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ARHEOBOTANIČNE RAZISKAVE NA NAJDIŠČIH Z LJUBLJANSKEGA BARJA

DOKTORSKA DISERTACIJA

ARCHAEOBOTANICAL INVESTIGATIONS AT THE SITES OF LJUBLJANSKO BARJE, SLOVENIA

DOCTORAL DISSERTATION

Ljubljana, 2011

Doktorsko delo je zaključek Doktorskega študija bioloških in biotehniških znanosti, področje biologija na Biotehniški fakulteti Univerze v Ljubljani. V okviru programa mlade raziskovalke je bilo raziskovalno delo opravljeno na Inštitutu za arheologijo Znanstveno raziskovalnega centra Slovenske akademije znanosti in umetnosti v Ljubljani, pod vodstvom mentorja MR dr. Antona Veluščka. Na Oddelku za lesarstvo Biotehniške fakultete v Ljubljani so bile opravljene dendrokronološke analize arheološkega lesa pod vodstvom mentorice podiplomskega študija prof. dr. Katarine Čufar. Na Institut für Prähistorische und Naturwissenschaftliche Archäologie (IPNA) v Baslu (Švica) pa je bila pod vodstvom prof. dr. Stefanie Jacomet opravljena identifikacija makrorastlinskih ostankov.

Na podlagi Statuta Univerze v Ljubljani ter po sklepu Senata Biotehniške fakultete in sklepa Senata Univerze v Ljubljani z dne 25.01.2007 je bila 09.08.2007 izdana odločba o sprejetju teme disertacije. Komisija za podiplomski študij Oddelka za biologijo je za mentorico doktorskega dela imenovala prof. dr. Katarino Čufar.

Komisija za oceno in zagovor:

Predsednik: prof. dr. Nejc Jogan

Član: prof. dr. Katarina Čufar

Član: doc. dr. Anton Velušček

Član: prof. dr. Stefanie Jacomet

Datum zagovora: 13.10.2011

Podpisana se strinjam z objavo svoje naloge v polnem tekstu na spletni strani Digitalne knjižnjice Biotehniške fakultete. Izjavljam, da je naloga, ki sem jo oddala v elektronski obliki, identična tiskani verziji.

Naloga je rezultat lastnega raziskovalnega dela.

Tjaša Tolar

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AI Primerjali smo tri različne metode dela tretiranj z arheobotaničnimi ostanki iz z vodo prepojenih neolitskih sedimentov. M1 je vključevala grobo spiranje preko sit in kasnejše sušenje makrorastlinskih ostankov, M2 grobo spiranje in ohranjanje frakcij s sit v mokrem mediju in M3 nežno spiranje z vodo, pri čemer smo uporabili najmanjše sito z velikostjo odprtin 0,355 mm in pregledovali vzorce v mokrem mediju. Samo M3, ki je v ostalih evropskih laboratorijih že vpeljana, je dala reprezentativne rezultate. M3 je bila uporabljena pri raziskovanju pozno neolitske jezerske naselbine Stare gmajne na Ljubljanskem barju (SG), in nam omogočila odkritje 93 rastlinskih taksonov. Prvič s slovenskih predzgodovinskih najdišč so bili odkriti nezogleneli ostanki lanu (*Linum usitatissimum*) in različnih vrst pšenice (*Triticum*). Prepoznali smo najpomembnejše kulturne rastline: *Triticum dicoccum*, *Hordeum vulgare*, *T. monococcum*, *Linum usitatissimum*, *Papaver somniferum*. Primerjava SG s sočasnimi naselbinami severno od Alp (SA) je pokazala, da *Triticum durum/turgidum*, ki je pogosto najdena na najdiščih SA, na SG ni bila odkrita. Nasprotno pa sta *Trapa natans* in *Vitis vinifera* ssp. var. *sylvestris* pogosto najdeni na SG in redko ali sploh ne na najdiščih SA. Ker je natančno datiranje ključnega pomena pri primerjavah med najdišči, smo uporabili dendrokronološke in radiokarbonske metode za datiranje slovenskih kolišč. Ugotovili smo, da so SG obstojale okoli leta 3332 pr. n. št. in bile ponovno naseljene v obdobju med 3160 in 3109 pr. n. št. Med pomembnejšimi najdbami smo predstavili sekiro, ki je bila narejena iz uvoženega kamna. Ostanek lesenega ročaja v njej je bil narejen iz lesa drena (*Cornus* sp.), ki pa je najverjetneje rasel v bližini kolišča. Na kolišču Hočevarica, ki je datirano v 37./36. stoletje pr. n. št., smo našli najstarejše grozdne pečke pri nas, ki so bile najverjetneje semena divje vinske trte.

KEY WORDS DOCUMENTATION

DN	Dd
DC	561:902.6(497.4Ljubljansko barje)(043.3)=163.6
CX	archaeobotany/dendrochronology/Ljubljansko barje/identification/dating
CC	
AU	TOLAR, Tjaša
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P	SI – 1000 Ljubljana, Večna pot 111
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TI	ARCHAEOBOTANICAL INVESTIGATIONS AT THE SITES OF LJUBLJANSKO BARJE, SLOVENIA
DT	Dissertation thesis
NO	IX, 90 p., 1 fig., 10 ann., 56 ref.
LA	sl
AL	sl /en

AB We compared three different archaeobotanical recovery techniques for waterlogged Neolithic sediments. M1 included rough wet-sieving and subsequent drying, M2 rough wet-sieving and keeping the fractions wet, and M3 gentle washing with the smallest sieve mesh size of 0.355 mm and sorting of macroremains in wet state. Only M3, which is already widely used in other European laboratories, gave representative results. M3 was used at the late Neolithic lakeshore settlement Stare gmajne at Ljubljansko barje (SG), and helped us to identify 93 plant taxa. Uncarbonised remains of *Linum usitatissimum* and various species of *Triticum* were determined for the first time at a prehistoric site in Slovenia. The most important cultivated plants were *Triticum dicoccum*, *Hordeum vulgare*, *T. monococcum*, *Linum usitatissimum*, *Papaver somniferum*. Comparisons between SG and contemporaneous settlements north of the Alps (NA) showed that *Triticum durum/turgidum* that is frequently found at NA was not found at SG. On the other hand, *Trapa natans* and *Vitis vinifera* ssp. *sylvestris* were frequent at SG and rare or absent at NA. Since exact dating is essential for comparisons between sites, we used dendrochronology and radiocarbon wiggle-matching for dating of the sites of our archaeobotanical investigations. We found out that SG existed around 3332 cal BC and was resettled in the period from 3160 to 3109 cal BC. Among the specific artifacts we presented an axe, which was made from imported stone and has a wooden handle made of *Cornus* sp. that possibly grew in the vicinity of the dwelling. At the settlement Hočevarica dated to the 37th/36th century BC, we found the oldest *Vitis vinifera* pips in Slovenia, which were most likely seeds of a wild grape vine.

KAZALO VSEBINE

KAZALO SLIK

str.

KAZALO PRILOG

str.

OKRAJŠAVE IN SIMBOLI

ZRC SAZU - Znanstveno raziskovalni center Slovenske akademije znanosti in umetnosti
IPNA - Institut für Prähistorische und Naturwissenschaftliche Archäologie, Basel, Švica
SG – Stare gmajne (ime najdišča-kolišča)
HOC – Hočevarica (ime najdišča-kolišča)
MP – Maharski prekop (ime najdišča-kolišča)
CR – Črešnja pri Bistri (ime najdišča-kolišča)
SM – Spodnje mostišče (ime najdišča-kolišča)
VO – Veliki Otavnik (ime najdišča-kolišča)
BB – Blatna Brezovica (ime najdišča-kolišča)
SA – najdišča severno od Alp
NA – north Alpine sites
M1 – metoda 1
M2 – metoda 2
M3 – metoda 3
Q4, 5, 9 – kvadranti v izkopani sondi
pr. n. št. – pred našim štetjem
n. št. – našega štetja
BC – before Christ
BP – before present
SI – Stummer index

ZNANSTVENI ČLANKI

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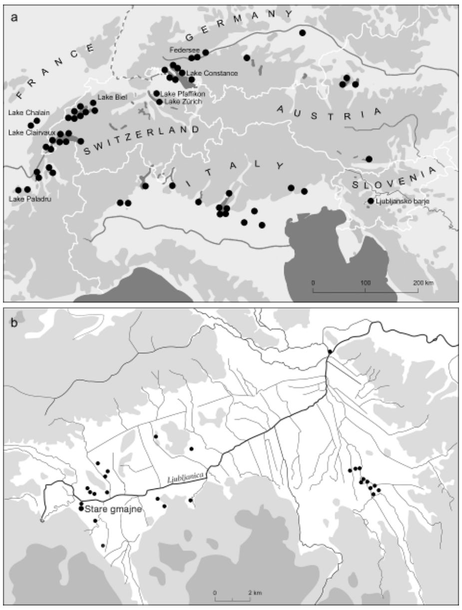
1 UVOD

1.1 OPREDELITEV PROBLEMA

Ljubljansko barje je bogato s prazgodovinskimi najdbami (Velušček, 1997), ki so se ohranile zaradi mokrih in ilovnatih tal. Organski arheološki (predvsem rastlinski) ostanki se lahko dobro in dolgo ohranjajo v okoljih, kjer je možnost razvoja gliv in bakterij zaradi pomanjkanja kisika zmanjšana (n. pr. Jacomet in Kreuz, 1999). Tudi kemično in fizično se organski ostanki spreminjajo zelo počasi (n. pr. Lowe in Walker, 1997). V vodi, močvirjih, glinenih plasteh i. pd., kjer preživetje mikroorganizmov omejuje pomanjkanje kisika, se sčasoma lahko začne proces fosilizacije, kjer se substance celične stene spremenijo v visoko kondenzirane snovi, kasneje pa se mineralizirajo (Fengel, 1991).

Koliščarji so na Ljubljanskem barju živeli v obdobju mlajše kamene, bakrene in bronaste dobe (t. j. od pribl. 4600 – 1700 pr. n. št.) (Velušček, 2004). To je čas začetkov udomačevanja živalskih in tudi rastlinskih (poljedelskih) vrst, zato so naravoslovne raziskave tovrstnih naselbin še posebej pomembne in zanimive. Poleg tega lahko le raziskave lesa ob uporabi dendrokronologije in radiokarbonskega datiranja omogočijo natančno datiranje naselbin.

Do danes je bilo na Ljubljanskem barju evidentiranih okoli 40 kolišč (Sl. 1b) (Velušček, 2004), ki v alpskem svetu predstavljajo najbolj jugovzhodno območje razprostranjenosti prazgodovinskih naselbin na mokrih tleh (»waterlogged sites«) oz. kolišč (Sl. 1a) (Schlichterle in Wahlster, 1986; Menotti, 2004; Velušček, 2004).



Slika 1: a) Lokacije pomembnejših obalpskih jezerskih naselbin (kolišč) v Evropi (prirejeno po: Schlichterle in Wahlster, 1986: Sl. 2) in b) lokacije pomembnejših kolišč z Ljubljanskega barja (po: Velušček, 2004: Sl. 5.1)

Na jugozahodu Ljubljanskega barja leži tudi bakrenodobno koliščarsko naselje Stare gmajne (Sl. 1b), ki je bilo slučajno odkrito leta 1992 (Velušček, 1997). Naselbina Stare gmajne je še posebej zaslovela po tem, ko so leta 2002 na njej odkrili leseno kolo z osjo (Velušček in sod., 2009), ki s starostjo najmanj 5100 let velja za enega najstarejših ohranjenih lesenih koles na svetu. Iz arheoloških sedimentov naselja Stare gmajne je bil v veliki večini pridobljen material za pričujočo disertacijo.

Glavni namen doktorske disertacije je bil raziskava lesa in ostalih makrorastlinskih ostankov (semen in plodov, dimenzij nad 0,355 mm) s kolišča Stare gmajne. Opravljene raziskave vključujejo: odvzem vzorcev s terena, pripravo dendrokronoloških in arheobotaničnih vzorcev, dendrokronološko analizo lesa, identifikacijo makrorastlinskih ostankov in obdelavo podatkov z interpretacijo.
V doktorskem delu se posvečamo tudi nekaterim specifičnim arheobotaničnim raziskavam, kot so na primer: identifikacija lesenih artefaktov (t. j. vrednejših arheoloških predmetov iz lesa), izolacija DNK, morfološka analiza semen in druge analize (n. pr. analize koprolitov, ostankov kuhane hrane v posodah, vlaken tekstila i. pd.), ki omogočajo še bolj poglobljen vpogled v življenje koliščarjev in njihovo poznavanje uporabnosti različnih rastlinskih vrst.

1.2 CILJI RAZISKOVANJA

Cilji doktorske disertacije so:

- preveriti uveljavljene metode arheobotaničnih raziskav na Ljubljanskem barju in v skladu s trenutno splošno sprejetimi svetovnimi standardi uvesti metodologijo, ki bo omogočila pridobitev reprezentativnih rezultatov, ki bodo primerljivi rezultatom raziskav na podobnih najdiščih severno od Alp,
- podati ugotovitve in rezultate arheobotaničnih raziskav ob uporabi standardiziranih metod in jih primerjati z rezultati, pridobljenimi na drugih evropskih naselbinah iz istega obdobja,
- absolutno datirati slovenska kolišča iz 4. tisočletja pr. n. št. s pomočjo dendrokronoloških in radiokarbonskih raziskav,
- vpeljati in ovrednotiti nekatere specifične raziskave v arheobotaniki, ki nam lahko podajo pomembne informacije o preteklih dogodkih.

1.3 DELOVNE HIPOTEZE

Glavne hipoteze doktorske disertacije so:

1. Pri dosedanjih raziskavah na prazgodovinskih arheoloških najdiščih kolišč z Ljubljanskega barja zaradi velikih količin materiala in omejenih metodoloških možnosti ni bil v celoti izkoriščen raziskovalni potencial makrorastlinskih ostankov. Izboljšava metod bo prinesla nova spoznanja o poljedelstvu, prehrani in rabi rastlin na naselbini Stare gmajne in na Ljubljanskem barju ob koncu 4. tisočletja pr. n. št.
2. Les s kolišč z Ljubljanskega barja vsebuje velik raziskovalni potencial. Izbira in raba različnih lesnih vrst pričata o interakciji človeka z okoljem v okolici naselbin in o

njegovem poznavanju lastnosti lesa in različnih tehnoloških postopkov. Dendrokronološka raziskava lesa skupaj z radiokarbonskim datiranjem omogoča absolutno datacijo obstoja posameznega kolišča in časovno relacijo do drugih kolišč iz 4. tisočletja pr. n. št. na Ljubljanskem barju in v Evropi. Datiranje je nujno za primerjavo sočasnih naselbin in interpretacijo rezultatov arheoloških raziskav.
3. Genetske in morfološke raziskave arheoloških semen so nam lahko v pomoč pri ugotavljanju začetkov kultivacije oz. udomačevanja rastlinskih vrst.

2 ZNANSTVENI ČLANKI

Raziskave v doktorski nalogi so predstavljene v 5 člankih, objavljenih v revijah, ki jih citira SCI oz. SSCI. Njihova vsebina se povezuje kot sledi:

2.1 NAČINI PREUČEVANJA SEDIMENTOV Z ARHEOLOŠKIH NAJDIŠČ NA MOKRIH TLEH: PRIMERJAVA RAZLIČNIH METOD DELA Z VZORCI IZ NEOLITSKIH JEZERSKIH NASELBIN (RECOVERY TECHNIQUES FOR WATERLOGGED ARCHAEOLOGICAL SEDIMENTS: A COMPARISON OF DIFFERENT TREATMENT METHODS FOR SAMPLES FROM NEOLITHIC LAKE SHORE SETTLEMENTS)

Tolar T., Jacomet S., Velušček A., Čufar K. 2010. Recovery techniques for waterlogged archaeological sediments: a comparison of different treatment methods for samples from Neolithic lake shore settlements. Vegetation History and Archaeobotany 19: 53-67

Članek predstavlja primerjavo različnih tretiranj (metod dela) z z vodo prepojenimi neolitskimi sedimenti, da bi ugotovili ali ob uporabi različnih metod pride do tega, da se deli ali nekateri tipi rastlinskih ostankov popolnoma uničijo ali pa manjkajo oz. so premalo zastopani zaradi uporabe neprimernih metod dela (tretiranj) z arheološkimi sedimenti. V okviru izkopavanj na približno 5200 let starem neolitskem kolišču Stare gmajne na Ljubljanskem barju, ki so potekala v letu 2007, smo primerjali tri metode dela za raziskovanje rastlinskih makroostankov: metoda 1 (M1), ki je vključevala grobo spiranje z vodo in kasnejše sušenje ostankov s sit; metoda 2 (M2), pri kateri smo grobo spirali z vodo in vzorce s sit hranili v mokrem stanju; in metoda 3 (M3), pri kateri smo sediment spirali nežno, s polflotacijo in vzorce s sit hranili v mokrem, z vodo napojenem, stanju. Izkazalo se je, da je M3 dala najboljše in najbolj reprezentativne rezultate. Bolj grobi metodi, M1 in M2 sta se izkazali kot neprimerni, saj so bila z vodo prepojena nezoglenela semena taksonov kot so n. pr. *Linum usitatissimum*, *Papaver somniferum* in *Brassica rapa*, ter z vodo prepojene nezoglenele žitne pleve in nežni perikarpi taksonov kot so n. pr. Maloideae in *Quercus* sp., ki so vsi zelo nežni in fragilni ter zato ob izsušitvi podvrženi propadu, premalo zastopani ali pa so v vzorcu povsem manjkali. Zato so bili vzorci, tretirani z M1 in M2, vrstno šibkejši, po drugi strani pa so bile rastlinske vrste z odpornejšimi in lignificiranimi rastlinskimi tkivi v stenah semen/plodov, kot so n. pr. *Cornus mas*, *Corylus avellana* ali *Rubus* sp. zastopane v večjem (prevelikem) številu. Uporaba M3 nam je pomagala, da smo na slovenskih koliščih prvič identificirali nezoglenele ostanke lanu

(*Linum usitatissimum*) in različnih vrst pšenice (*Triticum*). Študija kaže, da bi bilo potrebno metode v arheobotaniki standardizirati za raziskave po vsem svetu in še posebno po obalpskih koliščih v Evropi. Raziskava je pokazala, da je lahko spekter najdenih (identificiranih) rastlinskih vrst močno okrnjen, če se uporablja neprimerna metoda dela, še posebno kadar gre za z vodo prepojene arheološke sedimente, kakršni so na Ljubljanskem barju.

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ORIGINAL ARTICLE

Recovery techniques for waterlogged archaeological sediments: a comparison of different treatment methods for samples from Neolithic lake shore settlements

Tjaša Tolar · Stefanie Jacomet · Anton Velušček · Katarina Čufar

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Abstract This paper presents the first comparable overview of different recovery techniques used for waterlogged Neolithic sediments in the surroundings of the Alps in the last decades. Such an investigation became necessary because it was not known which parts of plants and types of remains were absent or completely underrepresented due to inappropriate recovery techniques in Slovenian archaeobotany up to 2006. During the 2007 excavation of the approximately 5,200 years old Neolithic pile dwelling site of *Stare gmajne*, Ljubljansko barje, Slovenia, we compared three methods for the investigation of botanical macroremains: method 1 (M1) included rough wet-sieving and subsequent drying of the fractions; method 2 (M2) rough wet sieving and keeping the fractions wet; and method 3 (M3) washing over and keeping the fractions wet. M3 with gentle washing, systematic subsampling, examination, and sorting of macroremains while wet, as well as using 0.355 mm as the smallest sieve mesh size gave the best results. When using the cruder M2 or M1 methods, waterlogged uncarbonized seeds of taxa such as *Linum usitatissimum, Papaver somniferum* and *Brassica rapa,* waterlogged chaff of Cerealia and pericarps of Maloideae and *Quercus* sp., which are all fragile, were underrepresented or even completely absent and therefore the plant spectra were strongly biased. On the contrary, taxa with lignified seed/fruit walls like *Cornus mas, Corylus avellana* or *Rubus* sp. were overrepresented when using the M2 and particularly the M1 method. The application of the M3, instead of the M1 method which has been traditionally used in Slovenian archaeobotany, helped us to identify uncarbonized remains of *Linum usitatissimum* and various species of *Triticum* for the first time in a waterlogged Neolithic site in Slovenia. Our study should contribute to a standardization of methods, which is desperately needed in archaeobotany. The study clearly shows that the plant spectra can be strongly biased if inappropriate handling techniques are used. The conclusions hold for all kinds of waterlogged sediments of different periods.

Keywords Waterlogged plant remains · Recovery techniques · Pile dwelling · Neolithic · Slovenia

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Introduction

The accuracy of the reconstruction of past environments and people/plant relationships heavily depends on the quality of the botanical remains and data recovered during the excavations, as well as on the quality of the analysis and interpretation of such data. The recovery of plant material on archaeological sites is influenced by specific preservation conditions (for example Willerding 1991; Van der Veen 2007), as well as by the selection of the appropriate sampling methods (for example Jacomet and Brombacher 2005 for Neolithic lakeshore settlements) and recovery techniques (for example Hosch and Zibulski 2003; Vandorpe and Jacomet 2007). It is also crucial to assess the loss due to taphonomic influence like carbonization or mineralization.

The main aim of this paper is to look at how different recovery methods for waterlogged sediments affect the representation of the types of remains and taxa and to discuss the implications of this information in terms of understanding the assemblages, as in Van der Veen (2007) which describes mainly differences between desiccated and carbonized plant remains. In this context, we will compare the method that has been traditionally applied in archaeobotany laboratories in Slovenia (Jeraj et al. 2009) and a slightly modified method with the procedure applied to waterlogged sites of the northern part of the Alpine foreland, mainly in Switzerland. The comparison of different methodologies can help to assess the quality of the results obtained as well as showing the biases that arise when sample treatment is not appropriate. An additional aim is to suggest a minimal volume of sediment samples that should be taken from the field to obtain a representative quantity of organic material in each of the fractions, such as for obtaining at least 384 identifiable plant remains for reconstructing the right proportions of the most important taxa with a probability of $95 \pm 5\%$, as proposed by Van der Veen and Fieller (1982).

The state of the art concerning the archaeobotany of Neolithic lake dwelling sites north of the Alps which existed between 4300 and 2400 cal B.C., was recently published by one of the authors (see Jacomet 2006, 2007, 2009; Jacomet and Brombacher 2005). One of the goals of this present study was therefore also to build a methodological basis for the comparison of Neolithic lake dwellings in Slovenia with those in the northern Alpine foreland.

Characteristics and formation processes of waterlogged archaeological plant assemblages, especially in Neolithic lake dwellings

Plant remains from the distant past can be preserved under water or in water-logged conditions for centuries or even for millennia. Waterlogging occurs when a material is deposited and preserved under the water table. This is the case for the prehistoric lake dwelling sites in the circumalpine region during the Neolithic (ca. 4300 to 2400 cal B.C.) and the Bronze Age (ca. 1900 to 800 cal B.C.), among others. Much archaeobotanical research on such sites has been carried out, above all North of the Alps (for example Jacomet et al. 1989; Maier 2001, 2004; Hosch and Jacomet 2001, 2004). Such sites have shown excellent preservation conditions for waterlogged plant materials. The decay of organic plant compounds in these sites has been hindered by continuous waterlogging, low temperatures in the soil and anoxic circumstances (Retallack 1984). Therefore, most of the plant remains seem to be more or less well preserved. Such finds may include several thousand identifiable items per litre and usually 20–50 taxa per sample of <500 ml (Jacomet et al. 1989). Preservation by waterlogging, as is also the case with desiccation (Van der Veen 2007), therefore allows a much greater insight into the diversity of plant use than on average dry land sites where in most cases only carbonized plant remains are preserved. If the conditions are favourable, fragile plant tissues may survive in an excellent state, and we may even encounter green leaves when digging out freshly waterlogged sediments.

Waterlogged cultural layers contain well preserved plant assemblages which are usually mixed deposits and consist of rubbish layers mixed with dung. They represent the former "living surface" and contain two types of plant materials: they consist partly of "secondary refuse", discarded material which had been used in some other place. Partly, however, we also observe a remarkable in situ preservation of the materials (Maier 2001; Hosch and Jacomet 2004; Jacomet 2004). Therefore, there is often evidence of discrete activities or "snapshots" of human or animal activity in waterlogged plant materials. There may be a distinct pattern in a cultural layer showing different activities (Maier 2001; Jacomet and Brombacher 2005).

Waterlogged plant assemblages include large amounts of remains connected to crop plant cleaning for the preparation of food and kitchen waste. Above all, the proportions of waterlogged cereal chaff in Neolithic lake shore settlements are high (Brombacher and Jacomet 1997). In addition, there may also be stored foods for humans and fodder for animals (Maier 2001; Hosch and Jacomet 2004), table waste and snack foods.

Besides human food there may also be remains of animal fodder, bedding, fuel, temper or building material, such as decaying wall plaster, insulation and roofing material. Such materials may include wood, mosses and also cereal straw and chaff. Animal dung and droppings as well as human faecal material, such as human coprolites from Neolithic lake shore settlements, are sources of plant material as well (Akeret et al. 1999; Kühn and Hadorn 2004; Maier 2001).

Finally, the remains of the local vegetation are present in the investigated layers as well. In the case of lake shore settlements, these remains may have been transported by water or they were just deposited where they grew (Jacomet 1985). They can help to identify the nature of the vegetation inside the settlement or in its immediate vicinity, and may show whether a layer was deposited in the water environment or on the land. It is important to make sure that the plant remains are contemporary with the investigated settlement.

Besides waterlogged plant remains (maybe over 90%), small amounts of well preserved carbonized remains are also encountered regularly in waterlogged lakeshore settlement layers. The fewer carbonized remains may reflect what is preserved when the conditions are not favourable for waterlogged preservation. In Neolithic waterlogged settlements on average 20–50 taxa are encountered in a waterlogged state and less than ten taxa in a carbonized state (Jacomet et al. 1989). More carbonized material may be present when settlements had burnt down, like in the charred layer AH1 of the site Hornstaad Hörnle 1 at Bodensee (Lake Constance), Germany, where large cereal stores with many whole ears were preserved in situ (Maier 1996, 2001).

