Europe was driven by climate. Conversely, the late Holocene was characterised by a comparatively stable climate and exploitation of the environment by human populations which exceeded climatic forces in driving environmental change. However, in the mid Holocene, a combination of climatic factors and steadily increasing human impact produced a palaeoenvironmental signal which is complex and extremely difficult to define (*Birks & Line 1993*).

Explaining the mechanisms of change

The dramatic environmental change apparent in the early Holocene phase was driven entirely by an increase in summer temperatures of 4–10°C between 12 and 9ka BP (*Kutzbach & Guetter 1986; Kutzbach et al. 1993*). All other factors relating to environmental change during this period are linked to increased temperature, in particular moisture availability (*Willis 1994; Bennett & Willis 1995*) and soil development (*Pennington 1986; Willis et al. 1997*). Expansion of primary forest at the onset of the Holocene in southern Europe occurred in response to climate change and was characterised by a rapid succession from raw mineral soils supporting coniferous parkland to a mixed deciduous forest on organic soils, characterised by high variability and high species turnover (*Bennett & Willis 1995*).

The mid Holocene phase of south-east Europe is characterised by floristic stability, with the development of a secondary deciduous forest of usually one dominant taxon (e.g. *Carpinus* sp. in Greece, *C. betulus* in Bulgaria, *Quercus ilex* in Croatia and *Fagus* in Slovenia – *Willis 1994 and references therein*) which persists to the present day, albeit in reduced importance. This phase is eloquently summarised by Bennett & Willis (*1995*) as *pattern 2* of their scheme for Holocene vegetational development. In climatic terms, the mid Holocene forest developed during an optimum growth period when temperatures were

2°C higher than present (*Huntley & Prentice 1993*) and humidity more suitable for dense deciduous woodland (*sensu Magri 1996*). In human terms, the mid Holocene forest matured at a crucial point in the establishment of sedentary societies in southeast Europe who, in addition to growing arable crops, exploited the forest for raw materials, fuel, pasture, fodder and wild food resources.

The late Holocene phase is characterised by almost complete domination by human activity as an environmental driving mechanism. Climatic forces remained very much in evidence and periodic oscillations such as the Little Ice Age from ca. AD 1590–1850 (*Lamb 1977*) were of sufficient magnitude to cause local re-advance of Alpine glaciers (*Grove 1988*). However, increasingly intensive land-use from the late Bronze Age/early Iron Age (ca. 3ka BP) onwards initiated irreversible soil erosion (*van Andel et al. 1990; Halstead 1996*), a reduction of 50% of global forest cover (*Birks & Line 1993*) and the expansion of arable field and meadow plant communities.

Synthesis of Mid Holocene Human Impacts

The dominant driving forces behind early and late Holocene environmental change are undoubtedly climatic and human agencies respectively, but the situation for mid Holocene environmental change is not so clearly defined. Climatic change alone cannot account for the subtle changes in forest composition evident in this study, yet other than the proximity of known archaeological sites, there is no evidence from the sedimentary or charcoal records to suggest a dominantly human origin for these changes.

Comparison of the characteristics of Holocene forest species decline with long pollen sequences from previous warm stages serves as a guide to unravel human impacts from natural processes. Several such sequences exist in southern Europe (e.g. *Ioannina (Tzedakis 1993; 1994)* and Tenaghi Phillipon (*Wijmstra 1969; van der Wiel & Wijmstra 1987a; 1987b*) in Greece; Valle di Castiglione (*Follieri et al. 1988*) in Italy; and Les Echets (*de Beaulieu & Reille 1984*) and La Grande Pile (*Woillard 1978; de Beaulieu & Reille 1992*) in France), each of which extend back to at least the oxygen isotope stage 5e (Eemian interglacial) and reveal the development of a forest assemblage composed of ecological groups which bear striking similarities to those seen in the Holocene of south-east Europe. The distinction should be made that species may or may not adopt the same

positions in previous warm-stages as they do in the Holocene or may be totally absent (*Bennett & Willis 1995*) (cf. *Fagus* at Ioannina and *Carpinus betulus* at Les Echets and La Grande Pile*)*, but the overall ecological classification (e.g. temperate deciduous, boreal etc.) is similar. Therefore, at the onset of each warm-stage a coniferous woodland assemblage existed which changed rapidly to a mixed temperate deciduous forest. This was followed by a mature 'secondary' forest with a dominant broad-leaved taxon which developed by the middle of each stage.