Materials and methods

The investigation area

All major lake and marsh prehistoric settlements in Slovenia can be found within Ljubljansko barje (the Ljubljana Moor), which is situated at the edge of the south-eastern Alps, near Ljubljana, Slovenia (Fig. 1). It covers an area of 163 km^2 (Lah and Adamič 1992) and is rich in Neolithic pile dwelling settlements that existed from the first half of the fifth millennium B.C. (Čufar and Korenčič 2006) until the first half of the second millennium B.C. as revealed by dendrochronological investigations and radiocarbon dating (Velušček and Čufar 2002; Velušček 2004; Čufar and Velušček 2004). The selected site *Stare gmajne* is dated to the second half of the fourth millennium, around 3200 B.C. (Fig. 1; Velušček 2004).

The material

In 2007, a trench was excavated at *Stare gmajne*. It was 3 m wide, 5 m long and divided into 15 quadrants of 1 × 1 m^2. The cultural layer was 20–40 cm thick, its colour was dark brown to black with yellow clay patches, and it consisted of slightly clayey material with many waterlogged plant remains.

During the excavation, several sub-layers were distinguished. The samples for our comparative investigation come from the cultural layer between 288.87 m and 288.98 m (7th depth-cut) in Quadrants 5 and 9 (Q5, Q9). In total, six sediment samples were taken, two of 30 and four of 2 l, three from each quadrant, and each treated with a different method (see Table 1).

The 2 l samples for comparing different sieve mesh sizes were also taken from the same layer (7th depth-cut) but from the fourth quadrant (Q4; Table 2).

All methods included the same procedures of sampling in the field, subsampling in the laboratory, identification and counting.

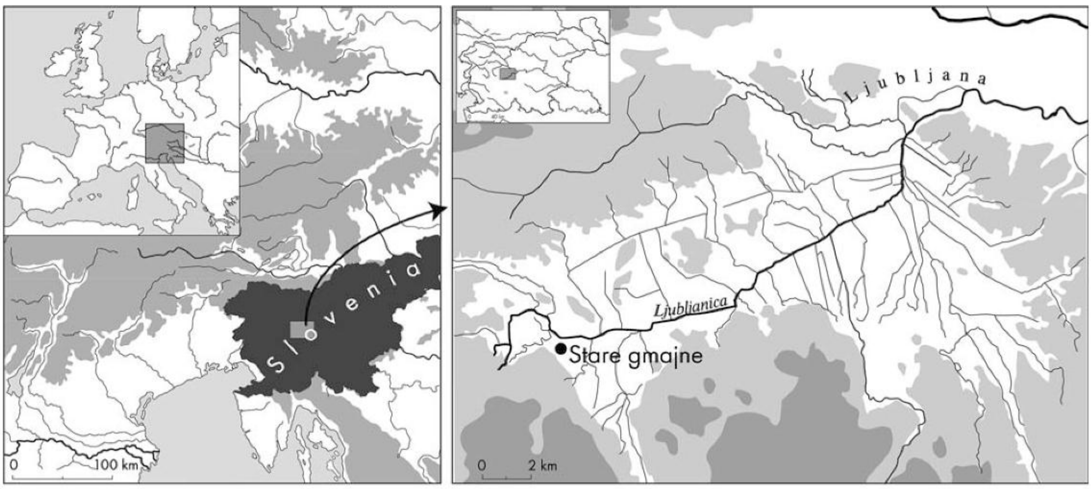


Fig. 1 Location of the Ljubljansko barje with the *Stare gmajne* Neolithic site, Slovenia

Table 1 Volumes of the sediment samples, organic fractions and examined subsamples for the compared methods: M1 dried, M2 rough wet, M3 wash-over

Method	Quadrant	Volume of the sediment samples (l)	Wet sieving method	Sieve mesh sizes (mm)	Volumes of the organic fractions (ml)		Storage	Volumes of the examined subsamples	
					Large fraction 3 mm	Small fraction 1 mm		Large fraction 3 mm (ml)	Small fraction 1 mm (ml)
M1	Q5	30	Rough	3; 1	400	150	Dry	400	25
M1	Q9	30	Rough	3; 1	500	200	Dry	450	25
M2	Q5	2	Rough	3; 1	150	70	Wet	150	25
M2	Q9	2	Rough	3; 1	180	35	Wet	180	25
M3	Q5	2	Wash-over	3; 1	280	225	Wet	280	25
M3	Q9	2	Wash-over	3; 1	530	320	Wet	260	25

Table 2 Volumes of the sediment samples, organic fractions and examined subsamples for the compared sieves with different mesh sizes: 3/1 mm (for Q5, Q9) and 2/0.355 mm (for Q4)

Method	Quadrant	Volumes of the sediment samples (l)	Wet sieving method	Sieve mesh sizes (mm)	Volumes of the organic fractions (ml)		Storage	Volumes of the examined subsamples (ml)	
					Large fraction 3 mm	Small fraction 1 mm		Large fraction 3 mm	Small fraction 1 mm
M3	Q5	2	Wash-over	3; 1	280	225	Wet	280	25
M3	Q9	2	Wash-over	3; 1	530	320	Wet	260	25
M3	Q4	2	Wash-over	2; 0.355	280	300	Wet	160	25

Method 1: rough wet sieving and subsequent drying (M1)

The first method, M1 or dry method was the one which was used in Slovenian laboratories until 2006 (Jeraj 2004; Culiberg 2006). The collected 30 l sediment samples were washed on two different sieves with 3 and 1 mm mesh sizes. The washing was done in the field as fast as possible with very rough washing and hand kneading of the clay material (Table 1; Fig. 2a).

After washing the sediment, the fractions were dried. The material was easy to store in a dry state, and the materials like bones, ceramic artefacts, charred plant remains (charcoal, cereal grains and chaff) and seeds/fruits with hard and lignified outer layers (*Rubus fruticosus, Corylus avellana* etc.) could be quickly picked out (Fig. 2b).

Before our analysis started, a systematic subsampling of both fractions was done (Table 1). Subsamples of 400–450 ml of the large fraction held on the 3 mm sieve and 25 ml of the small fraction on the 1 mm sieve were examined separately. These volumes gave a reliable minimal number of items in both fractions, that is, at least 384 identifiable plant remains in each fraction (Van der Veen and Fieller 1982).

Method 2: rough wet sieving and keeping the fractions wet (M2)

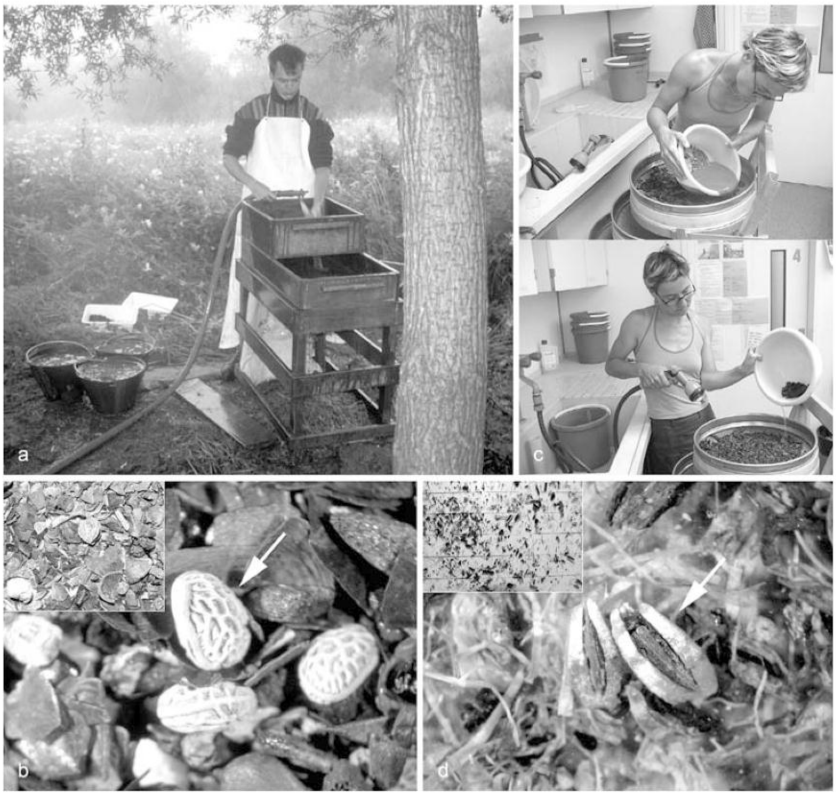
The second method, M2 or rough wet method, comprised the sieving of 2 l sediment samples in the same way as in M1 (Fig. 2a), but afterwards the collected material that remained on the 3 and 1 mm sieves was not dried (Table 1). This modification was done to find out which organic material (plant remains) was lost because of drying. The wet fractions were kept in airtight bags before the analysis was carried out. Sorting and counting were also done while the material was wet (Fig. 2d).

The subsampling was done only for the small fractions; just as in M1, 25 ml subsamples were taken and analysed (Table 1). The whole large fractions, 150 ml in Q5 and 180 ml in Q9, had to be examined, because the 2 l sediment samples taken from the field were not large enough to reach the required number of 384 identifiable plant remains (Van der Veen and Fieller 1982; Table 1).

Method 3: wash-over (flotation) and keeping the fractions wet (M3)

The third method, M3 wash-over, was described by Kenward et al. (1980) for waterlogged sediments of medieval

Fig. 2 The applied methods: **a** rough washing in the field (M1, M2); **b** dried material after sieving (M1) with hard and lignified (dried) fruit (small endocarp) of *Rubus fruticosus*; **c** gentle washing-over (M3); **d** wet material (M2, M3) with fragile and soft (waterlogged) fruit (mericarp) of *Oenanthe aquatica*



York and has been used since then in several European laboratories as at Wiesbaden by A. Kreuz and at Basel by S. Jacomet. It involves gentle washing with a sort of flotation, called wash-over (Fig. 2c). After washing the fraction of the macroremains is kept wet during all phases of work including subsampling, examination, sorting and finally storing. It was applied in the lake dwellings area in the 1990s (see mainly Hosch and Zibulski 2003). Using this method, the organic material was gently separated from the inorganic. Before sorting and counting of plant remains in water, a systematic subsampling, especially for the small fractions was necessary (see Table 1). The wet organic remains were stored and sorted in water (Table 1; Fig. 2d).

Sieve mesh sizes

In order to define which sieve mesh size is best for obtaining most of the taxa, especially for the economically important ones, the 2 l sediment samples from Quadrant 4, which were also from the 7th depth-cut, were washed in the laboratory of the Institute for Prehistory and Archaeological Science (IPAS) in Basel, where sieves with 2 and 0.355 mm mesh sizes are normally used for waterlogged sediments. For comparison, we used sieves with mesh sizes of 3 and 1 mm which were usually used in the laboratories in Ljubljana for sieving 2 l sediment samples from Quadrants 5 and 9 (7th depth-cut). In both cases the M3 wash-over method was used (Table 2).

Identification and counting

Before sorting, we defined the types of the remains which were counted as one piece ("counting units") to make sure that our target number of 384 items per fraction contained comparable remains; for justification of counting 384 remains per fraction and not per sample, see Hosch and Jacomet (2001). For cereals, we considered Hillman et al. (1996) and for other remains the system used in the Basel laboratory (Table 3; Hosch and Jacomet 2004).

When there were more than 384 plant remains in the whole examined volume, the examination of the subsample was concluded (Tables 1, 2; Van der Veen and Fieller 1982). If this was not the case as in most of the large

Table 3 Types of the remains used for identification of different taxa which were counted as 1 piece

Type of remain ("counted unit")	Identification of taxa
Whole seed/fruit and grain	All taxa
Grain fragments with embryo end	Cerealia
Glume base	Hulled *Triticum* sp.
Rachis fragment	*Hordeum vulgare*
Fragments of seed/fruit with the tip	e.g. *Cladium mariscus*
Fragments > 1/4 of a seed	Maloideae
Fragments > 1/4 of the pericarp	*Quercus* sp., *Fagus sylvatica*, Maloideae
Fragments > 3 mm of a seed/fruit	*Viscum album*
The base of the seed/fruit	*Quercus* sp., *Corylus avellana*, *Malus* sp., *Trapa natans*
Capsule fragments > 3 mm or capsule fragments with a tip	*Linum usitatissimum*

fractions (see Table 1), the subsample had to be enlarged and sorting and counting continued until more than 384 plant remains were counted or until we ran out of the material. The latter was the case in the samples of Q5 (M1 and M2, both large fractions) and Q9 (M2, large fraction; see Table 1; ESM Table S1; Table 4).

In order to assess the comparability of the results of the M1 dried and M3 wash-over treatments, we counted all the remains, including all the vegetative parts, in two 40 ml subsamples of the 3 mm and 10 ml of the 1 mm fractions from Quadrant 9, 7th depth-cut. On the basis of the results obtained, the various percentages of remain groups were calculated (Table 5).

For examining, sorting and identifying the material, we used a Leica MZ75 stereomicroscope with magnifications of 6.3–50. For precise identification of plant remains, the reference collection of IPAS, Basel, was used and special literature (Anderberg 1994; Cappers et al. 2006; Jacomet 2008; Berggren 1969, 1981).

Table 4 Summarized archaeobotanical record per Quadrants 4, 5 and 9 (Q4, Q5, Q9) and method (dry—M1, rough wet—M2, wash over—M3): total numbers of plant groups

Quadrant	4	5	9	4	5	9	4	5	9
Depth-cut	7	7	7	7	7	7	7	7	7
Cultural layer	3	3	3	3	3	3	3	3	3
Method	M1	M1	M1	M2	M2	M2	M3	M3	M3
Sample volume in litres before sieving	~16	?	?	2	2	2	1.5	2	2
Sediment type	Clay/org.	Clay/org.	Clay/org.	Clay/org.	Clay/org.	Clay/org.	Clay/org.	Clay/org.	Clay/org.
Large fractions									
Vol. of organic remains (ml) in the large fraction	400	400	?	110	150	180	280	280	530
Vol. of examined subsamples (ml) of the large fraction (ml)	90	400	450	110	150	180	160	280	260
Total cultivars	8	17	14	5			55	6	1
Total edible oleiferous seeds							8	4	7
Total legumes	1						2		
Total edible collected plants	20	164	288	30	44	53	206	284	351
Total plants growing outside the lakeshore		3	9			3	12	12	12
Total plants of the lakeshore and water plants	9	29	34	3	1	1	58	29	17
Overall Total	38	213	345	38	45	57	341	335	388
Small fractions									
Vol. of organic remains (ml) in the small fraction	?	150	?	25	70	35	300	225	320
Vol. of examined subsamples (ml) of the small fraction (ml)	25	25	25	25	25	25	25	25	25
Total cultivars	4.88	3.91	4.28	4	16	14	19	23	90
Total edible oleiferous seeds	1.49	0.37	2.05		3	4	129	28	43
Total legumes									
Total edible collected plants	13.39	63.80	18.60	67	60	209	34	53	70
Total plants growing outside the lakeshore	32.55	356.00	488.62	180	587	1,420	86	367	307
Total plants of the lakeshore and water plants	17.30	14.32	15.62	130	45	149	88	24	37
Overall total	69.61	438.41	529.17	381	711	1,796	356	495	547

Table 5 Comparison of the proportions of different remain groups, obtained by using method 1 (M1-dry) and method 3 (M3-wash-over) from Quadrant 9 (Q9), 7th depth-cut, by counting all the remains in a 40 ml subsample of the large fraction (3 mm mesh sieve) and a 10 ml subsample of the small fraction (1 mm mesh sieve), *T* thin-walled, fragile, *H* hard-walled, robust

	Types of remains	M1 dry *n*	M1 dry %	M3 wash-over n	M3 wash-over %
40 ml 3 mm	3 mm various plant remains T	174	97.8	600	86.2
40 ml 3 mm	3 mm total seeds/fruits T	2	1.1	26	3.7
40 ml 3 mm	3 mm total seed/fruit/needle fragments T	2	1.1	70	10.1
40 ml 3 mm	3 mm overall total T without varia	178	10.7	696	67.1
40 ml 3 mm	3 mm total stones and animal remains H	584		53	
40 ml 3 mm	3 mm total different plant remains (wood, charcoal) H	760		250	
40 ml 3 mm	3 mm total other remains H	1,344	94.5	303	89.1
40 ml 3 mm	3 mm total seed/fruit/needle H	32	2.3	24	7.1
40 ml 3 mm	3 mm total seed/fruit fragments H	46	3.2	13	3.8
40 ml 3 mm	3 mm overall total H without varia	1,422	85.8	340	32.8
40 ml 3 mm	3 mm varia T & H	57		1	
40 ml 3 mm	Total seeds/fruits T & H incl. varia	34	2.1	51	4.9
40 ml 3 mm	Total seeds/fruits fragments T & H incl. varia	105	6.3	83	8.0
40 ml 3 mm	Total other remains T & H	1,518	91.6	903	87.1
40 ml 3 mm	40 ml 3 mm overall total T & H incl. varia	1,657		1,037	
10 ml 1 mm	1 mm various plant remains incl. dung T	631		3,066	
10 ml 1 mm	1 mm total Insects T	3		12	
10 ml 1 mm	1 mm total other remains T	634	94.2	3,078	91.0
10 ml 1 mm	1 mm total seed/fruit/other T without varia	38	5.6	101	3.0
10 ml 1 mm	1 mm total seed/fruit/other fragments T without varia	1	0.1	204	6.0
10 ml 1 mm	1 mm overall total T without varia	673	15.1	3,383	66.2
10 ml 1 mm	1 mm total small stones H	29		52	
10 ml 1 mm	1 mm total animal remains (bones, scales etc.) H	1,403		560	
10 ml 1 mm	1 mm total various plant remains H	1,148		931	
10 ml 1 mm	1 mm total other remains H	2,580	68.7	1,543	89.7
10 ml 1 mm	1 mm total seed/fruit/other H without varia	1,160	30.9	157	9.1
10 ml 1 mm	1 mm total seed/fruit/other fragments H without varia	13	0.3	21	1.2
10 ml 1 mm	1 mm overall total H without varia	3,753	84.3	1,721	33.7
10 ml 1 mm	1 mm varia T & H	26		8	
10 ml 1 mm	Total seeds/fruits T & H incl. varia	1,198	26.9	258	5.0
10 ml 1 mm	Total seeds/fruits fragments T & H incl. varia	40	0.9	233	4.6
10 ml 1 mm	Total other remains T & H	3,214	72.2	4,621	90.4
10 ml 1 mm	10 ml 1 mm overall total T & H incl. varia	4,452		5,112	
3 + 1 mm	Overall total incl. varia	6,109		6,149	

Grouping of the taxa

The main table presents the main results of the archaeobotanical analysis resulting from all three processing methods (ESM Table S1). This shows the counts of all recognizable plant remains per quadrant, fraction and method (M1 dry; M2 rough wet; M3 wash-over), separately for each state of preservation (C, carbonized; N, uncarbonized; N/C, half-carbonized), including an indication of the robustness of the type of remain (for waterlogged remains: T, thin (fragile); H, hard, robust; T/H, thin to hard; C, carbonized). Other, mostly small fragments of plants like leaves, needles, roots, buds, wood fragments or mosses, etc. and parts of animals like bone fragments, fish scales, coprolites, etc. are marked as present in a semi-quantitative way (x, few; xx, small numbers; xxx, many; xxxx, very many and xxxxx, dominant).

For an easier interpretation of the results, the identified taxa have been divided into six plant groups, based on current ethnographic and ecological knowledge. This grouping is as detailed as considered necessary for our methodological approach: (1) cereals, (2) edible oleiferous seeds (cultivars and collected wild plants like *Brassica rapa*, *Linum usitatissimum*, *Papaver somniferum*), (3) legumes (*Pisum*), (4) edible collected fruits, nuts (like *Cornus*, *Corylus*, *Malus*, *Rubus fruticosus*, *Trapa natans* etc.), (5) plants growing outside the lakeshore area (like *Abies alba*, *Chenopodium* sp., *Silene* sp. etc.), (6) plants of the lakeshore and water plants (like *Alnus* sp., Apiaceae, *Carex* sp., *Cladium mariscus*, *Mentha* sp., *Lythrum salicaria*, *Potamogeton* sp., *Oenanthe aquatica*, *Sparganium* sp. etc.; see ESM Table S1; Table 4).

Results and discussion

Comparability of the results

The comparison of the counts in the subsamples of Quadrant 9 where all the remains were counted is shown in summary in Table 5; for details see ESM Tables S2 and S3.

The material which was kept wet and treated gently with the M3 method was not richer in plant remains than the M1 dried one in terms of numbers (Table 5). However, the composition of both fractions was completely different. In M3 wash-over, fragile plant remains with thin vegetative plant tissues, leaf fragments, waterlogged cereal chaff etc. were abundant with 66–67% for all the remains in both fractions (Table 5; Fig. 3). On the contrary, in M1, the dried sample, hard remains like animal bones, wood, charcoal, *Corylus* nutshells, *Chenopodium* fruits etc. were dominant with around 85% of all the remains in both fractions (Table 5, for details see ESM Tables S2, S3). Therefore, it can be concluded that different treatments lead to different spectra of the remains so that in M1 the dried fractions, a large part of the fragile remains had changed either into unrecognizable remains or into dust and had disappeared, whereas the hard lignified remains survived and were dominant.

The results for both sieve size fractions, 3 and 1 mm, are not different in terms of the proportions of thin- and hard-walled remains: in both fractions of the M1 treatment with drying, the proportions of the robust remains are around 85%, whereas in the fractions of the M3 wash-over treatment, these proportions are around 33% (Table 5; Fig. 3). The latter figure is the real proportion of the hard-walled remains in the samples. The hard-walled remains in the dried samples are therefore overrepresented there by more than 50%; their proportion is more than two to almost three times more than their real proportion, because a large part of the fragile remains had disappeared.

But not only are the proportions of the thin- and hard-walled remains different in individual treatment groups, the spectra of taxa also differ. In the 3 mm fraction almost all the thin-walled taxa remains are found in the M3 wash-over sample. In contrast, the difference between the two treatments is not that great when looking at the hard-walled remains (ESM Table S2). This might be due to the fact that

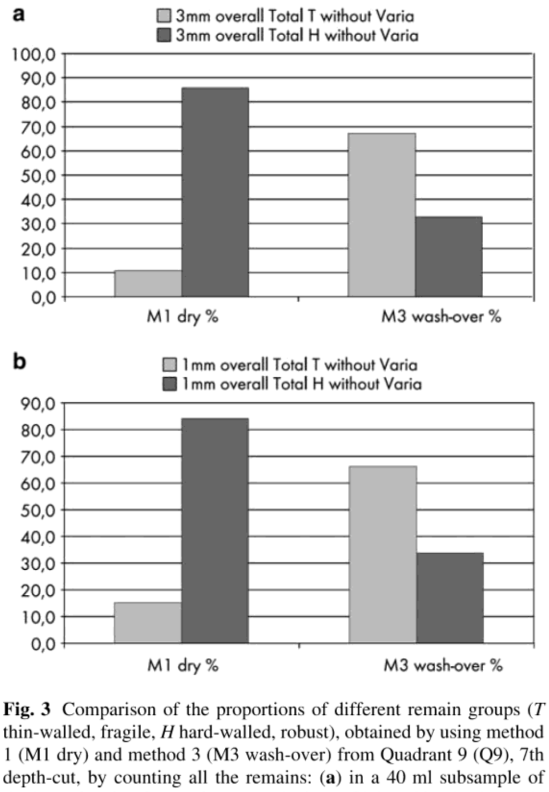


Fig. 3 Comparison of the proportions of different remain groups (*T* thin-walled, fragile, *H* hard-walled, robust), obtained by using method 1 (M1 dry) and method 3 (M3 wash-over) from Quadrant 9 (Q9), 7th depth-cut, by counting all the remains: (**a**) in a 40 ml subsample of the large fraction from a 3 mm mesh sieve; (**b**) in a 10 ml subsample of the small fraction from a 1 mm mesh sieve

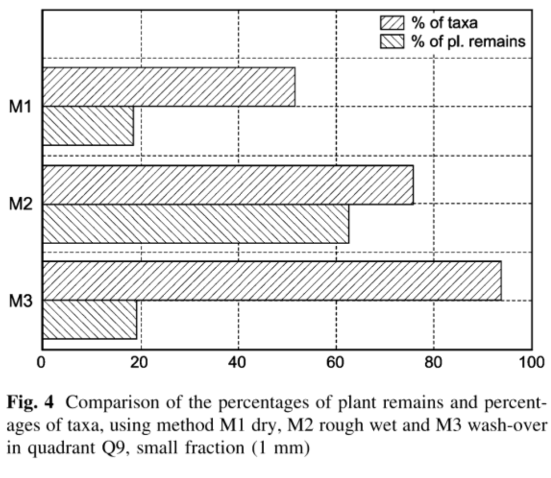


Fig. 4 Comparison of the percentages of plant remains and percentages of taxa, using method M1 dry, M2 rough wet and M3 wash-over in quadrant Q9, small fraction (1 mm)

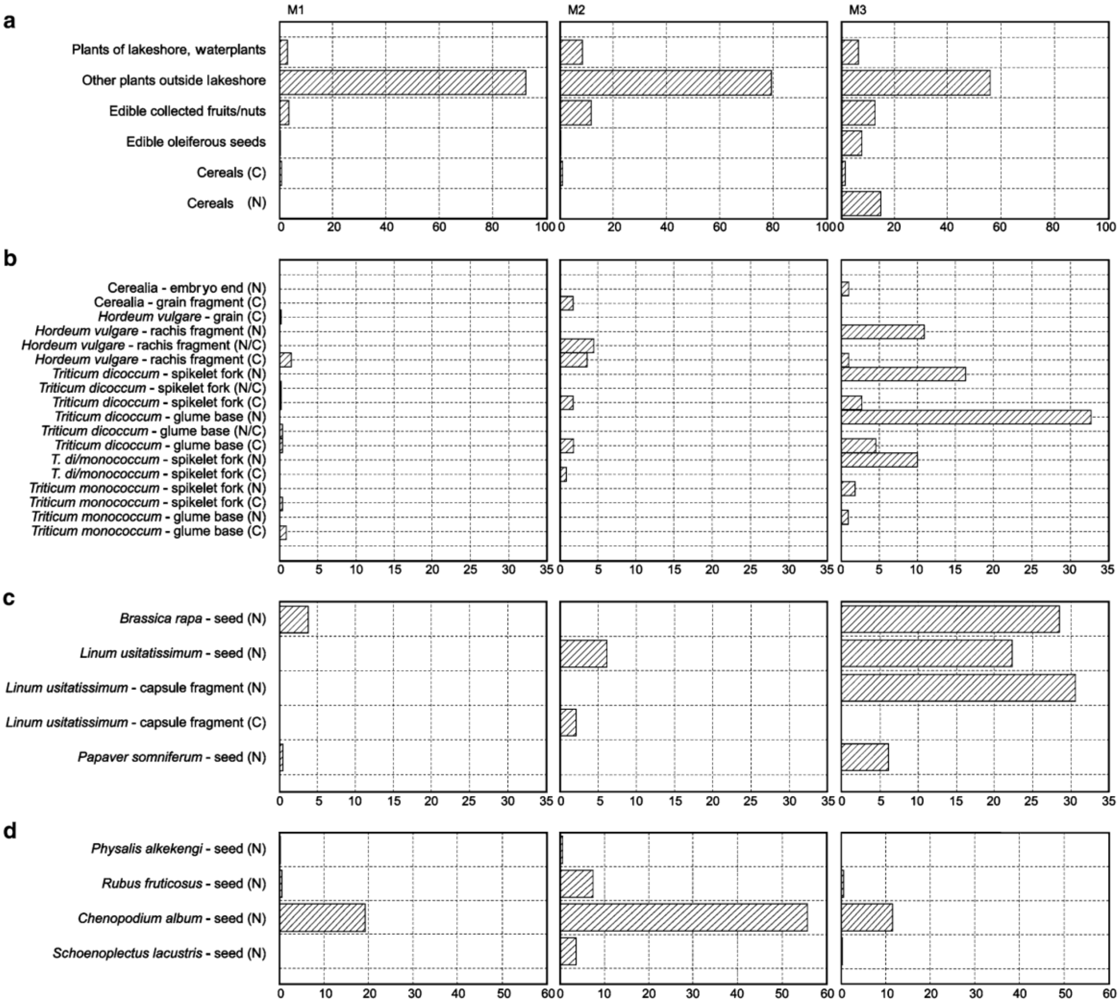


Fig. 5 Comparison of (**a**), plant groups and (**b**–**d**), specific taxa: (**b**) cereals; (**c**) oleiferous plants; (**d**) examples of plants with hard outer tissues. % of plant remains per method (M1, M2, M3) in quadrant 9, 1 mm fraction. *N* uncarbonized, *C* carbonized, *N/C* half-carbonized

in the large fraction there are more taxa with lignified seeds/fruits present like *Prunus spinosa*, *Cornus mas*, *Corylus avellana* etc.

Regarding the 1 mm fraction, the diversity of the taxa spectrum is much higher in the M3 wash-over sample (ESM Table S3). Among the thin-walled, fragile remains in the M3 sample, 20 taxa are present whereas in the M1 dried sample only six taxa were found. All the remains of waterlogged cereal chaff, flax or poppy were found in the M3 wash-over sample. Again, the spectrum of taxa is not that different regarding the hard-coated seeds/fruits. Here, we can see a distinct overrepresentation of some of the hard-coated taxa in the M1 dry sample. Extremely high numbers show a greater representation of *Chenopodium* and also *Rubus* (ESM Table S3). This is the only case where countable seeds/fruits reach a proportion of 26.9% in contrast to 5% in the M3 fraction (see Table 5; ESM Table S3). Therefore, in order to obtain comparable values for the different treatment methods M1 and M3, the counts of the dried small M1 fractions had to be multiplied by 0.186 (obtained by dividing the proportion values of the M3 sample with those of M1 ($5 \div 26.9 = 0.1858736$).

The results of the archaeobotanical record according to the various quadrants and methods are presented in Table S1 (ESM). The comparable value column presents the multiplied and therefore comparable values for the M1 dry samples for the small fractions. In the following, we rely on these values (Figs. 4, 5).

Representativity of the results

Large fractions

The volumes of the examined (sub)samples processed with each method differ in the large fractions (3 mm) of Quadrants 5 and 9 (Tables 1, 4). Not all the sediment samples taken in the field were large enough to reach the required number of 384 identifiable plant remains (Van der Veen and Fieller 1982). However, it becomes clear that the number of identifiable plant remains depends mostly on the treatment method. With the M3 wash-over method the required numbers were almost reached even with comparably small sediment samples of 1,500–2,000 ml. This was not at all the case when the samples were treated inappropriately. The M2 rough wet method turned out to be especially the worst—the numbers reached were less than 57 items per large fraction (ESM Table S1; Table 4). The numbers reached with the M1 drying method seemed to be better at first glance, but the sample volumes were much higher (over 10 l). Unfortunately, these volumes were not processed in two cases, Q5 and Q9, where the numbers of remains were the highest. To summarize, only the large fractions of Q9 and treatments M3 and M1 are to some extent comparable in terms of their taxa spectra because they contained >345 identified plant remains.

The volumes examined of the M1 dried (sub)samples were large, 400 ml in Q5 and 450 ml in Q9 (see Tables 1, 4). Despite this, the numbers of taxa (18 in Q5 and 16 in Q9) and identifiable plant remains (213 in Q5 and 345 in Q9) were lower than in the M3 wash-over subsamples (31 taxa and 335 plant remains in the 280 ml of examined subsample from Q5 to 19 taxa and 388 plant remains in the 260 ml of examined subsample from Q9) (see ESM Table S1, Table 4). Therefore, in cases of inappropriate treatment much more material has to be checked to provide a large enough amount of remains, in order to obtain a reliable number of taxa of seeds/fruits. All in all, the M3 wash-over (sub)samples were by far the best for obtaining a representative number of remains and taxa in the large fraction.

Small fractions

The volumes of small fractions from the 1 mm sieve from each of the M1, M2 and M3 treatments in all three quadrants were large enough to provide subsamples in which the required number of remains (>384) could be attained (ESM Table S1, Table 4). Even when the numbers counted in the M1 dried subsamples were divided by 0.185 (see Table 4) they were high enough with one exception (Q4; Table 4). Therefore, these results are mostly representative and comparable. The volume of the examined organic material in subsamples with each method was 25 ml in all three cases (see Tables 1, 4). In the following, therefore, only the results of the small fractions (Figs. 4, 5) are considered.

Results for the small fractions of the samples from Quadrants 5 and 9

In order to highlight the most important results we have chosen the Quadrants 5 and 9 which gave very similar results (see ESM Table S1). The results are therefore presented together, and some examples of the results for Q9 are highlighted (Figs. 4, 5).

Figure 4 shows that the M3 wash-over sample in Q9 contained by far the largest proportion (94%) of recognizable taxa, although only relatively few remains (under 20%) were counted. The opposite result is shown by the M2 rough wet sample in Q9 where over 60% of the remains had to be counted in order to obtain a higher amount of taxa.

ESM Table S1 and Fig. 5a show that the M1 dry and the M2 rough wet samples have a similar pattern: most of the remains consist of the group “plants outside the lakeshore”, which are mostly weeds, above all from the Chenopodiaceae, with hard-coated seeds/fruits in proportions, based on numbers of remains of 80–90%. Moreover, edible collected fruits and nuts and plants of the lakeshore are relatively well represented, with a maximum of 10%. Seeds of edible oleiferous plants and waterlogged uncarbonized cereal remains are absent; carbonized cereal remains are represented in very low amounts.

In contrast, the M3 wash-over sample shows much more balanced picture: the group “plants outside the lakeshore” is still the most common, with slightly more than 50%. However, the other groups are represented much more evenly. It can therefore be stated that the M3 method is the only one which gives a balanced spectrum of the taxa.

If we look more closely at the taxa spectrum, the differences between the methods and their influence on the spectra of taxa represented become even clearer. On the basis of other work on material from Neolithic lake shore settlements (Hosch and Zibulski 2003), it is known that remains and taxa with very delicate tissues like waterlogged cereal chaff are destroyed and disappear when samples are not appropriately treated (Fig. 6a). This is well visible in Fig. 5b: waterlogged uncarbonized cereal remains are only present in the M3 sample; in addition, they represent the largest part of all the cereal remains. Carbonized cereal remains, in contrast, are present in all three treatments of Q9, always in low amounts. The spectrum diversity of the cereals does not differ between individual treatments; all of them contain *Hordeum vulgare, Triticum dicoccum* and *T. monococcum*. If we

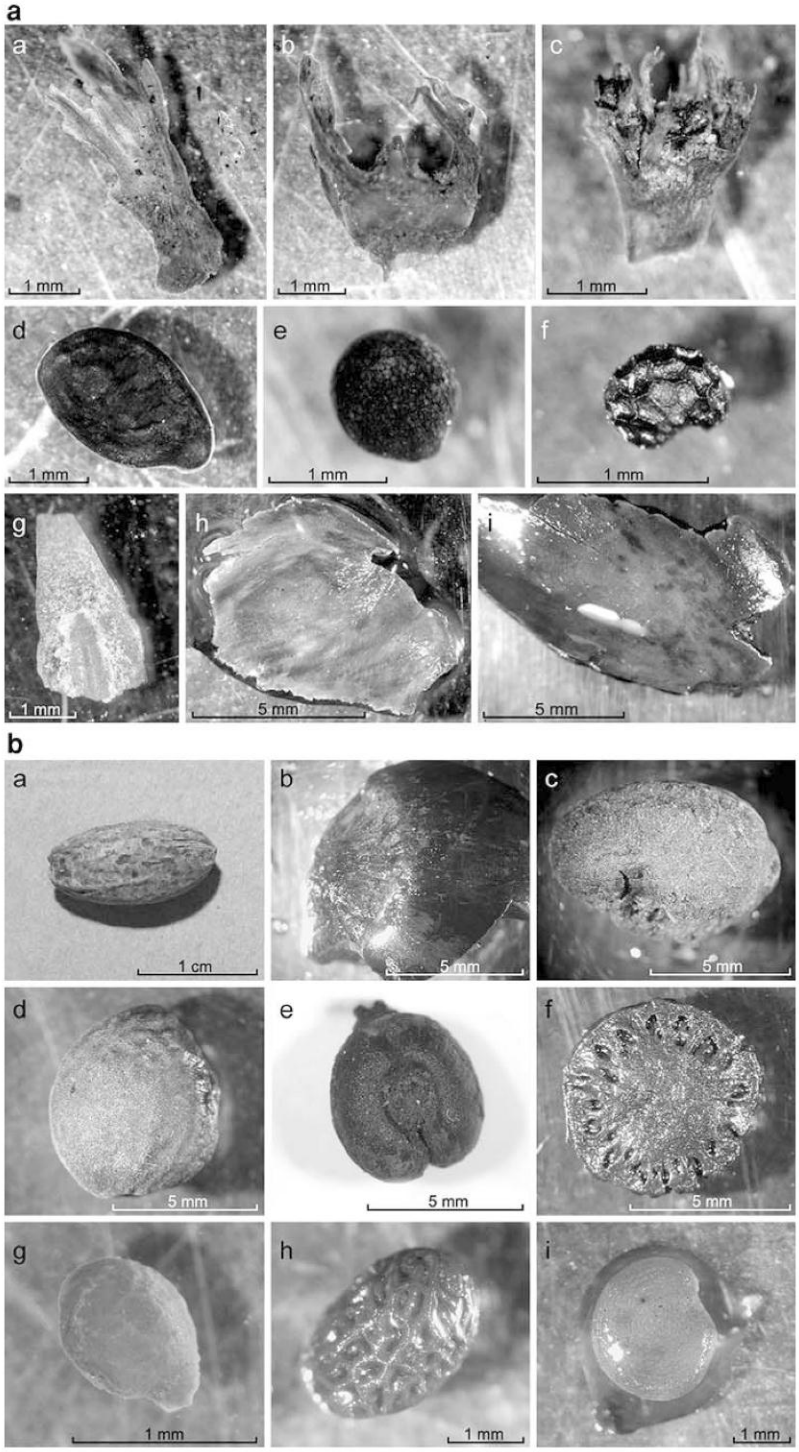


Fig. 6 **a** Thin and fragile non-carbonized remains: cereal remains: *a Triticum dicoccum* glume base and *b* spikelet fork; *c Hordeum vulgare* rachis fragment. Seeds and fruits of oleiferous plants: *d Linum usitatissimum* seed; *e Brassica rapa*; *f Papaver somniferum*; *g Linum usitatissimum* capsule fragment, *h Malus* sp. pericarp fragment; *i Quercus* sp. pericarp fragment. **b** Hard and lignified seeds/fruits: *a Cornus mas*; *b Corylus avellana*; *c Crataegus monogyna*; *d Prunus spinosa*; *e Vitis vinifera* ssp. *sylvestris*; *f Quercus* sp.; *g Fragaria vesca*; *h Rubus fruticosus* agg.; *i Physalis alkekengi*

Table 6 Comparison of plant remains obtained from different sieves, small wash over fractions (0.355 mm-Q4 and 1 mm-Q5, Q9): plant group, volume of the examined subsample, total number of plant remains (Q4, Q5, Q9), number of taxa, preservation (Pres.): C-carbonized, N/C-half carbonized, NC-noncarbonized (waterlogged), seed/fruit cover (Sc) (hardiness of the outer tissue of the diaspore), *T* thin, *H* hard, *T/H* thin to hard

Group of plants	Q4—0.355 mm	No. of taxa	Q5—1 mm	No. of taxa	Q9—1 mm	No. of taxa	Pres.	Sc
Volume of the subsample	25 ml		25 ml		25 ml			
Total no. of plant remains	356	28	495	18	547	31		
Cereals	19	2	23	3	90	3		
	12		16		81		NC	T
	7						N/C	C
			7		9		C	C
Edible oleiferous seeds	129	2	28	3	43	3		
	95		17		29		NC	T
	35		11		14		NC	T/H
Edible collected fruits/nuts	34	6	53	5	70	9		
	26		11		35		NC	T/H
	8		42		35		NC	H
Other plants outside the lakeshore	86	8	367	3	307	6		
	2						NC	T
	1		5		6		NC	T/H
	83		362		301		NC	H
Plants of the lakeshore, water plants	88	10	24	4	37	10		
	55				2		NC	T
	15		14		27		NC	T/H
	18		10		8		NC	H

look at their proportions based only on the carbonized remains, the differences do not seem to be very important. There are, however, differences if we include uncarbonized chaff in the calculations: by far the most important cereal—at least in Quadrant 9—was *Triticum dicoccum* (emmer). This clearly shows that without considering uncarbonized waterlogged cereal remains, our conclusions regarding the importance of cereals would have been strongly biased. Only M3 wash-over treatment provides a reliable picture of cereals.

A very similar statement can be made regarding other seeds/fruits with fragile coats, especially the remains of oleiferous plants like *Linum usitatissimum, Brassica rapa* and *Papaver somniferum* (Figs. 5c, 6a). Most of them—or even all of them in the case of poppy seeds—are only present in the M3 wash-over sample. Their presence in the M1 dry and M2 rough wet samples is only occasional. Quite the opposite can be found out if we look at the proportions of the taxa with hard-coated lignified seeds/fruits which tend to be overrepresented in the M1 treated samples (see above, under "comparability of the results"). They survived drying and rough washing well (Fig. 2a, b) and became overrepresented because they were almost the only "survivors" when samples were badly treated. The degree of overrepresentation is shown by the proportions of *Physalis alkekengi, Rubus fruticosus, Chenopodium album* and *Schoenoplectus lacustris* in Fig. 5d (pictures, see Fig. 6b). Even more stable carbonized cereal remains can show a certain degree of overrepresentation. This is visible in Q5 where they were present in larger amounts in the M1 and M2 treated samples (see ESM Table S1).

Differences between the sieve mesh sizes

There were no obvious differences between the results obtained when using a 2 mm mesh sieve used in IPAS Basel University and the 3 mm mesh sieve as used in Slovenia, for the large fractions (see ESM Table S1). Nothing was lost if 3 and 1 mm sieves were used instead of a 2 mm one. However, there may be differences between the results from using a 0.355 mm sieve as at IPAS Basel University, and a 1 mm sieve as was used Slovenia before introducing new methods. It is of some importance to know what exactly has been missing from the Slovenian spectra until now, in order to compare earlier results with the modern ones. Therefore, we conducted a small, additional study to find out the differences. For this purpose, the 0.355 mm fine sieved fraction

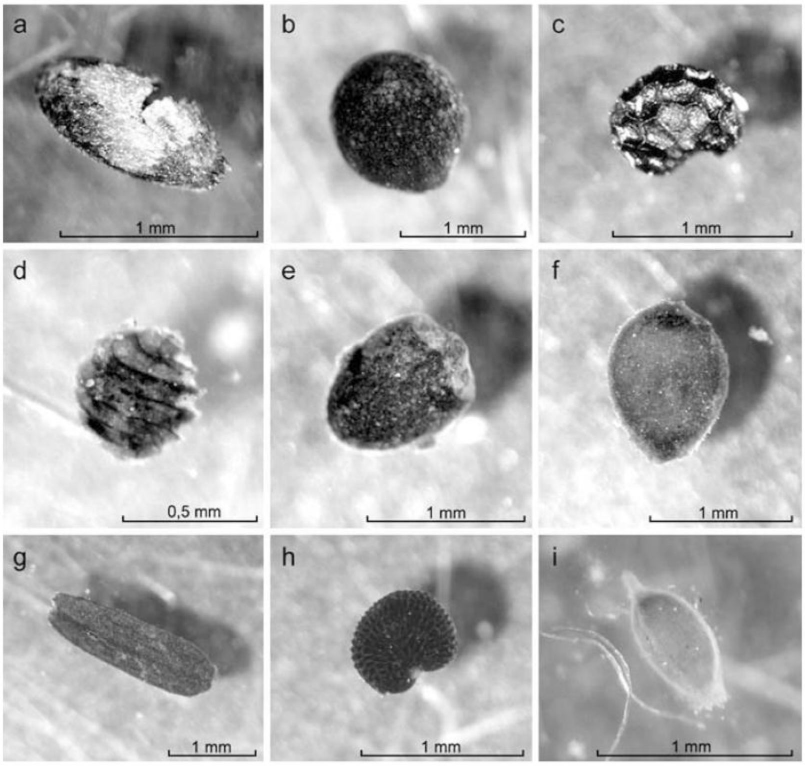


Fig. 7 Small waterlogged seeds: **a** *Lythrum salicaria*; **b** *Brassica rapa*; **c** *Papaver somniferum*; **d** algae oospores *Chara* sp., *Nitella* sp.; **e** *Mentha arvensis/aquatica*; **f** *Urtica doica*; **g** *Eupatorium cannabinum*; **h** *Arenaria serpyllifolia*; **i** *Cyperus fuscus*

of Q4 and the 1 mm fractions of Q5 and Q9 were compared, both treated with the M3 wash-over method (see Tables 2, 6; for detailed identifications of plant remains see ESM Table S1).

Table 6 shows that the sample from Q4, using the 0.355 mm sieve, contained many more small-seeded remains than expected. In the group of oleiferous plant remains especially *Papaver* and Brassicaceae were much more frequent in Q4 than in Q5 and Q9 where the 1 mm sieve was used. There was also an obvious difference in the number of remains of small-seeded plants, growing on the lakeshore or in water, for example *Lythrum salicaria*, *Mentha arvensis/aquatica*, *Urtica dioica* or the oospores of *Chara* sp. and *Nitella* sp., where once again Q4 using a 0.355 mm sieve contained many more such plant remains (for examples, see Fig. 7). The results show that taxa with small seeds, also including *Eupatorium cannabinum*, *Verbascum* sp./*Scrophularia* sp., *Camelina microcarpa* and *Arenaria serpyllifolia*, are generally not properly represented or even absent when only using 1 mm as the finest meshed sieve, as in Q5 and Q9 (for more details, see also ESM Table S1). Therefore spectra from Slovenian settlements, where 1 mm sieves were the finest meshes used, are not comparable with modern studies in terms of the recovery of small seeded taxa.

Conclusions

The comparison of the M1 rough wet sieving, M2 wet sieving, and M3 wash-over methods for preparation and subsequent treatments, M1 with drying, versus M2 and M3 kept wet, of macrobotanical remains from waterlogged archaeological layers clearly confirms that the M3 wash-over method is the best one. When using the gentle wash-over procedure, many vegetative plant remains such as mosses, leaf and needle fragments, stalks, various epidermis etc. were very well preserved. In addition, fragile reproductive plant remains, above all waterlogged cereal chaff but also pericarps as well as seeds/fruits of oleiferous plants were also present in large amounts. Fragile animal remains like insects, molluscs, coprolites, fish scales etc. were also very well represented. All in all, the results of Hosch and Zibulski (2003) from Swiss Neolithic lake shore settlements could be corroborated. In addition, it could be shown that the finest sieve mesh which should be used is

0.35 mm, for obtaining a proper representation of small-seeded taxa, at least those which are of economic importance; for other problems it might be appropriate to use even finer sieve meshes. For future studies, not only of Neolithic waterlogged materials but in general, we would strongly recommend the use of the wash-over method, already described in 1980 by Kenward et al. which, however, is not applied regularly and everywhere. If the sediments are strongly compacted, we recommend freezing and thawing as a gentle and easy pre-treatment method (Vandorpe and Jacomet 2007).

In contrast, in the M1 and M2 treated samples the fragile remains were missing to a large extent, and hard, lignified and partly also charred seeds/fruits were concentrated and overrepresented because their rigid outer layers protect them from shrinking during drying and damage during rough washing, both of which damage the material. A comparison of the numbers of all the counted remains in two subsamples allowed us to estimate the degree of overrepresentation of hard, lignified remains in the M1 treated samples in comparison with the gentle M3 treatment: it is over 50%.

There were also clear differences between the methods concerning the diversity of taxa obtained. By applying the gentle M3 method and using 0.355 mm as the finest sieve mesh size, the diversity of taxa was by far the highest and only with this method was it possible to establish reliable proportions of useful plants. Using the gentle M3 wash-over method it was possible to find uncarbonized waterlogged remains of *Linum usitatissimum* (flax, seeds as well as capsule fragments) and chaff of *Triticum* species for the first time in a Slovenian Neolithic site.

As far as sample volumes are concerned, we can recommend the use of at least 3 l sediment samples for Neolithic lake shore settlements when preservation is good. This volume and the use of the M3 wash-over method make it possible to reach the required number of identifiable plant remains in both the 3 mm and the 0.355 mm fractions for a representative result. A large volume is especially needed in order to gather enough identifiable and countable remains in the large fraction. For the small fraction, the analysis of a small subsample of about 25 ml may already provide enough identifiable material. This result corroborates the conclusions by Hosch and Jacomet (2001) based on the material from northern Alpine Neolithic lake dwellings.

Our study should be seen as a contribution to a desperately required standardization of methods in archaeobotany. It clearly shows how the use of inappropriate methods can severely bias the plant spectra obtained. Moreover, it shows that a clear description of the methods applied in archaeobotanical studies is very important. With our study we are now able to judge what might be missing from earlier archaeobotanical studies carried out in Slovenia. By using the M3 wash-over method it is possible to produce reliable data which are comparable with those from the northern Alpine Neolithic lake shore settlements for the first time.

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2.2 RABA RASTLIN NA POZNO NEOLITSKEM SLOVENSKEM KOLIŠČU ZA ČASA »ÖTZIJA« (PLANT ECONOMY AT A LATE NEOLITHIC LAKE DWELLING SITE IN SLOVENIA AT THE TIME OF THE ALPINE ICEMAN)

Tolar T., Jacomet S., Velušček A., Čufar K. 2011. Plant economy at a late Neolithic lake dwelling site in Slovenia at the time of the Alpine Iceman, Vegetation History and Archaeobotany, 20: 207-222.

V članku predstavljamo prve reprezentativne arheobotanične rezultate z neolitskih objezerskih naselbin z Ljubljanskega barja, natančneje s kolišča Stare gmajne. Kulturni horizonti te naselbine kažejo, da je bila poseljena v dveh obdobjih, ki se končata okoli 3332 in okoli 3109 pr. n. št., kot je bilo ugotovljeno z dendrokronološkimi in radiokarbonskimi raziskavami na konstrukcijskih pilotih iz hrasta (*Quercus* sp.) in jesena (*Fraxinus* sp.) (Čufar in sod., 2010). Analiziranih je bilo 14 sistematično odvzetih arheobotaničnih vzorcev, tretiranih s standardno metodo za z vodo prepojene sedimente, ki so jo razvili med raziskovanjem severnoalpskih jezerskih naselbin. Velika večina ostankov na kolišču Stare gmajne je bila ohranjena v z vodo prepojenem nezoglenelem stanju. Identificirali smo 93 taksonov. Kot najpomembnejše kulturne rastline na raziskanem kolišču so se izkazale dvozrna pšenica (*Triticum dicoccum*), ječmen (*Hordeum vulgare*), enozrna pšenica (*Triticum monococcum*), lan (*Linum usitatissimum*) in najverjetneje tudi mak (*Papaver somniferum*). Med številnimi možnimi rastlinskimi vrstami, ki so jih nabirali, sta bili tudi vodni orešek (*Trapa natans*) in vinska trta (*Vitis vinifera* ssp. *sylvestris*). Bela metlika (*Chenopodium album*) in oljna repica (*Brassica rapa*), s semeni/plodovi bogatimi z olji in maščobami, sta bili najverjetneje tudi med pogosto nabiranimi rastlinami, saj so bila njuna semena prisotna v precejšnem številu. V članku je opisana tudi prva primerjava slovenskih rezultatov z rezultati istočasnih severno alpskih kolišč. Izkazalo se je, da tetraploidna trda pšenica (*Triticum durum/turgidum*), ki je pogosto najdena v sedimentih s severno alpskih kolišč, na Starih gmajnah manjka. Nasprotno pa vodni orešek in vinska trta pogosto manjkata na severnoalpskih najdiščih, kar je najverjetneje posledica različnih ekoloških razmer severno in južno od Alp pred 5000 leti. Razlike v kulturnih rastlinah pa so skoraj zagotovo posledica različnih navad, in različnega spektra gojenih rastlinskih vrst tedanjega časa.