All of the mid warm stage forest phases from the long terrestrial sequences outlined above are terminated by the expansion of cold tolerant forest elements (e.g. *Picea* or *Pinus)* over secondary deciduous taxa, thus completing the 'interglacial cycle' (*Birks 1986*). In no instance is there a shift in forest composition as seen in the Podpeško Jezero sequence (Figs. 4a–b) and no secondary expansion of advantageous taxa such as *Corylus*. Similarly, the nature of the transition to secondary forest at Sirok Nyírjes Tó whereby a *Corylus* dominated forest (which has no modern analogue) is punctuated by cycles of *Carpinus betulus* (the secondary forest dominant) expansion is not apparent in any of the long sequences. The implication of underlying climatic trends producing distinct ecological phases in warm-stage forest development serves as a guide in evaluating the additional external factors experienced during the mid Holocene. Thus, although a climatic cause could possibly produce the change in forest composition at these sites, it is not apparent in previous warm stages and, given the presence of agricultural communities, is more likely to have resulted from human activity.

Comparing the Evidence

The on-going excavations at Breg have revealed lithic and ceramic evidence for Mesolithic and early Neolithic occupation of Ljubljana Moor and biological analyses in progress are expected to produce data on subsistence strategies (*M. Budja, personal communication, 1999*). Similarly, excavations at Maharski Prekop (*Bregant 1974a; 1974b; 1975*) have revealed the full range of crops and animals used by the inhabitants of the region and have demonstrated a community reliant on arable agriculture, but which maintained important livestock herds and continued to exploit wild resources. In contrast, there is no firm palaeoecological evidence for Neolithic arable agriculture in any of the available sequences for the area (*e.g. this study; Culiberg & Šer-*

celj, 1978a; 1978b; Andrič, 1997). Similarly, archaeological excavations of the nearby Tarnabod tells have revealed a typical ALP assemblage comprising a full range of domesticated plant and animal remains (*Kalicz & Makkay 1977*) which is not recorded in the Tarnabod palaeoecological sequence (*Gardner 1999*). The attendant off-site sequences, Podpeško Jezero and Sirok Nyírjes Tó, do not display any evidence of arable farming activity from the pollen record (*sensu Behre 1981; 1986*) during these settlement phases, nor do they show any evidence of landscape instability from the sedimentological record. In contrast, both sites display a subtle suite of changes to the forest composition which are interpreted from this study to be a result of managed forest-use.

The forest-farming model of Carugati *et al.* (*1996*) has already been presented and serves as a useful scheme for visualising the changes apparent in a south-east European landscape during the early Neolithic, yet offers no cultural basis for the sequence of human activities suggested. Harris (*1996a; 1996b*) advances a more detailed conceptual model for plant and animal exploitation in which he proposes a multi-stage transition from dependence on wild resources to dependence on domesticated resources. For the plants he suggests two phases of cultivation in which initially small clearings are used for morphologically wild plants before intensive agriculture begins with fully domesticated crops. Similarly, an intermediate 'protection' phase is suggested by Harris (*1996a; 1996b*) to demarcate exploitation of wild animals and full domestication.

Harris' (*1996a*) model serves as a useful conceptual basis on which to explain the forest changes apparent in this study. Table 4 shows a development of the Harris model adapted to clarify proposed impacts on mature south-east European forest during the preliminary stages of Neolithic agriculture. Initial agriculture, both arable and pastoral, impinged on relatively untouched forest and influenced forest development to the extent that the composition changed and there was a shift in canopy dominance. Subsequent agricultural expansions introduced greater influence on the environment by a change to large-scale clearance practices, which did not introduce any clearance-abandonment cycles and allowed the partial recovery of certain forest elements (*sensu Iversen 1941*).