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ORIGINAL ARTICLE

Plant economy at a late Neolithic lake dwelling site in Slovenia at the time of the Alpine Iceman

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Abstract We present the results of a plant macroremain study of the late Neolithic lakeshore settlement Stare gmajne (SG) at Ljubljansko barje, Slovenia, with cultural horizons that ended around 3330 and 3110 cal. B.C., as obtained by dendrochronological and radiocarbon dating of the most frequent construction timbers of *Quercus* sp. (oak) and *Fraxinus* sp. (ash). Fourteen systematically taken samples were investigated, using standard methods for studying waterlogged plant remains, which had been developed during lake dwelling research north of the Alps. Most of the remains were preserved in a waterlogged state, and we identified a total of 93 taxa. The most important cultivated plants were *Triticum dicoccum* (emmer), *Hordeum vulgare* (six-rowed naked barley), *T. monococcum* (einkorn), *Linum usitatissimum* (flax) and *Papaver somniferum* (opium poppy). The numerous possibly gathered plants also included *Trapa natans* (water chestnut) and *Vitis vinifera* ssp. *sylvestris* (wild grapevine). *Chenopodium album* (goosefoot) and *Brassica rapa* (turnip) with seeds/fruits rich in oil and starch were probably gathered as well. Comparisons of the Stare gmajne results with contemporary north Alpine sites (NA) showed, among other things, that *Triticum durum/turgidum* (tetraploid naked wheat), frequent at NA, was not found at SG. *Trapa natans* (water chestnut) was rare and *Vitis* (grapevine) was not found at NA. The observed differences in the wild plant spectra may have ecological causes, for example a warmer climate south of the Alps, but differences in cultivar spectra are more likely for cultural-historical reasons.

Keywords Plant macroremains · Late Neolithic · Ljubljansko barje · Slovenia · Waterlogged preservation

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Introduction

Pile dwellings existed in various parts of Europe during the Neolithic period (Menotti 2004), and their number is especially high in the circum-Alpine region (Fig. 1a). Because of their importance, many of them have been nominated for entry in the UNESCO list of world cultural heritage sites, including the Slovenian ones (Suter and Schlichtherle 2009). Archaeological excavations and interdisciplinary investigations, supported by systematic archaeobotanical studies have been conducted on lake dwelling sites in Switzerland, Germany and France since the 1980s (for example Jacomet 2006a, 2009). In contrast, similar studies using comparable methods have been rare in regions south of the Alps, including Slovenia. A compilation of the state of the art in northern Italy was recently published by Rottoli and Castiglioni (2009).

Approximately 40 Neolithic and Bronze Age pile dwelling sites (from ca. 4600–1700 cal. B.C.) have been

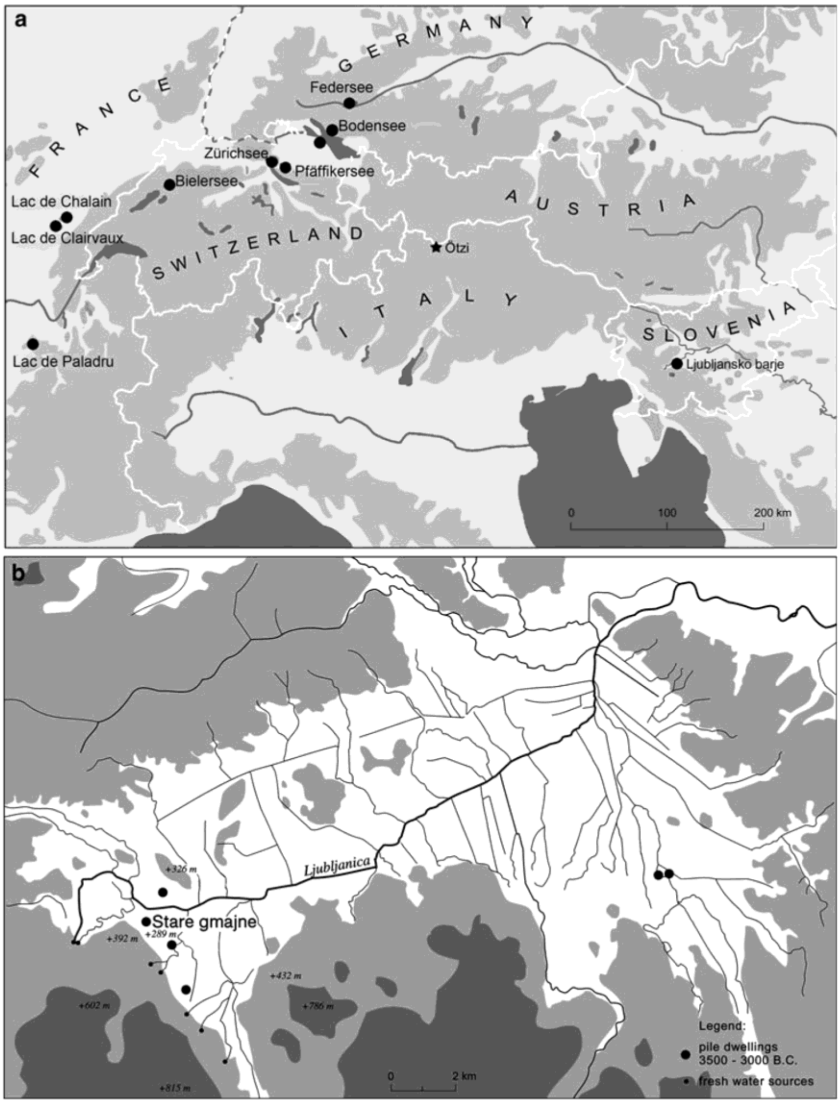

Fig. 1 Maps with positions of **a** Ljubljansko barje, Slovenia and other archaeobotanically investigated European pile dwelling sites (*dots*) around the Alps, dated 3500–3000 cal. B.C. The location at which the Alpine Iceman Ötzi was found (*star*) is also shown; **b** Ljubljansko barje shown as a white area, with the Stare gmajne site and locations of other known contemporary Neolithic pile dwellings dated 3500–3000 cal. B.C. The stratigraphical position of the elevated terrain in m a.s.l. is indicated in *grey*

recorded at Ljubljansko barje, Slovenia (Fig. 1). Some of these have been investigated in the last 130 years (Velušček 2004). Archaeological excavations were often accompanied by archaeobotanical studies (Jeraj et al. 2009), but the recovery techniques used were not in agreement with those used north of the Alps (Hosch and Zibulski 2003; Jacomet et al. 2004). Tolar et al. (2010) showed that too rough washing, inadequate sieve mesh sizes and drying of the fractions after sieving resulted in taxa represented by fragile parts not being recorded, and that taxa with tough lignified diaspores were overrepresented. The same study also suggested a procedure that would ensure representative results, which would be useful for comparisons with other studies. The lack of standardization of archaeobotanical methodologies has been among the main obstacles to reliable comparisons of plant economies of prehistoric settlements both north and south of the Alps.

Furthermore, the archaeological sites in Slovenia have not been exactly dated until recently, in contrast to most of the corresponding sites north of the Alps. Recent introduction of dendrochronology and radiocarbon wiggle-matching have now provided more exact dating than previously of eight pile dwelling settlements at Ljubljansko barje, with end dates from 3547 to 3071 cal. B.C. (Čufar et al. 2010). Culturally, they belong to the late Neolithic (Jacomet 2007), in Slovenian terminology corresponding to the Eneolithic or Copper Age, when copper metallurgy played a crucial role in society (Velušček 2004, 2009). Unfortunately, no archaeobotanical investigations have been carried out there or, if they have been, the recovery techniques were not adequate to obtain reliable data to compare them with sites north of the Alps.

One of the dated pile dwellings is Stare gmajne (Fig. 1b). It was settled in two periods. According to radiocarbon dating the activities at the earlier dwelling ended around 3300 B.C. (3332 cal. B.C.) and at the later one around 3100 B.C. (3109 cal. B.C., Čufar et al. 2009, 2010). Between the two phases, a major settlement gap was recorded at Ljubljansko barje.

The settlement was located at the edge of the floodplain of Ljubljansko barje, which was a lake at the time of occupation. Its immediate vicinity was rich in various habitats. The settlement was likely to have been located on the marshy, temporarily flooded terrain, but the dwellers also had access to the lake. Only about 700 m southwest of the site, the first slopes of the Dinaric Karst started. They are nowadays covered by extensive woods of *Abies alba* (silver fir) and *Fagus sylvatica* (beech), and they were probably also covered by widespread woodland in Neolithic times, as indicated by pollen analyses (Šercelj 1996).

The period from around 3500 to 3000 cal. B.C. was also characterized by intensive occupation in the entire circum-Alpine region (Stöckli 2009). One of the best parallels to the older phase of Stare gmajne is the settlement of Arbon Bleiche 3 at Lake Constance (Bodensee), which was recently investigated as part of a large interdisciplinary project (Jacomet et al. 2004). The settlement at Stare gmajne also corresponds to the time of the Alpine Iceman (Ötzi), who died between 3320 and 3050 cal. B.C. (Kutschera and Müller 2003). Archaeobotanical research conducted on the plant material recovered from the Iceman's body and from the settlements that existed during his lifetime have helped us greatly to learn more about the plant economy at the time of his life (Dickson et al. 2009; Oeggl 2009; Heiss and Oeggl 2009; Jacomet 2009).

The first objective of this study was to identify plant remains from two settlement phases of the Stare gmajne lake dwelling and to evaluate the role of various plant taxa in its economy. The main objective, however, was to compare the obtained results with those from contemporary sites in other parts of the Alpine area. In addition, we discuss some general questions of Neolithic circum-Alpine sites concerning the introduction of cultivars to various parts of Europe.

The investigation area

The excavations at Stare gmajne (ca. 100 × 300 m) were performed in 2002, 2004, 2006 and 2007 in 13 drainage ditches. During the excavations, a total of 932 pieces of wood (mainly piles) were collected. Dendrochronological and radiocarbon wiggle-matching enabled us to date the building activities on the site (Čufar et al. 2009; Čufar et al. 2010). Based on the locations of the piles and other archaeological artefacts, it could be reconstructed that two areas had been occupied, one in the western and one in the eastern part of the investigated area (Fig. 2a). The area in between (ditches 7–11) contained no wood or other artefacts.

The western part (ditches 12, 13, Fig. 2a) had been settled in two periods: there was an earlier settlement of short duration, ca. 20 years, which ended around 3330 cal. B.C. (end date of the youngest tree-ring 3332 ± 10 cal. B.C.), and a later settlement, which ended around 3110 (end date of the youngest tree-ring 3109 ± 14 cal. B.C.). In the later phase, the eastern part of the area (ditches 1–6) was also occupied, in addition to the western part; several building phases were recorded there, indicating that the site was occupied for ca. 50 years. Here, 3109 cal. B.C. is the end date of the latest dated tree ring, but the occupation probably continued for some years after that date.

Materials and methods

In 2007, a trench was dug to collect material for archaeobotanical investigations, in which we detected two cultural layers (Fig. 2a, b). Based on dendrochronological dating (Čufar et al. 2009), we assumed that the lower one corresponded to the earlier and the upper one to the later settlement, in the western part of the area (see Fig. 2c).

For sampling, the trench was divided into 15 quadrants (Q). Three quadrants, Q1, Q9 and Q13, were randomly selected for horizontal sampling (Fig. 2b). Vertical sampling was made along five depth-cuts (depth-cuts 4, 5, 6, 7 and 8) (Fig. 2c). The depth-cuts 8 and 7 were attributed to the earlier settlement, which ended around 3330 cal. B.C. and the depth-cuts 5 and 4 correspond to the later settlement with an end date around 3110 cal. B.C. The depth-cut 6 was located in between and could not be exactly ascribed to either of the settlement phases.

For archaeobotanical investigations, sediment samples of up to 1 l were taken systematically from three quadrants and from the early, intermediate and late cultural layers. Altogether, 14 samples with a total volume of ca. 9 l were analysed (for details, see Table 1 in supplementary material).

Examination of the material

The samples were washed over and sieved as proposed for waterlogged sediments by Hosch and Zibulski (2003). In

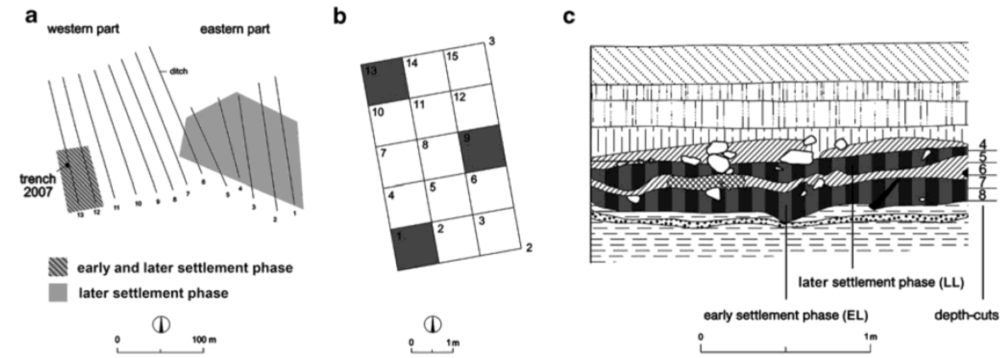

Fig. 2 Stare gmajne. **a** the site (current situation) crossed by 13 drainage ditches (*lines*). The *hatched area* to the west indicates the location of the early settlement, which ended around 3330 B.C. (duration ca. 20 years). The location was resettled after ca. 170 years, when the area to the east, shown in *grey* was also settled; the duration of the later settlement was ca. 50 years and ended after 3110 cal. B.C. The trench excavated in 2007 for archaeobotanical investigations is located in the western part. **b** The trench with quadrants (*horizontal samples*); sampling was carried out in quadrants 1, 9 and 13 (*grey*). **c** The vertical stratigraphy of the trench with cultural layers of two distinct settlement phases: early phase (depth-cuts 7 and 8) and later phase (depth-cuts 4 and 5). Depth-cut 6 indicates an intermediate layer

addition, the clayey and compacted sediment was first frozen and then thawed to make washing easier (Vandorpe and Jacomet 2007). The sediment was washed using sieves with 2 and 0.355 mm mesh sizes at the Institute for Prehistory and Archaeological Science (IPAS), Basel, Switzerland. The collected fractions from the sieves were stored in water and at low temperatures in a refrigerator to prevent desiccation or decay and, consequently, their deformation or destruction.

Prior to analysis, systematic, random sub-sampling of the large (2 mm) and especially the small (0.355 mm) fraction was necessary, because the samples were very rich in macro-remains. According to Van der Veen and Fieller (1982), our aim was to count 384 identifiable plant remains. Since in waterlogged sites the spectra of the taxa vary greatly, this number was aimed for in each of the fractions (Hosch and Jacomet 2001). This allowed us to reconstruct the right proportions of the most important taxa with a probability of 95 ± 5%. For counting, we had to define the types of remains that counted as one piece (see Table 1).

We first examined 90 ml of the large and 25 ml of the small fractions. The subsamples, especially the large fraction, were then enlarged to obtain the reliable minimal number of items. When there were more than 384 plant remains in the examined volume, examination of the subsample was concluded. In some of the large fraction samples, all the material had to be analysed (see Table 1 in supplementary material). The volumes of the examined subsamples are shown in Tables 1 and 2 in supplementary material.

Very small botanical fragments, where less than one quarter of the seed, fruit or grain was found and the plant remains were smaller than 0.3 mm, were not counted. We assessed the abundance of the plant remains in the following categories: not found, single find, small amount, abundant, very abundant. We also noted the presence of animal remains (see Table 1 in supplementary material).

Table 1 Types of plant remains (SFC) that were counted as a single piece

Type of plant remain ("counted unit")	Taxa
Whole seed/fruit and grain	All taxa
Grain fragments with embryo end	Cerealia
Glume base	Hulled *Triticum* sp.
Rachis fragment	*Hordeum vulgare*
Fragments of seed/fruit with the tip	e.g. *Cladium mariscus*
Fragments >1/4 of a seed	Maloideae
Fragments >1/4 of the pericarp	*Quercus* sp., *Fagus sylvatica*, Maloideae
Fragments >3 mm of a seed/fruit	*Viscum album*
The base of the seed/fruit	*Quercus* sp., *Corylus avellana*, *Malus* sp., *Trapa natans*
Capsule fragments >3 mm or capsule fragments with a tip	*Linum usitatissimum*

Table 2 Volumes of the sediment, examined fractions and total number of identified plant remains, seeds, fruits, chaff, capsule and pericarp fragments in the large and small fractions, and their concentrations per litre of sediment for different depth-cuts and layers

Depth-cuts/layers	Sediment vol. (ml)	Volume of organic fractions (ml)	*n* plant remains		Sum	Average (conc./l)
			2 mm	0.355 mm		
4	1,200	95	57	434	491	1,240
5	2,000	325	295	797	1,092	1,903
Later layer (total)	3,200	420	352	1,231	1,583	1,572
6 = intermediate layer	2,200	250	421	1,666	2,087	4,729
7	1,900	410	941	1,984	2,925	9,094
8	1,350	420	607	1,123	1,730	6,027
Early layer (total)	3,250	830	1,548	3,107	4,655	7,560
Total	8,650	1,500	2,299	5,392	7,691	

Depth-cuts 4 and 5 = later layer, end date ca. 3110 cal. B.C.; depth-cut 6 = intermediate; depth-cuts 7 and 8 = earlier layer, end date ca. 3330 cal. B.C., for all three sampled quadrants

A Leica MZ75 stereomicroscope with 6.3–50 magnifications was used for examining and sorting. For identification we used the reference collection of IPAS, Basel, as well as special literature (Berggren 1969, 1981; Anderberg 1994; Cappers et al. 2006; Jacomet 2006b). In order to facilitate interpretation, the identified taxa were divided into groups, first of all based on their actual use and secondly based on their ecology. The nomenclature of plant names follows Zohary and Hopf (2000) for crop plants, Binz and Heitz (1990) for wild plants, supplemented by Martinčič et al. (1999).

Results

Amounts of plant remains and their concentrations

All recognizable plant remains from all quadrants and layers are listed in Table 1 in supplementary material. The entire archaeobotanical record includes 93 plant taxa, mostly identified to species level.

Representative results in accordance with Van der Veen and Fieller (1982) were obtained for the small fractions in all quadrants and in most layers. The large fractions were representative only in the depth cut 8 of quadrant 1 and in the depth cuts 6 and 7 of quadrant 9. Representative numbers could have been achieved if the sample size had been increased to 3 l, as recommended for well preserved waterlogged layers (Hosch and Zibulski 2003; Jacomet and Brombacher 2005).

The concentrations of plant remains are shown in Table 2. They varied with layers and were highest in the lowest (earliest) layer, and averaged 7,560 remains/l. They decreased to the uppermost and latest layer, where they amounted to an average of 1,572 l^{-1} of sediment. The concentrations also varied horizontally. In the later and intermediate layers they proved to be richest in the easternmost quadrant 9. Within the early layer, the concentrations were rather high in all quadrants, although slightly different.

Cultivars

The cereals, *Triticum dicoccum* (emmer) and *Hordeum vulgare* (6-rowed naked barley) showed the highest concentrations, whereas *T. monococcum* (einkorn) was less frequent (Table 3). Cereals were mostly represented by chaff remains such as rachis fragments, glume bases and spikelet forks, but grains were rare (see Table 2 in supplementary material). *Papaver somniferum* (poppy) and *Linum usitatissimum* (flax) had the highest concentrations among the oil and fibre plants. However, high concentrations of *Papaver* could be ascribed to its numerous small seeds and these do not necessarily mean that it was the most important in the diet (see Table 3). The least frequent were remains of pulses, and we found only two whole and one fragment of *Pisum sativum* (pea) in the examined samples (Table 1 in supplementary material).

A detailed list, with the numbers of plant remains, separately for grains, chaff, and other remains, with their state of preservation (carbonized, semi-carbonized, non-carbonized = waterlogged) is given in Table 2 in supplementary material. The cereal grains and peas were mostly preserved in a carbonized state and all other remains mostly or only in waterlogged state.

Gathered plants

Wild plants with edible seeds and fruits

We identified 16 presumably gathered plant taxa (Table 3). The oil/starch rich seeds of *Chenopodium album* (goosefoot) and *Brassica rapa* (turnip) were the most abundant in terms of concentrations. Shell fragments of fruits of

Table 3 Average plant concentrations of the most important edible taxa at Stare gmajne for the early, intermediate and later phase/layer

Plant group		Taxon	Concentration (l^{-1})		
			Layer		
			Early	Trans.	Late
Cultivars		*Triticum dicoccum* (seed, chaff)	330	106	14
		Triticum di/monococcum (seed, chaff)	136	56	19
		Triticum monococcum (seed, chaff)	55	3	14
		Hordeum vulgare - naked (seed, chaff)	131	92	82
		Papaver somniferum (seed)	1,304	596	5
		Linum usitatissimum (seed, capsule)	155	62	7
		Pisum sativum (seed)	<1	0	0
Gathered plants	Nuts and other oil/starch rich taxa	*Chenopodium album* (seed)	1,869	835	213
		Brassica rapa (seed)	392	68	17
		Quercus sp. (pericarp)	189	61	7
		Quercus sp. (fruit base)	13	6	1
		Corylus avellana (fruit base)	11	8	0
		Trapa natans (fruit base)	7	3	0
	Wild fruits	Maloideae (pericarp)	187	129	4
		Maloideae (seed)	33	16	0
		Fragaria vesca (seed)	158	109	8
		Rubus fruticosus agg. (seed)	141	35	5
		Physalis alkekengi (seed)	22	19	2
		Cornus mas (seed)	3	0	0
		Crataegus monogyna (seed)	2	4	0
		Prunus spinosa (seed)	2	1	0
		Vitis vinifera ssp. *sylvestris* (seed)	2	0	0
		Rosa sp. (seed)	1	0	0

The term "seed" includes all types of diaspores when not specified. The preservation state of most of the remains is waterlogged (details in Table 1 in supplementary material)

Quercus sp. (acorns), *Corylus avellana* (hazelnut) and *Trapa natans* (water chestnut), which are also calorific, were found in considerable numbers as well (Table 3). They were mainly represented in the lower, earlier layers.

Among juicy fruits and berries, Maloideae (wild apples/pears), *Fragaria vesca* (strawberries), *Rubus fruticosus* (blackberries) and *Physalis alkekengi* (bladder cherries) were most abundant. In total, ten taxa were found which can be considered to have been part of the diet (Tables 3 and 1 in supplementary material). In addition, we can assume that other wild plants may also have been used for purposes such as for spices or medicinal plants, although such uses cannot be directly proven (Table 4; Maier 2001). Examples of such possibly useful plants could be *Viscum album* (mistletoe), *Agrimonia eupatoria* (common agrimony), *Anagallis* sp. (scarlet pimpernel), *Hypericum perforatum* (St. Johns wort), *Mentha* sp. (mint), *Solanum nigrum* (black nightshade) and *Thymus* sp. (thyme) (Table 1 in supplementary material). Of the latter group, not only the diaspores but also other plant parts were used.

Wild plants with other useful parts

In addition, we found parts of the fruiting bodies of various fungi and many fragments of mosses (Table 1 in supplementary material). The remains of a sort of fabric were found, too, and one larger piece of well-processed yarn.

Wild plants for construction purposes and fuel: wood

Wood deserves special attention. It was extensively used and was certainly a very important raw material. It was used to build houses, as well as various constructions and objects such as palisades, boats, wheels and carts, various tools and their handles, weapons such as bows, spears, arrows, kitchen utensils and for many other purposes (see Stotzer et al. 1976; Tolar and Zupančič 2009; Velušček et al. 2009a, b). Large amounts of wood were presumably also used for fuel, as in other comparable sites where charcoal remains were investigated (Dufraisse 2006, 2008). At Stare gmajne the wood consisted mainly of the remains of the vertical piles on which the houses were built. The upper parts of the constructions were not preserved and other wooden artefacts were very rare.

Quercus sp. (oak) and *Fraxinus* sp. (ash) were most frequently used for piles. Less often used were *Populus* sp. (poplar), *Salix* sp. (willow), *Alnus glutinosa* (alder), *Fagus sylvatica* (beech), *Acer* sp. (maple), *Corylus avellana* (hazelnut), *Carpinus betulus* (hornbeam) and *Abies alba* (silver fir). The selection and proportion of the woody taxa found in trench 2007 (Fig. 3a) slightly differs from those found in the larger excavated area (Fig. 3b). This is possibly due to the low and less representative number of wood samples in the trench (37 samples) compared to the total collection of samples (932 samples).

Wild plants according to ecological groups

The 71 taxa of wild plants were attributed to 6 larger ecological groups (in line with Behre and Jacomet 1991, see also Brombacher and Jacomet 1997). We considered only those taxa that could be assigned to one of the groups based on firm assumptions.

Water plants, plants of lake shore (reeds) and wetlands

Plants growing in the immediate proximity of the site or even at the site itself are represented by 28 taxa, which is 39% of all wild plant taxa found at the site (Fig. 4). Water plants are represented by eight taxa (11%). The most frequent taxa, Characeae and *Ranunculus aquatilis*, show their highest values in the lower part of the stratigraphy, whereas *Sparganium* sp. becomes much more common in the uppermost part of the cultural layer (Table 4).

Plants of the lake shore, and especially of reed beds, are represented by 20 taxa (28%) and are the most diverse group within the spectrum of Stare gmajne. By far the highest numbers are diaspores of *Oenanthe aquatica*, a

Table 4 Average concentrations of water and lakeshore/wetland plants, of the most important taxa of woodland, clearings and woodland edges and of the most important taxa of segetal and ruderal plants found at Stare gmajne for three phases/layers: early (ca. 3330 cal. B.C.), transitional, late (ca. 3110 cal. B.C.)

Plant group	Layer	Concentration (l^{-1})			Gathered
		Early	Trans.	Late	
Water plants	Characeae	137	67	1	
	Ranunculus aquatilis	53	60	157	
	Potamogeton sp.	16	0	3	
	Sparganium sp.	8	21	38	
	Trapa natans	7	3	0	x
	Nymphaea alba	2	0	0	
	Nuphar luteum	2	0	0	
	+ *Alisma plantago-aquatica* (total: 8 taxa)				
Lakeshore (reeds etc.), other wet places (marshes, pioneers on shores etc.) plants	*Oenanthe aquatica*	480	2,145	381	
	Cladium mariscus	295	9	2	
	Mentha arvensis/aquatica	271	151	614	
	Schoenoplectus lacustris	131	46	20	
	Cyperus fuscus	88	0	1	
	Lythrum sp.	83	8	5	
	Eupatorium cannabinum	45	0	2	
	Lycopus europaeus	9	0	7	
	Typha latifolia	7	0	0	
	Alnus glutinosa	4	0	0	
	Stellaria aquatica	4	0	0	
	Nasturtium officinale	0	5	0	
	Apium cf. *repens*	0	4	2	
	+ *Hippuris vulgaris*, *Ranunculus lingua*, *Rumex hydrolapathum*, *Rumex aquaticus*, *Sagittaria sagittifolia*, *Polygonum hydropiper*, *Molinia* sp. (total: 20 taxa)				
Wood	Maloideae	263	157	4	x
	Quercus sp.	202	67	8	x
	Physalis alkekengi	22	19	2	x
	Viscum sp.	12	2	0	x
	Fagus sylvatica	2	1	0	
	Vitis vinifera ssp. *sylvestris*	2	0	0	x
	+ *Abies alba*, *Moehringia trinervia*, *Pteridium aquilinum*, *Tilia platyphyllos* (total: 10 taxa)				
Clearings and wood edges	*Fragaria vesca*	158	109	8	x
	Rubus fruticosus agg.	141	35	5	x
	Epilobium hirsutum	13	0	7	
	Corylus avellana	11	8	0	x
	Betula pendula/pubescens	8	0	0	
	Cornus mas	3	0	0	x
	Crataegus monogyna	2	4	0	x
	Prunus spinosa	2	1	0	x
	Rubus cf. *idaeus*	2	0	0	x
	Fallopia dumetorum	1	6	0	
	+ *Cornus sanguinea*, *Rosa* sp. (total: 12 taxa)				
Field weeds and ruderals	*Chenopodium album*	1,869	835	213	x
	Brassica rapa	392	68	17	x
	Atriplex sp.	261	160	10	
	Urtica cf. *dioica*	73	56	2	
	Fallopia convolvulus	17	11	1	
	Anagallis foemina/arvensis	11	5	0	
	Arenaria serpyllifolia	8	14	0	
	Silene alba	5	5	1	
	Capsella sp. (cf. genus)	4	0	0	
	Camelina sp.	3	5	0	
	Daucus carota	0	7	0	
	Solanum nigrum	0	5	0	
	+ *Ranunculus repens*, *Sambucus ebulus*, *Galeopsis tetrahit*, *Lamium maculatum* (total: 16 taxa)				

The plants that have been assigned to the group of gathered ones are marked with "X" (cf. Table 3). Rare taxa are mentioned separately. For details, see Table 1 in supplementary material. The proportions of the plant groups are shown in Fig. 4

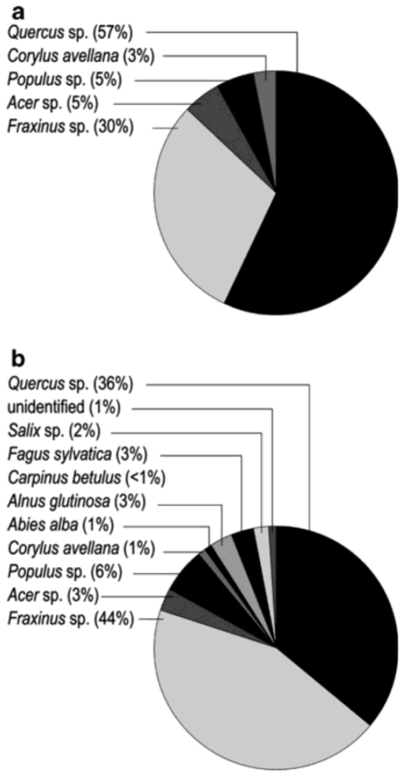

Fig. 3 Wood taxa used for constructions (piles) of Stare gmajne collected in: **a** trench of 2007 (37 samples). **b** in the entire site (ditches and trench, 932 samples)

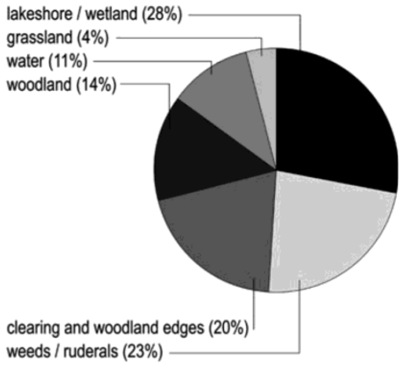

Fig. 4 Proportions of ecological groups, based on 71 taxa. Only wild plants are included

plant which mostly grows in eutrophic, quiet, flat water and tolerates occasional drying (Oberdorfer 2001). A similar environment is also typical of *Mentha arvensis/aquatica* (probably *M. aquatica*), the fruits of which occur in very large amounts. *Cyperus fuscus* is also worth mentioning as a pioneer plant on occasionally drying places, and it is present in by far the highest numbers in the lowest layer. Most of the *Carex* fruits, found regularly but for the most part not unambiguously identifiable to species level, probably belong to the group of lake shore plants (see Table 1 in supplementary material).

Plants of woodlands, clearings and wood edges

A considerable proportion (34%), 24 taxa, come from woodland habitats (Fig. 4). Most of the taxa assigned to clearings and woodland edges could also grow in woodland. Most taxa from these places represent plants that were probably gathered and have already been mentioned in the section “gathered plants”. Most of them can be also found in the present-day woodland southwest of Ljubljansko barje, which mostly consists of extensive Dinaric silver fir-beech woods (Šercelj 1996).

Plants of anthropogenic open habitats: field weeds, ruderal plants and plants of grassland

The field weeds and ruderals are well represented, with 16 taxa (23%, Fig. 4). They form the second largest group of wild plants found at Stare gmajne. We put these taxa into a single group because most of them can grow on all of the mentioned habitats. The majority of the taxa are nowadays typical of summer crops or gardens, such as *Chenopodium album*, or ruderal places. Typical winter annuals were not found. The highest concentrations within this group are shown by *Chenopodium album* and *Brassica rapa*, which were probably collected. The concentrations varied with the investigated layers (see Table 4).

The Apiaceae (*Conium/Seseli*) and *Thymus* sp. records could possibly be attributed to grassland. Furthermore, *Agrimonia eupatoria* and *Hypericum perforatum* might also have grown there, although they mainly belong to woodland edge communities. Remains of grassland plants are therefore rare at Stare gmajne (Fig. 4; Table 1 in supplementary material).

Other finds

We also found many coprolites, both whole and fragments, from goat/sheep, cattle and small mammals (Table 1 in supplementary material). They have not yet been analysed in detail. In addition to botanical material, we also found many fish scales, bones and teeth, which mostly belonged to *Esox* (pike) of the Cyprinidae family (Table 1 in supplementary material) (identified by Heide Hüster-Plogmann from IPAS, Basel University). These finds should also be examined in detail in the future.

Discussion

Although the size of the excavated trench and the amounts of the investigated material were rather small, it was possible to obtain some information on the presence versus absence of the most important cultivated and wild taxa, although perhaps not entirely representative. It is therefore possible to compare the results from a lake dwelling site in Slovenia with contemporary waterlogged sites north of the Alps. In the following sections, we mainly discuss cultivated and possibly gathered plants because of their great importance for human food and because they are considered to be properly represented.

Differences in concentrations of plant remains

The concentrations of plant remains in the earlier cultural layer of Stare gmajne indicated that the archaeological layers are very well preserved. The values correspond to those of contemporary sites north of the Alps; at Arbon Bleiche 3, for instance, 7,000 to 9,000 macro-remains per litre of sediment were found (Hosch and Jacomet 2004). In contrast, the later layer in Stare gmajne was less rich, with an average of 1,572 counted macro-remains per litre of sediment material.

The differences in the concentrations could have various reasons. Richer plant spectra in the early and intermediate layers with 7,560 counted macro-remains, for example, might occur due to a different intensity of human activity at the location of the trench in different periods. Dendrochronological investigations indicated that most of the piles were from the earlier phase of the settlement, which ended around 3330 cal. B.C. (Čufar et al. 2009). However, some piles from the later settlement phase were also found, which ended around 3110 cal. B.C. This indicates that the area of the trench was inhabited in both periods, but it might have been in the centre in the early phase and at the edge or even in a separate part of the settlement during the later phase (see Fig. 2a).

Ecological conditions around the site

Littoral zone (marshland and water plants)

The settlement was located close to the lake (Fig. 1b). We assume that many aquatic and littoral plants found in the cultural layers represent the remains of the natural vegetation at and around the site (Tables 4 and 1 in supplementary material).

Plants that probably grew nearby, or even in the settlement are *Schoenoplectus lacustris* (common clubrush) and other wetland (marshy) taxa, such as *Oenanthe aquatica* (fine-leaved water-dropwort), *Cladium mariscus* (great fen-sedge) and *Mentha* sp., probably *M. aquatica* (water mint) (Tables 4 and 1 in supplementary material). Their remains had been deposited at least partially naturally, which supports the assumption that the settlement was located on marshy ground. Aquatic plants probably became entangled in the maze of piles during flooding (Turk and Horvat 2009), which also suggests that the settlement was very close to the lake.

The finds of *Cyperus fuscus* (brown galingale) in the earlier layer are interesting. This plant is very typical of periodically dry lake shores. It has also often been found at sites north of the Alps, just at the transition from natural sediment, mostly lake marl, to the cultural layer (Jacomet 1985). Geoarchaeological (micromorphological) studies of other lake shore settlements have also revealed that a lowering of lake levels was observed before settlement activities began, as at Arbon (Ismail-Meyer and Rentzel 2004). This might also have happened at Stare gmajne (Turk and Horvat 2009).

In the intermediate layer, a massive increase of *Oenanthe aquatica* is evident (Table 4). This could indicate that the conditions at the settlement had changed, maybe due to reduced human activities there; for sedimentological analysis of the settlement surroundings, see Turk and Horvat (2009).

The remains of fish such as *Esox* (pike) and water plants like *Trapa natans* indicate the considerable importance of the lake for the economy. In addition, fishing and hunting of birds that live in wet environments have been proven by analyses at other pile dwellings on Ljubljansko barje (Janžekovič and Malez 2004; Velušček et al. 2004) and evidence was also found at Stare gmajne, but has not been investigated in detail so far (Velušček and co-workers, unpublished).

Many other seeds/fruits of aquatic and marshland plants found in the samples could also have been deposited in the cultural layer due to human activity, for instance by the use of reeds for roofing houses. What proportion of these plants was brought to the layer by human action and which were deposited naturally is hard to say. The remains of two dugout boats that were found at the dwelling from the later settlement phase also show that the people used lake resources (Velušček et al. 2009a, b).

Environment and its use around the site, outside the lake

From the wood spectra, we can assume that there must have been floodplain sites near the settlement where tree taxa such as *Alnus*, *Salix*, *Quercus* (*robur*), *Fraxinus* and *Populus* grew. Outside of the floodplain, on the slopes of the Dinaric mountains, woody taxa such as *Quercus* (*petraea*), *Fagus*, *Acer*, *Carpinus*, *Abies* and *Corylus* could have grown (Figs. 1b, 3).

For the piles, the settlers most probably preferred *Quercus* which has durable heartwood. In addition they used large quantities of *Fraxinus* which was presumably very abundant near the settlement. The largest part of the wood for the piles—at least half of it—must have originated from floodplain sites, and only a minor part—less than 10%—very probably came from the woodland on the slopes of the Dinaric mountains, which start ca. 700 m from the dwelling; human activities probably very much affected them. Based on our data, it is not possible to reconstruct the exact degree of human impact, but it is probable that especially the nearby woodland was used for cutting trees, for pasturing domestic animals, gathering, hunting etc. Strong anthropo-zoogenic influence and an intense use of these areas is indicated by 13 plant taxa characteristic of woodland clearings and margins in present day plant communities (see Table 1 in supplementary material). Seven of them were probably gathered: *Fragaria*, *Rubus*, *Physalis*, *Cornus*, *Prunus spinosa* (sloe), *Corylus* and *Crataegus monogyna* (hawthorn) (Table 4; see also the chapter on gathering). But not only edible fruits and nuts were gathered there, animal fodder and litter with leaves and branches were also brought to the site. Although we do not have exact data for animal husbandry and hunting at Stare gmajne, we can relate it to the results from slightly earlier nearby sites, Hočevarica and Črešnja pri Bistri, where the bones of mammals have been investigated (Toškan and Dirjec 2004; Velušček et al. 2004; Toškan 2008). At these sites, *Ovis aries* (sheep), *Capra hircus* (goat) and *Sus domesticus* (pig) predominated, whereas *Bos taurus* (cattle) were less frequent. Based on analyses of bones, domesticated animals provided an important source of meat for human nutrition. However, hunting was important, too. The most frequent hunted animals were *Cervus elaphus* (red deer), *Capreolus capreolus* (roe deer) and *Sus scrofa* (wild boar).

Based on the ecology of the weeds according to ecological indicator values (Ellenberg 1991), the fields must have been situated on moist to damp soils, possibly with a neutral pH, rich in nitrogen. Such suitable land for cultivation was probably situated on the slightly elevated edges of the floodplain. Flat plateaus on the hilly terrain may also have been used to lay out fields, for example, the elevated plateau at ca. 1 km south of Stare gmajne (Fig. 1b), because they were naturally protected from flooding. Other possibilities for fields were on the nearby islands in the lake, such as the hill Blatna Brezovica (326 m a.s.l.), at a distance of ca. 1.4 km from Stare gmajne, where the remains of another pile dwelling, Blatna Brezovica, settled around 3071 cal. B.C., have been found (Čufar et al. 2010).

It is not possible to ascribe different weeds to different crops. Therefore we cannot be sure about summer and winter crops, although summer crop weeds prevailed in the spectrum and both perennial and annual weeds were recorded. Since we found taxa among the perennials characteristic of disturbed habitats, the soil preparation was probably effective (see Bogaard 2002). For the many problems concerning the interpretation of Neolithic weed spectra, we refer to Hosch and Jacomet (2004) and also Bogaard (2004).

Comparison of the spectra of the economically important plants with those from other circum-Alpine sites

In the entire circum-Alpine area there were many settlements in the second half of the 4th millennium B.C. On the sites at Ljubljansko barje that existed at the same time as Stare gmajne unfortunately no adequate archaeobotanical investigations have been carried out (Tolar et al. 2010). Therefore, we selected 39 late Neolithic waterlogged sites dated between 3496 and 3000 cal. B.C. for which archaeobotanical data exist for comparison with Stare gmajne (Table 4 in supplementary material; Fig. 5). The selected sites are located in France, Germany and Switzerland (Fig. 1a; after Jacomet 2006a, 2009; Herbig 2009a).

Cereals

The three cereals found at Stare gmajne, *Triticum monococcum*, *T. dicoccum* and *Hordeum vulgare*, were also the most important cereals in lake dwellings north of the Alps (Fig. 5). In addition, they also seem to have been the most important cereal taxa south of the Alps in northern Italy (Rottoli and Castiglioni 2009). There is, however, one striking difference between the cereal spectra from Stare gmajne and those from the northern Alpine settlements: *Triticum durum/turgidum* (tetraploid naked wheat), one of the most common cultivars north of the Alps, was not found at Stare gmajne and also seems to have been rare in northern Italian late Neolithic sites. To our knowledge, *T. durum/turgidum* has not yet been found at any of the Slovenian Neolithic lakeshore settlements. This all confirms the hypothesis that *T. durum/turgidum* might have come to central Europe from the southwest and not from the southeast via the Balkans (Maier 1996; Jacomet 2007). In contrast, the great importance of *T. dicoccum* at Stare gmajne confirms the hypothesis that the rising importance of emmer during the late Neolithic in sites north of the Alps could have been influenced by the cultures to the east (Jacomet 2006a).

The archaeobotanical results from Stare gmajne show clear hints that processing of cereals was done in the settlement, because cereal chaff and weed seeds were found in large amounts (Tables 1 and 2 in supplementary material). This is similar to other lakeshore settlements. Carbonised grains were under-represented because we did not excavate any burnt structures.

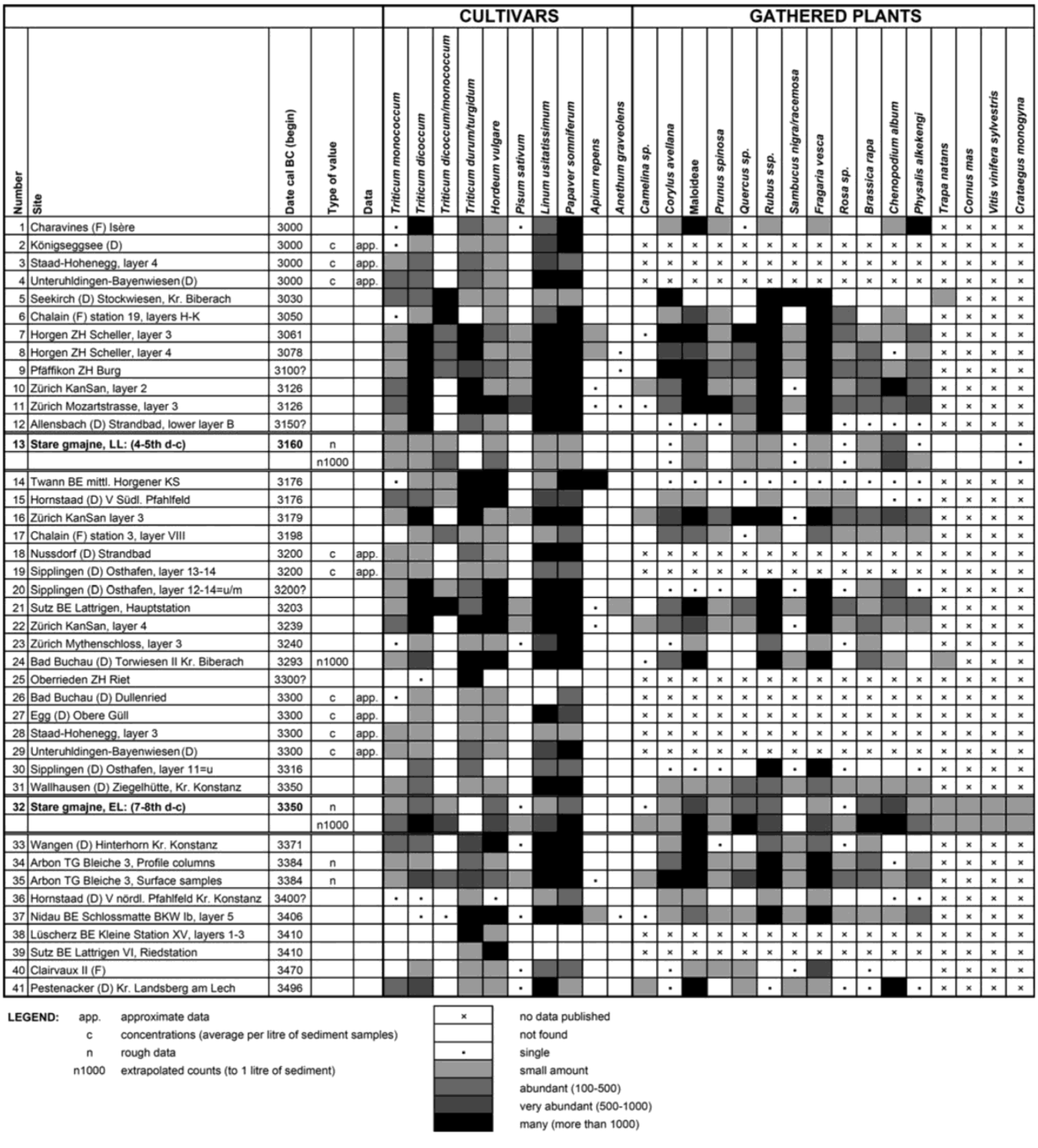

Fig. 5 Presence of crops and gathered plants in selected archaeobotanically investigated sites dated 3500–3000 B.C. in the Alpine region (compare Table 4 in supplementary material). The scheme has been compiled based on published numbers (see Table 3 in supplementary material). The last four columns show gathered plants with a significant presence in the early layer of Stare gmajne; they are mainly absent from other sites

Oil and fibre plants

The oil plants *Linum usitatissimum* and *Papaver somniferum* also provided important nourishment during the late Neolithic (Jacomet 2009; Kohler-Schneider and Cannepele 2009; Pieroni 1999). In addition, they may have been used for other purposes, *Linum* above all for its fibres, and *Papaver* for its medicinal and hallucinogenic properties (Zohary and Hopf 2000; Merlin 2003). The latter, however, cannot be proven by archaeobotanical means.

Papaver was found in considerable amounts in the north Alpine sites from the 2nd half of the 4th millennium cal. B.C. (Fig. 5; Table 3 in supplementary material). We presume that the *P. somniferum* found there is a cultivar, even if differentiation from the seeds of the wild ancestor *P. setigerum* is not clearly possible (Hammer and Fritsch 1977). However, *Papaver* is missing from Chalcolithic sites in northern Italy, but probably for taphonomical reasons (Rottoli and Castiglioni 2009). Our finds at Stare gmajne as well as the somewhat earlier Slovenian finds at Hočevarica, Ljubljansko barje dated ca. 3500 B.C. (Jeraj et al. 2009) now show that *Papaver* was present in the eastern part of the northern Mediterranean region during the late Neolithic. However, it remains unclear from where the *Papaver* arrived, as the origin of domesticated *Papaver* is not yet clear (for a very recent review, see Salavert 2010). We do not have enough data for detailed discussion here, and comparisons with early Neolithic data are not possible since the time gap between the early and late Neolithic is too large.

The remains of *Linum* found at Stare gmajne are also of great interest because these are the first flax finds in a Slovenian Neolithic site. This is mainly due to the improved recovery techniques, which did not allow its detection from former excavations on Ljubljansko barje (Tolar et al. 2010). The large amounts of *Linum* usually found in late Neolithic lakeshore settlements north of the Alps (Jacomet 2006a; Fig. 5) indicate its great importance for several purposes (Hosch and Jacomet 2004, for importance for textiles see Médard 2010). We suppose that it was important during the late Neolithic in Slovenia as well.

Pulses

Pulses are known as important sources of food, above all proteins. However, only *Pisum sativum* appears regularly at most sites north of the Alps (Jacomet 2009; Table 3 in supplementary material). Larger numbers of peas were only preserved there in burnt layers in a carbonised state. There are, however, also regular finds of uncharred pea pods and calyces at various lakeside and moorland sites in Germany as at Hornstaad (Maier 2001) and at Alleshausen-Hartöschle (Maier 2004). At Stare gmajne, we found only three pieces of carbonised *Pisum* seeds, and no waterlogged remains. This is similar to the case of Arbon Bleiche 3, where only three carbonized peas were found in a much larger amount, 340 l, of sieved cultural layer material (Hosch and Jacomet 2004). Since mostly small amounts of *Pisum* have been detected at different lakeside settlements, we can suppose that peas might have been of minor importance. On the other hand it is possible that pea remains were simply not preserved due to unknown taphonomic reasons (Jacomet 2006a, 2009).

Gathering

The list of wild plants probably used for human food, according to ethnographic literature (Ertug-Yaras 1997), is similar to that at other lakeshore settlements where gathered taxa were quantified (Fig. 5). Some hypothetical modelling allows the supposition that at Arbon Bleiche 3, for example, at least a third of the calories were provided by gathered plants. We assume that the great quantity of collected plants found at Stare gmajne indicates that gathering was very important there, too.

In terms of fruits containing starch and oil that could be used as staple foods, the most important gathered taxa at Stare gmajne were *Quercus* (acorns), *Corylus avellana* and *Trapa natans*. The latter are very calorific and can also be ground to flour. Acorns and hazelnuts have also been found in large amounts in other circum-Alpine prehistoric sites (Table 4 in supplementary material, Fig. 5; for the importance of acorns as a staple food see Karg and Haas 1996). *Quercus robur* could have been collected on the floodplain adjacent to the lake, *Q. petraea* from the slopes beyond, and *Corylus* from thinner woodland, woodland edges or clearings outside the swampy lake area.

The water plant *Trapa natans* is of special interest since it is not found everywhere in such large amounts. *Trapa* finds are more restricted to small and especially shallow meso- to eutrophic lakes which become warm in summer. Therefore, water chestnut was for instance common in the Federsee region during the whole Holocene until the Bronze Age (Karg 2006), but it has also often been found in various Neolithic sites of southeast Europe (Borojevič 2009). Federsee and also the lake that existed at Ljubljansko barje were presumably suitably shallow lakes with calm water and quiet bays offering favourable conditions for this plant (Fig. 1b), whereas in the larger, deeper lakes like Lake Constance (Bodensee) this plant could not survive because of the harsh winds and strong lake level fluctuations.