The scheme in table 4 can be fitted readily to the sequences from Sirok Nyírjes Tó (Figs. 3a–b) and Pod-

Wild food procurement	Food production		
	wild plants and animals important as food		domesticated food production dominant
Gathering and collecting	Cultivation • small clearances • minimal tillage		Agriculture • large clearances • increased tillage
Hunting Scavenging Fishing	Livestock keeping • pasture • forest grazing and browsing		Livestock raising • transhumance • nomadic pastoralism
Decreasing dependence on wild resources			
Increasing dependence on domesticated resources			
forest virtually unmodified	forest thinned; compositional change	partial recovery of forest	large scale landscape clearance

Tab. 4. Conceptual basis for evolution of agricultural systems and attendant impacts on forested environments (modified from Harris, 1996a; 1996c). Note that individual phases are not rigid and the entire scheme is temporally flexible.

peško Jezero (Figs. 4a–b) and serves to illustrate the extent of activity occurring within the catchments. In both cases the basal 'Harris zone' is relatively pristine forest, more or less unaffected by human activities. Previous work (*Mellars 1975; Simmons & Innes 1996*) has proposed forest firing by Mesolithic populations as a strategy for hunting success, although Rackham (*1980*) has discredited such theories on account of the incombustibility of temperate deciduous forest. Despite the excavations at Jászbérény (*Kertész et al. 1994*) in Hungary and Breg (*Chapman & Müller 1990; Budja 1997*) in Slovenia demonstrating Mesolithic occupation of the two study regions, there is no evidence from charcoal records or pollen data to suggest Mesolithic manipulation of forest. Therefore, the early Holocene forest at both sites can confidently be termed 'pristine'.

The second 'Harris zone' reveals two different manifestations of forest thinning. The Sirok sequence (Fig. 3b) shows a pollen assemblage interpreted as the forest response to a coppice regime, demonstrated by a high rate of change and fluctuations in *Corylus* and *Carpinus betulus*. Plant food produc-

tion occurred on the fertile terraces of the *Alföld* adjacent to the ALP settlements, as did pasture for livestock. At Podpeško Jezero, (Fig. 4b) repeated cycles of clearance for small cultivation or pasture plots are suggested in this study to have caused a shift in the composition of the forest canopy as a result of competitive interactions between tree species. Suitable land for cultivation was available on Ljubljana Moor, but this was probably under extreme pressure as a result of loss of low-lying land to unpredictable floods.

At Sirok and Podpeško Jezero the forest recovered partially as the smaller scale disturbance became more restricted. At Sirok, abandonment of coppicing initiated further development of secondary forest, leading to the expansion of *Fagus*. At Jezero, the *Abies-Fagus* forest recovered slowly and was interrupted by a phase of *Carpinus betulus* as changing hydrological conditions on Ljubljana Moor permitted greater exploitation of the land surface there.

The final phase of the Harris scheme occurs ca. 2000 BP at Sirok and Podpeško Jezero, during large-

scale landscape clearance. However, *Quercus* expands during this stage at Sirok and the total forest cover at both sites remains at 50%. Results from this study suggest that extensive settlement of both regions by Iron Age agricultural communities has resulted in widespread disruption of the natural environment and the establishment of the modern landscape.

Thus, the adoption of a modified 'Harris' model for Neolithic activity can be used to account for the environmental changes recorded in the palaeoecological sequences from Sirok Nyírjes Tó and Podpeško Jezero. No model is infallible, yet the Harris model serves to place the small scale palaeoecological changes observed at the two sites into a tangible archaeological context.

CONCLUSION

Palaeoecological models previously proposed to explain the earliest human activity are considered unsuitable for characterising the environmental response to Neolithic agriculture in Hungary and Slovenia. Such models over-emphasise the ability of Neolithic communities to change their environment and suffer problems concerning sampling resolution and chronology. Archaeological models fare better in terms of temporal resolution, but include few considerations of forest dynamics or broader environmental concepts. A new scheme, based on the existing 'Harris' archaeological model, is presented in an attempt to classify changes apparent in this study according to the human activity apparent from the archaeological record. By application of this model, it is evident that the environmental response to Neolithic activity is complex and can not be represented by simple models of forest clearance and arable field expansion. Consideration of contemporary ecological research is crucial to deciphering pollen signals of forest use by prehistoric societies, and by adopting appropriate methods and models suitable for unique geographical situations, a more realistic impression of human-environment interaction may be gleaned.

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