In addition to the gathered staple foods, there is a rather long list of gathered wild fruit taxa from Stare gmajne (Table 3). Most of them also often appear in settlements north of the Alps (Fig. 5). The taxa which are rarer north of the Alps include *Cornus mas* (cornelian cherry) and *Vitis vinifera* ssp. *sylvestris* (wild grape), which were found in the early layer of Stare gmajne. Their occurrence might be due to ecological conditions to the south of the Alps which were possibly more favourable than those north of the Alps. Finds of these taxa from Neolithic sites in northern Italy (Rottoli and Castiglioni 2009) point in the same direction. *V. vinifera*, for example, nowadays grows in Slovenia on warm and dry places in sub-Mediterranean areas or on sunny sand hills and river banks (Tolar et al. 2008). Near Stare gmajne there were such places appropriate for the growth of *Vitis*, especially on the nearby slopes with a southern exposure. In contrast, north of the Alps, *V. vinifera* probably grew only on larger floodplains such as those of the Danube and the Rhine. Remains are therefore not likely to be found in lakeshore settlements there. There is an isolated find of wild grape from Meersburg-Ramsbach on Lake Constance (Horgen culture, ca. 2900 cal. B.C.; Herbig 2009b).

Cornus mas is also fairly rare in natural stands north of the Alps. Finds of its fruits are usually rare or absent, or they are considered to have been imported. For *C. mas* fruit finds from the western Lake Constance region it is supposed that they were imported (Hoffstadt and Maier 1999; Maier 2001), and that there might have been some secondary but not indigenous stands at Lake Constance (Hosch and Jacomet 2004).

Chenopodium album and *Brassica rapa* commonly occur in fields as weeds. They can also show high densities on temporary fallows (Jacomet, personal communication). Both plants have seeds rich in starch, oil and proteins. Since they regularly appear and are often abundant in Neolithic cultural layers (Fig. 5), we assume that the settlers probably collected them for food (see Schlichterle 1981; Brombacher 1997).

It is also worth mentioning the regular appearance of *Viscum album*. Neolithic people could have used it in various ways. In Hornstaad (G) Hörnle IA, mistletoe remains were detected in human coprolites, which suggest that it was consumed. It was probably used for medicinal purposes (Maier 2001). On the other hand, remains of mistletoe regularly occur in the coprolites of ruminants (Kühn and Hadorn 2004).

In addition to the often mentioned gathered plants, we found parts of the fruiting bodies of various fungi that could not be exactly identified. Jacomet et al. (1989) reported that fungi, along with some other vegetable and salad plants, may have played an important role in the diet of Neolithic people. The abundance of their remains does not directly indicate how important they were, because they are rarely preserved. In a previous excavation at Stare gmajne the whole fruiting body of *Daedalea quercina* (maze-gill fungus) was found, which usually grows on dead wood, mainly oak and causes brown rot. Though inedible, its fruit bodies could have been used, for instance, as a natural comb (Rolfe 1974).

We also found many fragments of mosses which were presumably brought to the settlement for insulation material in the buildings (Table 1 in supplementary material; Hosch and Jacomet 2004). The remains of a sort of fabric were found, too. Its identification with the help of a scanning electron microscope showed that it was made of lignified material, probably bast (Reichert 2007). Finally, one larger piece of well-processed yarn was found during one of the previous excavations at the site in 2006. It originated from the latest settlement phase and was made of the spun fibre of an unknown Poaceae species (Pajagič Bragar et al. 2009).

Conclusions

The late Neolithic pile dwelling of Stare gmajne on Ljubljansko barje, Slovenia has only recently been exactly dated by dendrochronology. It was inhabited in two periods, during an early phase about 3350 to 3330 B.C. and during a later one lasting about 50 years and ending after 3110 cal. B.C. Based on this, the site can be considered to be partly contemporary with the Alpine Iceman (Ötzi).

Our investigations revealed that there are many similarities in useful plant spectra between Slovenian and northern Alpine lake dwelling sites. There are, however, also some differences. Among the crop plants, we noted the absence of *Triticum durum/turgidum* at Stare gmajne. Furthermore, we found *Papaver somniferum* in greater amounts. It was previously found only on one Slovenian site. Furthermore, the improved recovery techniques made it possible to recover the remains of *Linum usitatissimum* for the first time at a Slovenian Neolithic site. This all sheds a new light on the early history of these crop plants in Europe.

In addition to numerous similarities, we also observed some differences within the group of gathered plants. In the early layer of Stare gmajne *Vitis vinifera* ssp. *sylvestris*, *Cornus mas* and *Trapa natans* were found. They had previously already been found at other Slovenian pile dwelling sites but they are rare or absent north of the Alps. This may be due to ecological differences.

The people of Stare gmajne influenced the vegetation in the vicinity of the settlement by agricultural cultivation and gathering, as well as by pasturing and fodder collecting activities, as in other circum-Alpine lakeside settlements (Jacomet et al. 2004).

In future excavations on exactly dated sites, more material should be collected and investigated in a representative way, using appropriate recovery techniques. Only additional results can improve the picture of the nutrition, activities and organisation of the settlers, as well as of the ecological conditions at and around the pile dwellings in Slovenia. In addition, comparisons with pollen analyses and other interdisciplinary investigations should be made in order to interpret the climatic and ecological conditions and disturbances in the period of the 4th and also 3rd millennium B.C.

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2.3 DATIRANJE BARJANSKIH KOLIŠČ IZ 4. TISOČLETJA PR. N. ŠT. (DATING OF 4TH MILLENIUM BC PILE-DWELLINGS ON LJUBLJANSKO BARJE, SLOVENIA)

Čufar K., Kromer B., Tolar T., Velušček A. 2010. Dating of 4th millennium BC pile-dwellings on Ljubljansko barje, Slovenia. Journal of Archaeological Science 37: 2031-2039.

V članku predstavljamo absolutne datacije sedmih pozno neolitskih (eneolitskih) kolišč z Ljubljanskega barja. Z dendrokronološkimi in radiokarbonskimi raziskavami lesa s kolišč je bilo ugotovljeno, da so bila poseljena od pribl. 3600 do 3332 (± 10) pr. n. št. in 3160 do 3071 (± 14) pr. n. št. Definirali smo 11 obdobij intenzivne gradbene aktivnosti in eno večjo naselitveno prekinitev, to je obdobje, ko ni bilo najdenih na novo posekanih dreves za gradnjo ali obnovo bivališč, kar nakazuje, da je bilo območje v času od 3332 do 3160 pr. n. št. najverjetneje neposeljeno. Večja naselitvena prekinitev je najverjetneje sledila tudi po letu 3071 pr. n. št. Raziskava je vključevala preko 2500 kosov arheološkega lesa, večinoma ostankov kolov, na katerih so stale lesene hiše (kolišča). Med pomembnejšimi lesenimi najdbami je bilo tudi kolo z osjo (del dvokolesnega voza). Gre za eno najstarejših tovrstnih najdb na svetu. Poleg tega sta bila najdena tudi dva drevaka. Vsi trije artefakti so bili datirani v obdobje od 3160 do 3100 pr. n. št. Paralelne študije so pokazale, da je gospodarstvo kolišč na Ljubljanskem barju poleg vešče obdelave in uporabe lesa slonelo tudi na metalurgiji bakra, gojenju kulturnih rastlin, živinoreji, prav tako pa sta bila pomembna tudi lov in nabiralništvo. Barjanska kolišča so bila sočasna z mnogimi jezerskimi naselbinami severno od Alp. V 2/2 4. tisočletja pr. n. št. je živel tudi nedavno odkriti »ledeni mož« – Ötzi. Zaradi strateško ugodne pozicije Ljubljanskega barja, med zahodno centralno in vzhodno južno Evropo, predstavljajo datacije, ki jih navajamo v tem članku, pomemben korak za poznavanje življenja v prazgodovini in bazo podatkov za nove primerjave z zahodno Evropskimi istodobnimi naselbinami, ki so tudi dokaj natančno datirane. S tem bo mogoča tudi ocena povezanosti naselbin in njihovega kulturnega razvoja.

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Dating of 4th millennium BC pile-dwellings on Ljubljansko barje, Slovenia

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ABSTRACT

We present absolute dates of seven late Neolithic pile-dwellings on Ljubljansko barje, Slovenia. They were settled from ca. 3600 to 3332 (±10) and from 3160 to 3071 (±14) cal BC, as shown by investigations of wood using dendrochronology and radiocarbon wiggle-matching. We defined eleven periods of intensive tree felling (and building activities) and one major settlement gap (when no trees were felled) from 3332 to 3160 cal BC. A major settlement gap presumably also followed after 3071 cal BC (i.e., after the end date of the investigated sites). Our investigations included over 2500 pieces of wood, mainly from the piles on which the dwellings were built. Among important wooden artefacts were a wheel with axle (one of the oldest preserved wheels in the world) and two dugout canoes, all from the settlement phase from 3160 to 3100 cal BC. As shown by parallel studies, the economy in the sites was characterized by copper metallurgy, skilful wood processing and use, cultivation of domestic plants, gathering of wild plants, animal husbandry, hunting and fishing. The settlements were contemporaneous with a number of sites in the north of the Alps, the younger ones coincided with the lifetime of the Neolithic Iceman (Ötzi). Since Ljubljansko barje has a strategic position at the crossroads between western central and (south) eastern Europe the presented absolute dates provide a basis for their comparison with other dated contemporaneous sites (in the west), to revise the chronology of similar sites in the (south) east (which are not yet exactly dated), and to evaluate their interconnection and roles in cultural development in prehistory.

1. Introduction

Prehistoric pile-dwellings SE of the Alps are important for understanding the cultural interaction between north-western and south-eastern Europe at the time of their existence. However, their exact dating is crucial to be able to compare them with contemporary sites in the surrounding regions. Archaeological timbers, often well preserved in wetlands, have the potential to provide exact dates when the trees were felled (e.g., Haneca et al., 2009). Dendrochronological dating is only possible if adequate reference tree-ring chronologies are available for the region, tree species and period of interest. When they are not available, it is necessary to check whether a teleconnection exists and whether a dating can be made with remote reference chronologies. When even this is not possible, radiocarbon analysis can be used for absolute dating of the wood. Dating can be especially precise when several sequentially spaced ^{14}C dates are obtained and calibration can be performed with the aid of the wiggle-matching methodology (e.g., Kromer, 2009).

Ljubljansko barje is a 180 km^2 large floodplain in central Slovenia, situated at the SE edge of the Alps (Fig. 1). It has a strategic position at the crossroads between the Danube and the Po river lowlands and between the Eastern Alps and the Balkans and is known for its prehistoric pile-dwellings, which were first discovered in 1875. Since then, several archaeological excavations have taken place in the area and approximately 40 pile-dwelling sites have been documented (Velušček, 2004a). The settlements were not accurately dated for a long time after their discovery and exact dating was badly needed to evaluate their role in cultural development and interactions between western and south-eastern Europe in the late Neolithic.

In 1995, interdisciplinary research supervised by the Institute of Archaeology of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts started excavations with the aim of systematically collecting wood for dendrochronological and radiocarbon dating. Since then, numerous dendrochronological (University of Ljubljana) and radiocarbon (Heidelberg Academy of

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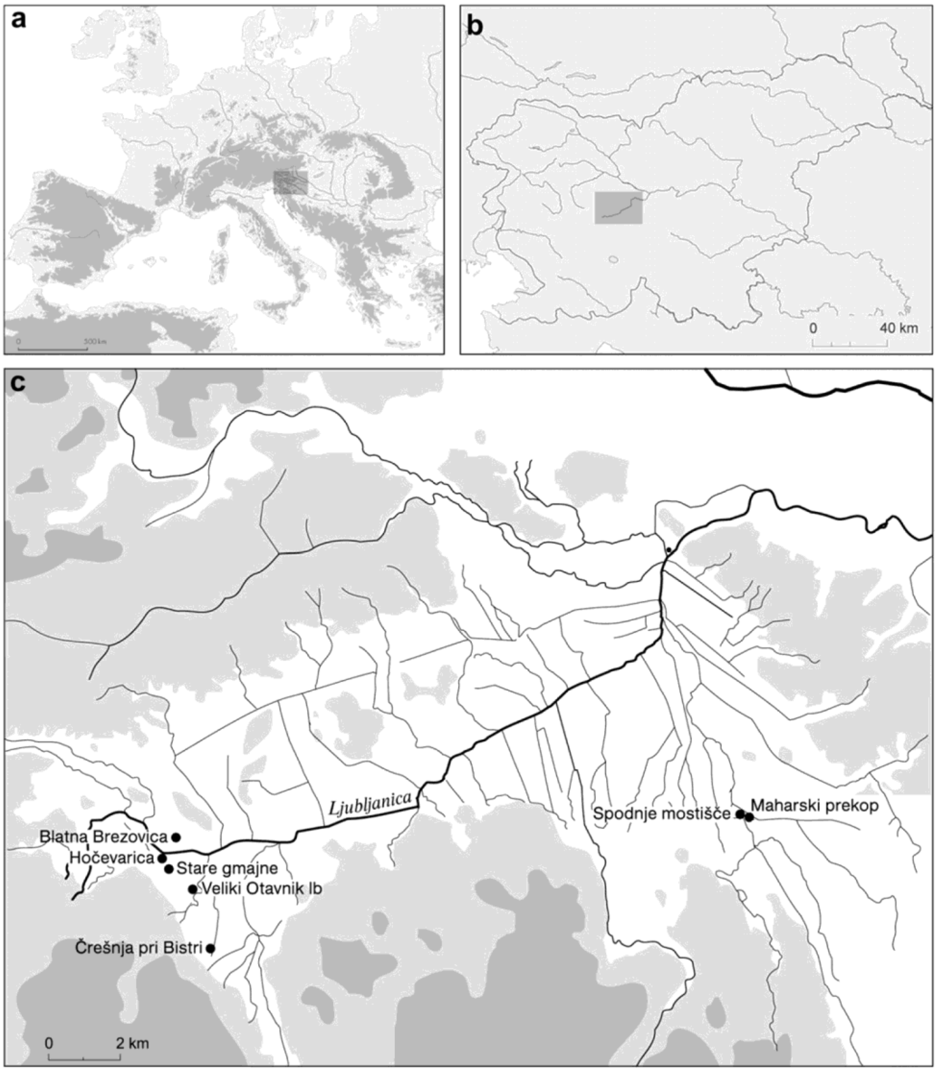

Fig. 1. The location of (a) Slovenia in Europe and (b) Ljubljansko barje in Slovenia. (c) The 4th millennium BC pile-dwellings on Ljubljansko barje from the oldest to the youngest: Hočevarica (HOC), Maharski prekop (MP), Črešnja pri Bistri (CB), Spodnje mostišče (SM), Stare gmajne (SG), Veliki Otavnik (VO), and Blatna Brezovica (BB).

Sciences) analyses have been performed. All this has provided us with the first absolute dates of the pile-dwelling settlements, from the oldest, dated to approx. 4600 cal BC, to the youngest ones from the beginning of the 2nd millennium BC (e.g., Velušček and Čufar, 2002; Velušček, 2006). With the exception of the oldest one from 4600 cal BC and few Early Bronze Age settlements, all other sites can be dated to the Late Neolithic (Eneolithic in Slovenian terminology) period, when copper metallurgy played a crucial role in the society (Velušček, 2004a).

This article is devoted to a group of lakeshore pile-dwellings of the 4th millennium BC. Culturally, the oldest settlement belongs to the "Furchenstich" horizon, while the others are contemporaneous to the Baden culture, which dominated the central Danubian area (e.g., Kalicz, 1991; Forenbaher, 1993).

The objectives of this study were:

- to perform excavations on prehistoric pile-dwellings of Ljubljansko barje and to collect wood for dating by means of dendrochronology and the radiocarbon wiggle-matching methodology,
- to assess the time of existence of the pile-dwellings and to reconstruct possible construction phases and repairs on them,
- to discuss the selection of wood species for building timbers and their importance for better understanding of the surrounding environment, and
- to obtain information on the occupation and abandonment of the Ljubljansko barje and relate it to occupation in the surrounding areas.

2. Material and methods

2.1. Archaeological sites

Between 1995 and 2007, we performed archaeological excavations at seven wetland sites: Hočevarica (HOC), Maharski prekop (MP), Črešnja pri Bistri (CB), Spodnje mostišče (SM), Stare gmajne (SG), Veliki Otavnik (VO), and Blatna Brezovica (BB). They were all located at the southern edge of Ljubljansko barje (Fig. 1, Table 1).

Table 1
Dendrochronologically investigated 4th millennium BC pile-dwellings on Ljubljansko barje with the year of their discovery, years of archaeological research, years when dendrochronological investigations were used at the site, type of excavation, and total number of wood samples collected.

Site code	Site name	Discovery	Archaeological research	Archaeology & dendro–chronology	Type of research
HOC	Hočevarica	1992	1995, 1998	1995, 1998	Rescue excavation in the drainage ditch (1995, 1998) Excavation – trench (1998)
MP	Maharski prekop	1953	1970-1977, 2005	2005	Excavation (1970–1977) Re-excavation (2005)
CR	Črešnja pri Bistri	2003	2003	2003	Rescue excavation in the drainage ditch
SM	Spodnje mostišče	1876	1996, 1997	1996, 1997	Underwater research (in the river)
SG	Stare gmajne	1992	1995, 2002, 2004, 2006, 2007	2002, 2004, 2006, 2007	Rescue excavation in the drainage ditch (2002, 2004) Excavation – trench (2006, 2007)
VO	Veliki Otavnik Ib	2006	2006	2006	Underwater research (in the river)
BB	Blatna Brezovica	1942	1953, 2003	2003	Excavation (1953) Re-excavation (2003)

The wooden dwellings were built on piles that were pounded in the ground. Copper metallurgy played an important role in the economy of all sites. The dwellers produced moderately decorated black or dark grey pottery and used mainly stone tools. They were skilful in wood processing and using it for constructional purposes, dugout canoes, charts (Fig. 2), and other products. Their economy was based on the cultivation of domestic plants, gathering of wild plants, animal husbandry, hunting and fishing (Velušček, 2004a).

2.2. Archaeological excavations

We used various strategies to collect the wood: (1) re-excavation, (2) rescue excavation and (3) underwater archaeology (Table 1). Re-excavation of previously investigated sites was made to collect wood that had been documented during previous excavations and was then reburied. Rescue excavations included documentation and excavation of wood and other remains (archaeological artefacts, remains of plants and animals, etc.) in drainage ditches on terrain currently used for agricultural production. In Hočevarica and Stare gmajne, we additionally made trenches with dimensions from 8 to 15 m^2 for acquiring macrobotanical and other remains. Techniques of underwater archaeology were applied at the sites Spodnje mostišče and Veliki Otavnik Ib (Fig. 1; Table 1), where samples were taken from piles found in the river beds. In this case, most of the wooden parts (mainly vertical piles) were still *in situ*, but the cultural layer had been destroyed by erosion.

2.3. Wood for dendrochronology and radiocarbon dating

We collected a total of 2541 samples of wood (Table 2). They were taken from all preserved wooden finds, regardless of their form, size or wood species. The precise geographic coordinates were first determined for each of the wooden finds on the ground plans of the dwellings and then 10–20 cm long samples were cut for analysis. In the laboratory, they were smoothed and observed under a stereo microscope for tree-ring counting, wood identification, and dendrochronological analysis. The preservation of the wood was sufficient for such investigations, although its structure and characteristics had changed due to water-logging over millennia (Čufar et al., 2002, 2008b).

Microscopic wood identification was done with the aid of standard identification keys (Schweingruber, 1982). Furthermore, for each of the samples we noted whether the bark and the last ring below it were preserved and whether the last ring was completed (indicating that the tree was felled after the end of vegetation period). We then counted the number of tree-rings and the number of sapwood rings (if the sapwood could be differentiated from the heartwood).

In all oak (*Quercus* sp.) and ash (*Fraxinus* sp.) samples containing 45 or more tree-rings, their widths were measured with the aid of a LINTAB movable table, stereo microscope and the TSAP/X or TSAP-Win programmes. The tree-ring series (ring widths vs. time) were visually and statistically cross-dated and compared with each other by calculating the *t*-values according to Baillie and Pilcher (1973). All the series that demonstrated visual and statistical (t-value > 3.5) agreement were combined into floating undated oak and ash chronologies. Further comparisons showed that the ash chronologies of different sites could not be cross-dated with other ash or oak chronologies, so we did not use them in the next steps of this study.

Since there are so far no absolutely dated reference chronologies for the prehistoric period in Slovenia, we attempted to date the oak chronologies with south German references (Billamboz, Tegel, Herzig, personal communication). These attempts were not successful, so we also prepared samples of wood for radiocarbon analysis.

Following the composition of the tree-ring chronologies, wood samples containing at least 40 g of wood were selected from each of the chronologies for radiometric radiocarbon dating. Because the wood (especially sapwood) was poorly preserved (see, e.g., Čufar et al., 2008b), we had to take 5–20 tree-rings from the outer heartwood to obtain the required mass of wood. The positions of the selected tree-rings were exactly documented on the chronologies. After the first ^{14}C dates had been obtained, we collected additional samples optimally to match the wiggles on the calibration curve. We thus obtained a series of closely sequentially spaced ^{14}C dates (Table 4, Fig. 3).

Calibration of the ^{14}C dates was done with the aid of the wiggle-matching methodology, which uses the non-linear relationship between the ^{14}C age and calendar age to match the shape of the ^{14}C calibration curve. In our case, the ^{14}C dates were calibrated using the "sequence" option of the OxCal 3.10 program using the IntCal04 calibration curve (Reimer et al., 2004). OxCal calculates the calibrated age and its confidence intervals for the midpoint of the youngest tree-ring sample, based on an optimal match of all the radiocarbon dates of the samples of the section (Galimberti et al., 2004).

3. Results and discussion

3.1. Wood species and oak chronologies

From a total of 2541 wood samples, oak (*Quercus robur* and *Quercus petraea*) and ash (*Fraxinus excelsior*) represented 41% and 36% of all samples, respectively (Table 2). The remaining wood

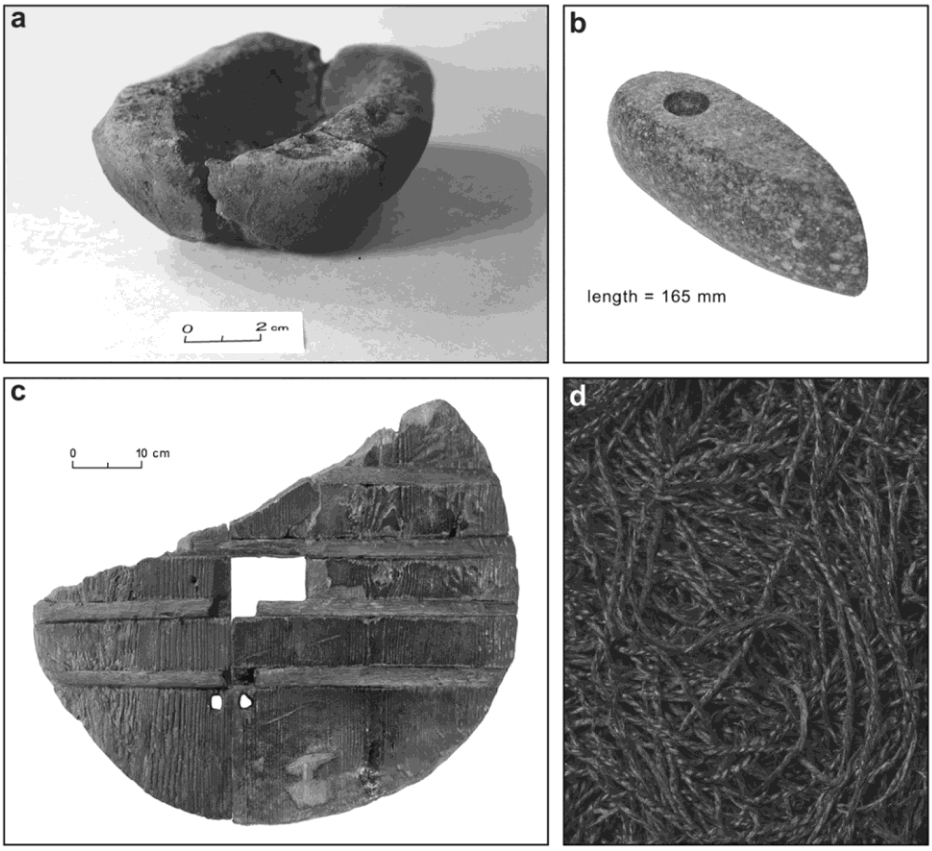

Fig. 2. Artefacts from the Stare gmajne pile-dwelling (after Velušček, 2009): (a) a crucible made of quartz-feldspathic siltite (34th century BC); (b) a shaft-hole axe made of metaultramafite (34th or 32nd century BC); (c) a wooden wheel (second half of the 32nd century BC or earlier); (d) restored remains of yarn (second half of 32nd century BC) probably made of the fibres of plants from the family of grasses (*Poaceae*).

belonged to alder (*Alnus glutinosa*), maple (*Acer* sp.), hornbeam (*Carpinus betulus*), hazel (*Corylus avellana*), beech (*Fagus sylvatica*), poplar (*Populus* sp.), willow (*Salix* sp.), elm (*Ulmus* sp.), silver fir (*Abies alba*) and yew (*Taxus baccata*). Only 18% of oak and 11% of ash had more than 45 tree-rings, which, on the basis of our observations, is the minimum number for performing statistically confirmed cross-dating. If the tree-ring series are shorter, they are less appropriate for building chronologies (e.g., Haneca et al., 2009) although they have research potential for studying wetland occupation (e.g., Billamboz, 2003).

Table 2
Number of samples of oak, ash and other species for each of the sites and the percentage of collected, dendrochronologically measured and cross-dated oak samples. Other species were: alder, maple, hornbeam, hazel, beech, poplar, willow, elm, silver fir and yew. For site names see Fig. 1 and Table 1.

Site code	Number of samples				Share of total (%)		
	Total	Oak	Ash	Other species	Oak	Oak measured	Oak cross-dated
HOC	361	57	213	91	16	5	4
MP	234	82	67	85	35	20	11
CR	124	61	25	38	49	19	14
SM	690	401	151	138	58	20	7
SG	932	334	409	189	36	21	9
VO	30	17	6	7	57	37	37
BB	170	87	55	28	51	11	8
	2541	**1039**	**926**	**576**	**41**	**18**	**9**

Measurements of tree-ring widths were therefore performed on samples of oak that had more than 45 tree-rings but only half of them (9% of the total) were cross-dated (Table 2). They were assembled into eight chronologies, two for Stare Gmajne (SG-old and SG-young) and one for each of the other sites (Table 3). Cross-dating (when t-values > 3.5) showed which chronologies overlap in time (Table 3). Finally, the overlapping chronologies MP-QUSP1, CR-QUSP1, SM-QUSP121 and SG-old could be joined into a composed chronology LJU4M-old. The chronologies SG-young and VO-QUSP1 were joined into LJU4M-young (Table 3, Fig. 4). The positions of HOC-QUSP1 and BB-QUSP1 could not be defined using the cross-dating procedure. We attempted to date the individual chronologies of sites and the two composed chronologies of Ljubljansko barje with south German references but the dating was not successful.

3.2. Calibrated ^{14}C dates and tree-ring chronologies

In the next steps, the chronologies were dated with the aid of ^{14}C dates calibrated with the wiggle-matching procedure (Table 4, Fig. 3). The radiocarbon dating of 8 samples of wood (Table 4) with known positions in the LJU4M-old chronology and their wiggle-matching with OxCal 3.10 (Fig. 3, white circles) helped to set the last ring of the chronology to 3342–3322 cal BC (2σ interval, 95% probability), i.e., 3332 ± 10 cal BC. Such a narrow interval (±10 years) could be obtained because we knew the distances (in years) among the individual ^{14}C dates. If we had calibrated each individual

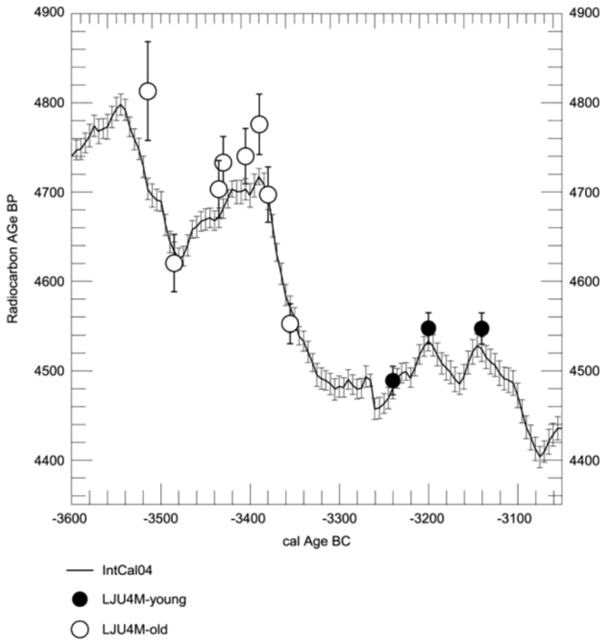

Fig. 3. Calibration using the "sequence" option of OxCal 3.10. Compare Table 4.

^{14}C BP date from the Table 4, we would have obtained much wider intervals of dating (e.g., 3890–3675 cal BC for sample Hd-22139; in Čufar and Kromer, 2004).

The further 3 samples for which we obtained 3 radiocarbon dates (Table 4, Fig. 3 black circles) helped us to set the last ring of the LJU4M-young chronology to 3123–3096 cal BC (2σ interval, 95% probability), i.e., 3109 ± 14 cal BC.

Since the end dates of the composed chronologies LJU4M-old and LJU4M-young were defined, we could also define the end dates of all chronologies cross-dated with them (Table 3, Fig. 4).

In addition to the samples described above, we also obtained three radiocarbon dates for Hočevarica (HOC) (Table 4) and their wiggle-matching helped to set the last ring of the chronology (HOC-QUSP1) to 3656–3636 cal BC (2σ interval, 95% probability). This indicated that HOC-QUSP1 was the oldest of all. Since the statistical parameters of its matching with other chronologies (e.g., MP-QUSP1, Table 3) were not significant, we matched the chronologies visually and estimated the end date of HOC-QUSP1 as ca. 3547 BC (Fig. 4).

The youngest chronology of Blatna Brezovica (BB-QUSP1) could also not be statistically significantly matched with other chronologies (Table 3). Its age was estimated by one sample dated to 4499 ± 21 BP (Table 4). The position of BB-QUSP1 is also estimated based on visual comparison with LJU4M-young chronology (end date 3071 cal BC).

3.3. *Occupation of sites and building activities inferred from dated tree-ring chronologies*

We could define the end date for each of the chronologies (year cal BC on the right of the chronologies, Fig. 4), indicating the year in which the youngest tree-ring was formed. Since in our study, most of the samples contained the bark and the last ring below it, we could assume that the end date of the chronology more or less corresponded to the final phase of site occupation. Based on the durability of oak wood, we can assume that constructions made from it could last for approximately a decade. However, despite this, according to our observations repairs were very frequent and they may have already started 1–2 years after the constructions were made.

Furthermore, we observed that in certain years or 1–3 year periods, larger amounts of trees were felled and piles with the same end year were located near to each other. Based on this, we assumed that building activities took place on the dwelling at a time when larger amounts of trees were cut. This could be particularly observed at Spodnje mostišče (SM) and Stare gmajne (SG), where we collected larger amounts of wood (Table 2). On this basis, we could estimate the time of occupation and the building activities at each of the sites. Individual trees felled in the years between building phases possibly indicated repairs to the constructions. Because we collected the wood from narrow ditches or small trenches we did not obtain enough data to reconstruct the exact ground plans of the dwellings.

The oldest settlement was Hočevarica with the end date of the oak chronology estimated to 3547 ± 10 cal BC. Previous investigations have shown that this was the second phase of the settlement, which had already appeared in the late 37th century BC (Čufar and Kromer, 2004).

Soon after Hočevarica was abandoned, the Maharski prekop pile-dwelling was settled on the other side of Ljubljansko barje. The samples indicate an occupation that lasted more than 20 years and ended around 3489 ± 10 cal BC (Figs. 1 and 4).

Sixty years later, Spodnje mostišče, located less than 200 m away from Maharski prekop, was occupied. We recorded several building phases, which ended around 3428, 3409, 3373, and 3353 ± 10 cal BC. At the same time, Črešnja pri Bistri was inhabited, in the opposite south-western part of Ljubljansko barje. Only one building phase was recorded here, with an end date of 3409 ± 10 cal BC, which coincided with one of the building phases at Spodnje mostišče. At Stare gmajne, in the south-western part of Ljubljansko barje, we recorded one phase of occupation, with an end date of 3332 ± 10 cal BC. After this, Ljubljansko barje was probably abandoned for approximately 170 years.

Table 3
Cross-dating parameters (*t*-values) and overlapping of the chronologies. The *t*-value is not given if the overlap is less than 50 years or when $t < 3$. For the codes, see also Table 1 and Fig. 4.

Chronology	Time span	Length	Maximal replication	*t*-Value/Overlap (years)			
	Cal BC	years	(No. of samples)	MP-QUSP1	CR-QUSP1	SM-QUSP123	SG-young
HOC-QUSP1	3685–3547 ± 10	139	16				
MP-QUSP1	3661–3489 ± 10	173	25				
CR-QUSP1	3545–3409 ± 10	137	17	4.9/57			
SM-QUSP123	3558–3353 ± 10	206	49	5.1/70	4.3/137		
SG-old	3506–3332 ± 10	175	6		3.7/98	4.7/154	
SG-young	3285–3109 ± 14	177	118				
VO-QUSP1	3239–3108 ± 14	132	11				8.8/131
BB-QUSP1	3145–3071 ± 14	75	13				

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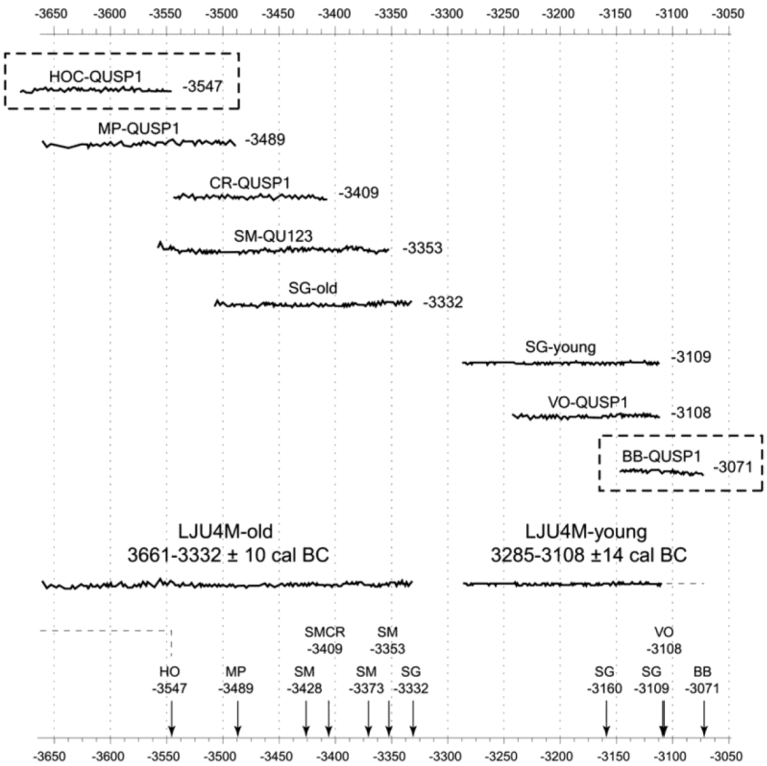

Fig. 4. Tree-ring chronologies of oak (QUSP) from Ljubljansko barje. Cross-dated chronologies of settlements MP, SM, CR, SG-old, SG-young, and VO, and most probable positions of HOC and BB (for legend of codes see Table 1 or Fig. 1). The numbers on the right represent the cal BC year of the last (youngest) tree-ring. Below: composed chronologies: LJU4M-old (MP, SM, CR, SG-old) with the last ring set at 3332 ± 10 cal BC and LJU4M-young (SG-young, VO) with the last ring set at 3109 ± 14 cal BC. Arrows show the years of intensive tree felling, indicating building phases at settlements.

After this gap, we recorded several renewed building activities at Stare gmajne (SG-young), from 3160 to 3109 ± 14 cal BC (Fig. 4). This period was characterized by intensive building activities that took place in 10–15 year intervals all over the site (Velušček, 2009). The end date of Stare gmajne coincided with that of Veliki Otavnik Ib (last ring 3108 ± 14 cal BC), located about 1 km away (Figs. 1 and 4). Visual matching of an ash chronology from Stare gmajne (not presented here) suggests that the settlement continued for some years after 3109 ± 14 cal BC. The Blatna Brezovica site, located less than 500 m away from Stare gmajne, was the youngest of all and was abandoned around 3071 cal BC.

After 3071 BC, Ljubljansko barje probably remained uninhabited for the next 300 years. The next phase of occupation was recorded at Parte-Iščica in the 29th/28th centuries BC (Velušček and Čufar, 2002).

Numerous building phases are presumably due to repairs that were necessary because of limited wood durability and due to needs to enlarge the settlements. However, dendrochronological research cannot explain the reasons for larger gaps between building activities, as for example between 3332 ± 10 and 3160 ± 14 cal BC. This gap could be due to a lack of preserved archaeological wood or more likely due to an occupation hiatus on Ljubljansko barje.

3.4. Characteristics of society and life on the pile-dwellings as inferred from archaeological finds

The collection of wood and other finds that was evaluated in parallel interdisciplinary investigations has helped us to obtain information on prehistoric society, its life in wet environments and its contacts with other settlements.

Interdisciplinary investigations were performed at locations at which cultural layers were sufficiently preserved, such as Hočevarica (Velušček, 2004b), Črešnja pri Bistri (Velušček et al., 2004), Stare gmajne (Velušček, 2009), Maharski prekop (Bregant, 1996) and Blatna Brezovica (Velušček, 2009). They included investigations of archaeological artefacts (pottery, tools), metal

Table 4
Radiocarbon dating. The samples of wood are sorted according to their positions on the calibration curve and dendrochronological matching with LJU4M-old or LJU4M-young tree-ring chronologies (compare Fig. 3). (AnaNrHd – sample code of the radiocarbon laboratory in Heidelberg, Nr(LJU) – sample number of the laboratory in Ljubljana, (*) position on chronology estimated visually).

AnaNrHd	NrLJU	$\delta^{13}C$	^{14}C BP	Cross-dated with
22 139	HOC-34	−28.37	4867 ± 26	LJU4M-old*
22 305	HOC-56(1)	−29.47	4825 ± 25	LJU4M-old*
20 765	HOC-56(2)	−29.19	4748 ± 26	LJU4M-old*
18 856	SM-564(1)	−27.76	4813 ± 55	LJU4M-old
21 329	SM-242	−29.34	4620 ± 32	LJU4M-old
18 785	SM-564(2)	−28.65	4703 ± 32	LJU4M-old
18 787	SM-619	−25.66	4733 ± 29	LJU4M-old
19 354	SM2-56(1)	−25.52	4740 ± 31	LJU4M-old
19 357	SM2-56(2)	−25.37	4766 ± 34	LJU4M-old
18 784	SM-26	−27.09	4697 ± 31	LJU4M-old
27 697	SG-745	−26.8	4552 ± 22	LJU4M-old
22 911	SG02-406	−27.86	4489 ± 16	LJU4M-young
27 938	SG-499	−29.8	4589 ± 26	LJU4M-young
22 385	SG02-441	−27.52	4547 ± 17	LJU4M-young
24 497	BB-03-48	−28.16	4499 ± 21	LJU4M-young*

objects and smelting equipment, botanical remains (pollen, macrobotanical samples, wood), remains of animals (domestic and wild mammals, birds, fish), and other finds. At the Spodnje mostišče and Veliki Otavnik Ib sites, which are underwater (in the river), the cultural layer is eroded, so interdisciplinary research was very limited.

The remains of pottery are important, because the typology served to estimate the age of the settlements before dendrochronology was introduced to Ljubljansko barje (e.g., Parzinger, 1984).

At Hočevarica, black and dark grey pottery prevailed (Fig. 5). The characteristic shapes were, for instance, a bowl with a large banded handle and ladle with a solid handle. Some fragments were decorated with furrowed incisions, an ornament that suggests that the settlement belonged to the Retz-Gajary culture after Dimitrijević (1980) or to the horizon of pottery with furrowed incisions, characteristic of Transdanubia in nearby Hungary (Kalicz, 1991; Velušček, 2004b).

At the slightly younger Maharski prekop, very moderately decorated black or dark grey pottery with many shapes similar to those at Hočevarica was found. We also observed some differences: for instance, vessels with handles were absent, furrowed incisions were lacking, and plastic decorations were present. At least some individual vessels therefore indicate contacts with the Boleráz group of the Baden culture (e.g., Parzinger, 1984; Velušček, 2009).

Pottery assemblages from Stare gmajne, which resemble the pottery from other studied settlements, strongly indicate contacts with groups of the Baden culture in the central Danube area and those from the *Caput Adriae*, the eastern Adriatic coast and the Alpine world in the second half of the 4th millennium BC (Velušček, 2009).

Nevertheless, the differences in pottery of the entire second half of the 4th millennium BC proved to be too small to be used for dating. Dendrochronology could not confirm the previous relative (and absolute) dating of the sites based on the typology of the pottery (Parzinger, 1984).

Copper metallurgy played an important role at all sites and it seems to have been introduced in the area for the first time in the 36th century BC at Hočevarica, where the remains of a crucible, a drop-shaped piece of copper and a flat copper axe were found (Velušček, 2004b; Trampuž Orel and Heath, 2008). Fragments of crucibles have also been found at other sites. At Stare gmajne, for instance, two complete crucibles were found, one made of clay and one of stone (Fig. 2a) (Velušček, 2009).

Fig. 5. Fragment of a pitcher from Hočevarica. The rich incised decoration on the outer surface is characteristic of the period of the "Furchenstich" horizon in the SE Alpine region.

The stone tools discovered show exploitation of local raw materials. Tuffs and tuffites originating not far from Ljubljansko barje were, for instance, used for axes and other tools. Imported materials were certainly used as well. Polished stone artefacts, such as two flat axes, for example, were made of HP metaophiolites, which can be found in north-western Italy, a few shaft-hole axes were made of serpentinites, which might have originated from central Austria and of metaultramafites (Fig. 2b), which might have come from areas more to the east. These finds indicate that Ljubljansko barje played a key role as a place of mediation between the Po lowland and the Danubian area and between the Eastern Alps and the Balkans (Bernardini et al., 2009).

Remains of mammals indicate that animal husbandry and hunting played an important role in all settlements. The studies of the remains of domestic animals indicate that stock-raising (both of cattle and small stock) was probably primarily oriented to the production of meat and fat (Velušček et al., 2004). It was concluded, for example, from the bones of domestic pigs at Hočevarica that slaughtering occurred late in the autumn and at the end of winter (Toškan and Dirjec, 2004). This indicated that the sites were settled all year around. Game, particularly roe deer and red deer, were also important sources of meat and fat.

The pile-dwellers on Ljubljansko barje grew barley and two types of wheat (*Triticum monococcum* and *dicoccum*). Poppy and flax seeds were also detected (Tolar et al., 2010). Large amounts of pips of the wild grape vine have been found in all settlements (Jeraj et al., 2009; Tolar et al., 2008).

The pile-dwellers needed large amounts of wood to build their dwellings. The wood was cut in the more or less nearby forests. We mainly investigated the remains of piles on which dwellings had been built. The upper parts of the constructions were not preserved. At Maharski prekop, the wood also came from a double enclosure, which protected the settlement, being similar to what has been found at some lakeshore settlements in the pre-Alpine regions in western and central Europe of this period.

The selection of wood species used for piles indicates that the settlers preferred oak with durable heartwood, which possibly grew on drier terrain at the edge of the floodplain. Such selection and skilful use of wood for different purposes shows that they were aware of the wood properties. In addition to oak, they also used large quantities of ash. Among the main reasons for this is that ash was very abundant and the amount of more durable oak was limited. In addition, ash presumably grew closer to the pile-dwellings, since it can grow on more swampy terrain than oak. Ash also has good stump regeneration (coppice) which made it possible to cultivate more timber, with a short rotation. They achieved the most desirable diameter (ca. 10 cm) in short period of time (10–15 years). The dwellers also frequently used the wood of alder, which is a typical species of occasionally flooded terrains (e.g., Čufar et al., 1997; Čufar and Velušček, 2004).

The piles usually contained the bark. The last ring below the bark normally contained the entire latewood, which indicates that the trees were felled after the vegetation period, i.e., in autumn or winter. Only occasionally did we observe a discontinuous band of the first earlywood vessels, indicating that the trees had been felled in early spring. All this supports the assumption that the sites were also occupied in winter.

In addition to the piles, we found some wooden artefacts. In Hočevarica, a bow made of yew (*Taxus baccata*) was found (Velušček, 2004b). The most valuable of all is the prehistoric wheel (Fig. 2c) with axle from Stare gmajne (dated between 3160 and 3100 cal BC) (Velušček et al., 2009a). It is among the oldest wooden wheels in the world (Bakker et al., 1999; Hartmann, 2006; Ruoff, 2006). Its design and elaboration again shows that the pile-dwellers were very familiar with the properties of wood and that they were skilful in wood processing. Two dugout canoes from the same settlement phase represent the oldest canoes in the area (Veluščck et al., 2009b).

3.5. Connection of Ljubljansko barje pile-dwellings to other contemporaneous sites

Many contemporaneous (dendrochronologically dated) pile-dwellings existed around lakes and peat bogs in Switzerland, SW Germany, SE France and northern Italy (Lake of Zürich, Lake of Constanz, Federsee, Lake of Chalain, Palù di Livenza, etc.) (e.g., Becker et al., 1985; Schlichtherle and Wahlster, 1986; Pétrequin et al., 1998; Billamboz, 1996, 2003; Čufar and Martinelli, 2004). On the other hand, settlements from eastern and south-eastern Europe are not as a rule exactly dated, so it is difficult to include them in comparisons.

Among the Alpine sites, those which were contemporaneous with the lifetime of the Alpine Iceman (Ötzi), who died between 3320 and 3050 cal BC (e.g., Kutschera and Müller, 2003), are particularly interesting. Jacomet (2009) made an overview and comparison of archaeobotanical data for several villages from the surroundings (radius ca. 100 km) of the place where the Iceman was found. They existed during his lifetime, and Jacomet (2009) reconstructed the use of plants and daily life in them in general. It was shown that even on exactly dated sites, comparisons can be difficult if recovery methods are not standardized.

The dating of prehistoric sites is not possible without dendrochronology supported by radiocarbon wiggle-matching, if no adequately long and replicated reference chronologies are available (e.g., Čufar, 2007; Haneca et al., 2009). A Slovenian reference tree-ring chronology for the 4th millennium BC does not yet exist. The majority of the investigated pieces of wood in our case had a low number of tree-rings and they could not be used for dendrochronology or we could only construct short chronologies. Although the chronologies are dated by radiocarbon, we could not exactly date them by means of dendrochronological teleconnection with remote references, for instance those from Germany (e.g., Becker et al., 1985). Future improvement and extension of Slovenian prehistoric chronologies should increase the likelihood of their teleconnection. Such teleconnection is already possible in the case of the 540 years long, well replicated, modern Slovenian oak chronology, which can be successfully cross-dated with chronologies within a radius of up to 700 km around Ljubljana (Čufar et al., 2008a).

4. Conclusions and future prospects

The presented dating of Ljubljansko barje tree-ring chronologies is so far the most accurate in the region. It has enabled us to assess settlement activities from ca. 3600–3071 cal BC, and an occupation gap from ca. 3332–3160 cal BC.

The dating fulfilled one of the basic requirements for comparisons of Ljubljansko barje with other archaeological sites. Comparisons with other Alpine sites could help to answer what role Ljubljansko barje had in the cultural development of the wider region. Located at the crossroads between west and east, it should be particularly interesting in this respect. Ljubljansko barje sites could also serve as a link to establish a revised absolute chronology for regions in eastern and south-eastern Europe that are not yet exactly dated. Examples of dendrochronological and ^{14}C dates from Ljubljansko barje have already indicated that a revision of the time of existence and interpretation of the mid 3rd millennium BC Pannonian cultures, e.g., the Late Vučedol and Samogyvár-Vinkovci cultures, is needed (Veluščck and Čufar, 2003).

Using the well replicated modern Slovenian oak chronology (time span A.D. 1456–2003) also confirmed that it could be a good reference point for developing dendrochronological dating in the regions SE of Slovenia, for which it does not yet exist (Čufar et al., 2008a).

Possible settlement gaps also deserve more attention, since occupation hiatuses have been detected on many places in west-central Europe in the 4th millennium BC (e.g., in Switzerland, SE France and SW Germany). They have been ascribed to climatic changes (towards a cooler and wetter climate), which seem to have been particularly turbulent in central Europe between 5550 and 5000 cal BP (Magny and Haas, 2004). The period from ca. 3332–3160 cal BC, when apparently no human activities (cutting of trees) took place on Ljubljansko barje, is particularly interesting for us. Future investigations should clarify whether this was a period of a settlement gap and whether it coincided with settlement gaps in other areas around the Alps.

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2.4 LESENO TOPORIŠČE KLADIVASTE SEKIRE S KOLIŠČA STARE GMAJNE NA LJUBLJANSKEM BARJU (THE WOODEN HANDLE OF A STONE HAMMER-AXE FROM THE ENEOLITHIC PILE-DWELLING SETTLEMENT STARE GMAJNE NEAR VERD IN THE LJUBLJANSKO BARJE, SLOVENIA)

Tolar T., Čufar K., Velušček A. 2008. Leseno toporišče kladivaste sekire s kolišča Stare gmajne na Ljubljanskem barju. Arheološki vestnik 59: 49-56

Na koliščarskem naselju Stare gmajne na Ljubljanskem barju je bila najdena kamnita kladivasta sekira iz druge polovice 4. tisočletja pr. n. št. z ostankom lesenega toporišča. Ker je bila kamnina za sekiro ali morda že izdelana sekira prinesena od drugod, je bila pomembna natančna identifikacija lesa toporišča. Anatomska preiskava je pokazala, da gre za les drena (*Cornus* sp.), ki je uspeval tudi v okolici kolišča. Les drena je zelo trd in trden ter ima visoko udarno žilavost, zato je bila njegova uporaba za toporišče velike in težke kamnite sekire zelo smiselna. To ponovno potrjuje, da je bil prazgodovinski človek dober poznavalec lastnosti lesa. Razpravljamo tudi o pomenu referenčnega materiala (vzorcev lesa in mikroskopskih preparatov sodobnih dreves in grmov) za razlikovanje lesa drena in pušpana (*Buxus sempervirens*). Slednji ima namreč podobno anatomsko zgradbo lesa, vendar kot sredozemska vrsta v prazgodovini domnevno ni uspevala v bližini kolišč z Ljubljanskega barja.

Arheološki vestnik 59, 2008, str. 49-56 49

Leseno toporišče kladivaste sekire s kolišča Stare gmajne na Ljubljanskem barju

Tjaša TOLAR, Katarina ČUFAR in Anton VELUŠČEK

Izvleček

Na koliščarski naselbini Stare gmajne na Ljubljanskem barju je bila najdena kamnita kladivasta sekira iz druge polovice 4. tisočletja pr. Kr. z ostankom lesenega toporišča. Ker je bila kamnina za sekiro ali morda že izdelana sekira prinesena od drugod, je bila pomembna natančna identifikacija lesa toporišča. Anatomska preiskava je pokazala, da gre za les drena (*Cornus* sp.), ki je uspeval tudi v okolici kolišča. Les drena je zelo trd in trden ter ima visoko udarno žilavost, zato je bila njegova uporaba za toporišče velike in težke kamnite sekire zelo smiselna. To ponovno potrjuje, da je bil prazgodovinski človek dober poznavalec lastnosti lesa. Razpravljamo tudi o pomenu referenčnega materiala (vzorcev lesa in mikroskopskih preparatov sodobnih dreves in grmov) za razlikovanje lesa drena in pušpana (*Buxus sempervirens*). Slednji ima podobno anatomsko zgradbo lesa vendar kot sredozemska vrsta v prazgodovini domnevno ni uspeval v bližini kolišč.

Ključne besede: leseno toporišče, kamnita kladivasta sekira, anatomija lesa, dren (*Cornus* sp.), eneolitik, druga polovica 4. tisočletja pr. Kr., Ljubljansko barje, Slovenija

Abstract

A stone hammer-axe from the second half of the 4th millennium BC was excavated at the pile dwelling Stare gmajne in the Ljubljansko barje, Slovenia. The axe had a preserved part of the wooden handle which is rare. Exact wood identification was important because the axe was made of imported stone that can not be found in Slovenia. We found out that the handle was made of cornel (*Cornus* sp.) that possibly grew in the vicinity of the pile dwelling. The cornel wood is hard, and has excellent mechanical properties including high impact strength; therefore it was an excellent material for the handle. This confirms that the prehistoric men had good knowledge of the wood properties. We discuss the importance of reference material (microscopic slides and samples of wood from modern trees and bushes) to differentiate the wood of cornel which has similar wood anatomy to that of boxwood (*Buxus sempervirens*). The boxwood as a Mediterranean species in prehistoric time supposedly did not grow in the vicinity of the pile dwelling where the axe was found.

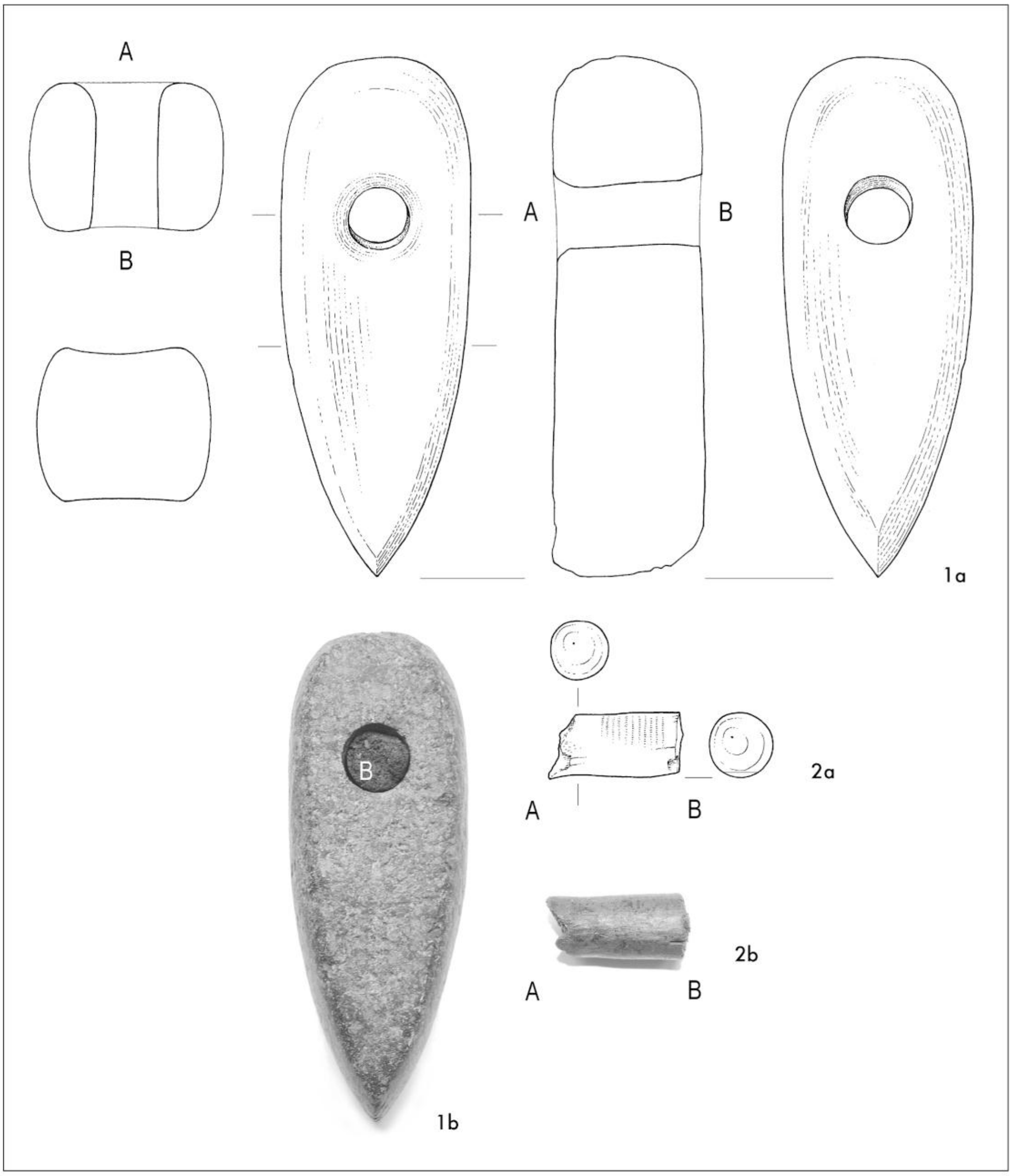
Key words: wooden handle, stone hammer-axe, wood anatomy, cornel (*Cornus* sp.), Eneolithic, second half of the 4th millennium BC, Ljubljansko barje, Slovenia

UVOD

Med izkopavanjem na koliščarski naselbini Stare gmajne iz druge polovice 4. tisočletja pr. Kr. je bila najdena kamnita kladivasta sekira (*sl. 1:* 1,2), izdelana iz kamnine, ki ne izvira iz Slovenije ter je bila prinesena od drugod, verjetno iz Italije. Ker je v sekiri ohranjen tudi kos lesenega toporišča, kar je redkost, nas je zanimalo, iz katerega lesa je to izdelano in ali bi morda vrsta uporabljenega lesa lahko pomagala pri ugotavljanju ali je sekira, vključno z ročajem, prišla na kolišče že kot gotov izdelek.

Anatomski pregled je pokazal, da ima les značilnosti drena (*Cornus* sp.) ali pušpana (*Buxus* sp.), ki imata podobno anatomijo lesa. Ker je dren uspeval tudi v okolici kolišč, pušpan pa takrat domnevno le v Sredozemlju in tudi v Italiji, od koder bi lahko izvirala kamnina za sekiro, smo se odločili za lesno anatomsko preiskavo ob uporabi recentnega referenčnega materiala.

Predstavljamo raziskavo, ki je vključevala makroskopsko in mikroskopsko preiskavo lesa ob uporabi ključev za identifikacijo lesa, referenčne literature in referenčnega materiala, to je vzorcev lesa in mikroskopskih preparatov iz recentnih dreves ali grmov. Dren in pušpan danes namreč nista široko uporabljani lesni vrsti, zato so opisi njunega lesa v literaturi pogosto preskopi, da bi brez referenčnega materiala lahko zanesljivo razlikovali obe vrsti, ki imata sicer dokaj podobne anatomske znake v lesu.



Sl. 1: Stare gmajne. Kladivasta sekira (1a,b); odlomek toporišča (2a,b). M. = 1:2.
Fig. 1: Stare gmajne. Hammer axe (1a,b); part of the handle (2a,b). Scale = 1:2.

MATERIAL IN METODE

Opis lesene najdbe

V raziskavo smo dobili moker košček lesa (*sl. 1:* 2), ki ga je leta 2004 našla ekipa Inštituta za arheologijo ZRC SAZU v ušesu kamnite sekire na kolišču Stare gmajne na Ljubljanskem barju (glej Velušček 2002, 51 ss; 2004, 77 s).

0,97 kg težka sekira z delno ohranjenim toporiščem je bila najdena na zahodnem delu koliščarske naselbine, ki glede na rezultate dendrokronoloških raziskav predstavlja najstarejši del kolišča.[1] Absolutno gledano je to čas približno 3300 pr. Kr. (glej Velušček 2005, 209 s).

Po mnenju geologa A. Horvata, ki je makroskopsko determiniral kamnino, iz katere je narejena sekira, gre za magmatsko kamnino, katere izvor je iskati izven ozemlja današnje Slovenije: verjetno v Italiji, Nemčiji, na Češkem ali v Franciji.[2]

Ostanek toporišča meri v dolžino 4,6 cm in ima premer 2,1 cm. Kljub visoki starosti se je les v mokrih tleh razmeroma dobro ohranil.

Metode dela

Za identifikacijo lesa smo uporabili makroskopsko in mikroskopsko metodo. Makroskopska temelji na anatomskih znakih, ki jih vidimo s prostim očesom ali lupo (Čufar, Zupančič 1999, 48). Za opazovanje pod lupo smo moker arheološki les najprej zamrznili, nato pa smo mu zgladili površine treh anatomskih ravnin. Za mikroskopsko preiskavo smo naredili tanke preparate.

Za svetlobno mikroskopijo smo vzorec arheološkega lesa velikosti: 0,5 × 0,5 × 1 cm vklopili v polietilen glikol (PEG) 1500. Les smo prepajali v vodnih raztopinah PEG z naraščajočimi koncentracijami (20 %, 50 %, 75 % in 100 %) pri temperaturi 60° C (prim. Zupančič, Jazbec, Čufar 2004, 285). Ko je bilo prepajanje zaključeno, smo vzorec posušili na zraku pri sobni temperaturi. Nato smo s pomočjo drsnega mikrotoma Leica SM 2000R z mikrotomskim nožem odrezali rezine lesa prečnega, radialnega in tangencialnega prereza, debelin 20 μm. Presežni PEG smo odstranili z vodo, rezine lesa pa obarvali z vodnimi raztopinami barvil safranin in astra modro, dehidrirali v etanolu naraščajočih koncentracij (50 %, 70 % in 95 %) ter rezine položili na objektna stekla, vklopili v Euparal in prekrili s krovnimi stekli. Za opazovanje smo uporabili svetlobni mikroskop Nikon Eclipse E800, fotografiranje pa smo opravili s pripadajočim digitalnim fotoaparatom Nikon Coolpix 995.

Za določitev vrste lesa smo uporabili ključe za makroskopsko in mikroskopsko identifikacijo lesa (Schweingruber 1990; Torelli 1991; Richter, Dallwitz 2002). Ti so prirejeni predvsem za izbor danes široko uporabljanih komercialnih lesnih vrst. Ker mnogih vrst znotraj istega rodu, npr. vrst rdeči in rumeni dren iz rodu dren (*Cornus*), po lesu z uporabo ključev ne moremo razlikovati, smo se odločili, da pripravimo tudi vzorce lesa in mikroskopske preparate rumenega drena (*Cornus mas*) in rdečega drena (*Cornus sanguinea*) ter botanično nesorodnega, a po lesu dokaj podobnega navadnega pušpana (*Buxus sempervirens*). Mikroskopske preparate recentnega lesa smo pripravili na podoben način kot preparate arheološkega lesa, vendar brez predhodnega vklapljanja v PEG.

Velikost celic in tkiv v lesu smo določili z računalniškim programom za analizo slike *Lucia G* v povezavi s svetlobnim mikroskopom Nikon Eclipse E800. Izmerili smo 50 naključno izbranih anatomskih elementov ter izračunali osnovno statistiko.

REZULTATI IN DISKUSIJA

Znaki vidni s prostim očesom in lupo, kot so razpored in velikost trahej in trakov, niso zadostovali za identifikacijo lesa toporišča. Pri pregledu arheološkega lesa pod mikroskopom smo ugotovili naslednje značilnosti: les je difuzno porozen, pore (traheje) so majhne (premeri pod 50 μm) in večinoma posamezne ter enakomerno porazdeljene po braniki (*sl. 2a*). Letnice so vidne. Aksialnega parenhima zaradi erozije celičnih sten ne moremo zanesljivo razlikovati od vlaken (*sl. 2a*). Perforirane ploščice trahej so lestvičaste, z večjim številom prečk (*sl. 2b*). Trakovi so večinoma 1- in 2- redni (*sl. 2c,d*) ter heterocelularni (*sl. 2c,d,e*). Dvoredni trakovi vsebujejo eno ali več vrst pokončnih celic (*sl. 2c,d,e*), vidne so tudi ovojne celice (*sl. 2e*). Višina trakov je 18-34 celic (*sl. 2c,d*).

Nato smo pregledali mikroskopske preparate recentnega materiala, to je lesa rumenega in rdečega drena ter navadnega pušpana iz dendrološko določenih dreves oz. grmov, ter jih primerjali z opisi v virih Schweingruber (1990) in Torelli (1991), računalniški ključ *Intkey* (Richter, Dallwitz 2002) pa je vseboval samo opis pušpana. V nadaljevanju smo pregledali še razpoložljive opise in slikovno gradivo iz internetnih virov *Inside wood*[3] in Schoch s sod.[4] *Inside wood* podaja razlikovalne znake rodov dren in pušpan, Schoch s sod. pa opise in mikroskopske posnetke lesa navadnega pušpana in rumenega drena.

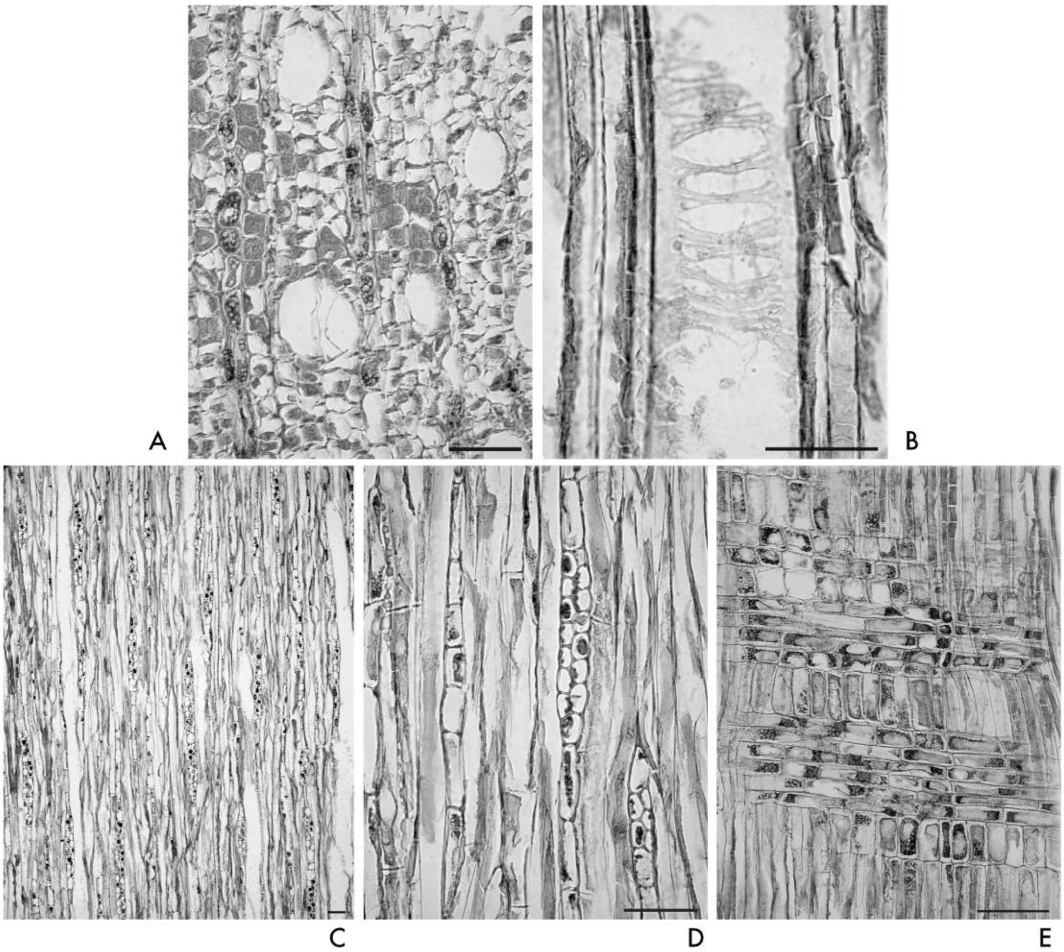
Les rumenega drena (*Cornus mas*) je difuzno porozen, pore (traheje) so običajno posamezne, enakomerno velike in enakomerno porazdeljene po

[1] K. Čufar, neobjavljeno poročilo o dendrokronoloških raziskavah na kolišču Stare gmajne, 2008.

[2] A. Horvat, neobjavljeno poročilo o makroskopski analizi dveh kamnitih sekir s Starih gmajn, 2008.

[3] *Inside Wood*, 2004. Spletna objava. http://insidewood/ lib. ncsu.edu/search [zadnji dostop 19. 8. 2008].

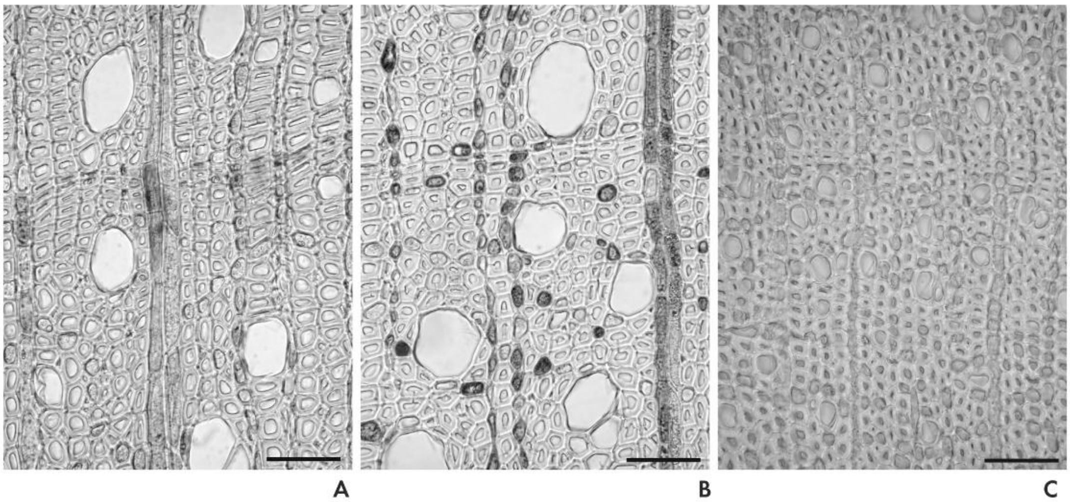
[4] W. Schoch, I. Heller, F. H. Sshweingruber in F. Kienast, *Wood anatomy of central European Species.* – Online version 2004: http://www.woodanatomy.ch



Sl. 2: Mikroskopski posnetki arheološkega lesa toporišča sekire: (a) prečni prerez z difuznim razporedom majhnih posameznih trahej; (b) radialni prerez z delom traheje z lestvičasto perforacijo; (c,d) tangencialni prerez s heterogenimi eno in dvo-rednimi trakovi; (e) radialni prerez s heterogenim trakovnim tkivom. Merilna daljica = 50 µm.
Fig. 2: Microphotographs of archaeological wood from the axe handle: (a) cross-section with diffuse distribution of small solitary vessels; (b) radial section, a part of a vessel with scalariform perforation plate; (c,d) tangential section with heterogeneous uni- or biseriated rays; (e) radial section with heterogeneous ray tissue. Scale bar = 50 µm.

braniki z dokaj velikimi razmaki (*sl. 3a*). Letnice so pogosto valovite. Vlakna so debelostena (*sl. 3a*). Aksialni parenhim je apotrahealen difuzen (*sl. 3a*), redkeje paratrahealen. Perforirane ploščice so lestvičaste, običajno z več kot 20 prečkami. Traheje imajo obokane do lestvičaste intervaskularne piknje s prehodi iz enega tipa v drugega. Trakovi so običajno 3- do 5-redni, redkeje 5- do 7-redni, pogosti so tudi enoredni trakovi. Trakovi so heterocelularni. Večredni trakovi imajo eno ali več vrst pokončnih robnih celic, enoredni pa so sestavljeni iz kvadratastih oz. pokončnih celic. Široki trakovi imajo običajno še ovojne celice. Višina trakov je 10 do 50 celic. Prisotne so tudi vlaknaste traheide. Lesa rumenega in rdečega drena (*sl. 3b*) običajno ni mogoče razlikovati (Schoch s sod.). *Inside wood* navaja, da imajo konci trahejnih členov drena helikalne odebelitve, te pa se na arheološkem lesu pogosto ne vidijo več.

Les pušpana (*sl. 3c*) je podoben, vendar se od lesa drena razlikuje po tem, da ima le do 20 prečk na perforacijah trahej, nasprotne ali izmenične majhne intervaskularne piknje (premer < = 4 µm), traheje brez helikalnih odebelitev in 1–3 redne heterogene trakove brez ovojnih celic. Srednji tangencialni premer por v prečnem prerezu je pri



Sl. 3: Mikroskopski posnetki prečnih prerezov recentnega lesa: (a) rumeni dren (*Cornus mas*); (b) rdeči dren (*Cornus sanguinea*); (c) pušpan (*Buxus sempervirens*). Merilna daljica = 50 µm.
Fig. 3: Microphotographs of cross-sections of modern wood: (a) Cornelian cherry (*Cornus mas*); (b) dog-berry (*Cornus sanguinea*); (c) boxwood (*Buxus sempervirens*). Scale bar = 50 µm.

pušpanu (*sl. 3c*) manjši (< 50 µm) kot pri drenu (*sl. 3a,b*) (< 100 µm) (Brazier, Franklin 1961; cit. po Torelli 1991).

Ključi omenjajo tudi razne vključke v celicah (kristali in škrob), ki pri arheološkem lesu te starosti niso ohranjeni. Dren raste v srednji Evropi (brez Sredozemlja), pušpan pa izvira iz Sredozemlja (*Inside wood*, Schoch s sod., glej op. 3 in 4).

Na podlagi primerjav znakov arheološkega lesa ter lesa recentnega drena in pušpana, ki jih predstavljamo v *tabeli 1*, predvsem izmerjenih velikosti por in številu prečk v lestvičastih perforacijah ter tipu heterogenega traku, smo potrdili, da je bilo toporišče kladivaste sekire narejeno iz lesa drena (*Cornus* sp.).

Les drena ima visoko do izjemno visoko gostoto - do 1000 kg/m^3, zato je trd, trden in žilav (Horvat 1959, 245). Zaradi fine teksture (majhnih trahej) in visoke gostote ga je mogoče zelo gladko obdelati. Navedene lastnosti so optimalne za les, ki ga želimo uporabiti za ročaje orodij.

V kulturnih plasteh koliščarskih naselbin so poleg drenovega lesa in oglja večkrat našli tudi njegova semena oz. plodove (npr. Šercelj, Culiberg 1978, 104; Culiberg 1984, 92; Jeraj 2004, 58 ss; Velušček et al. 2004, 44 s). Tako ni čudno, da so vrsto in njene lastnosti dobro poznali in jo znali vsestransko uporabiti (prim. Velušček et al. 2004, 44), tudi v tako specifične namene, kot je toporišče za skoraj 1 kg težko kamnito sekiro.

Tab. 1: Primerjava mikroskopske zgradbe lesa iz toporišča kladivaste sekire z recentnima drenom in pušpanom.
Tab. 1: see page 56 for English version.

RAZLIKOVALNI ZNAKI	**vzorec toporišča**	**dren** (*Cornus* sp.)	**pušpan** (*Buxus sempervirens*)
tangencialni premer por (povpr. v µm) *sl. 2:* a in *3:* a–c	36,51	32,12	14,63
lestvičaste perforacije (povpr. št. prečk) *sl. 2:* b	nad 20	nad 20	5 do 10
heterogeni trakovi (v radialnem prerezu) *sl. 2:* e	večredni trakovi imajo tudi po več vrst pokončnih robnih celic	večredni trakovi imajo tudi po več vrst pokončnih robnih celic	večredni trakovi imajo 1 ali 2 vrsti pokončnih robnih celic
heterogeni trakovi *sl. 2:* c,d	enoredni trakovi sestavljeni le iz pokončnih celic	enoredni trakovi sestavljeni le iz pokončnih celic	-
višina trakov *sl. 2:* c,d	18 do 34 celic	19 do 41celic	3 do 13 celic

Dren po gostoti in trdnostnih lastnostih praviloma presega vse naše danes uporabljane domače komercialne lesne vrste, tudi jesen, bukev in beli gaber, ki jih največ uporabljamo za ročaje orodij (prim. Čufar 2006, 185). Izstopajoče lastnosti drena so znane tudi današnjim lesarjem, vendar primerki počasi rastočega drena običajno ne dosegajo zadostnih dimenzij in ne nudijo dovolj lesa za njegovo množično uporabo.

Navadni pušpan v Sloveniji velja za tujerodno rastlinsko vrsto, ki je bila k nam prinesena iz Sredozemlja. Danes jo kultiviramo (npr. za žive meje), pogosto pa je podivjana (Brus 2005, 288). Tudi Wraber (2001, 66) navaja, da pušpan v flori Slovenije ni avtohtona, temveč le gojena, podivjana in ponekod vsaj začasno naturalizirana rastlina.

ZAKLJUČEK

Zaradi podobnosti anatomskih znakov lesa drena (*Cornus*) in pušpana (*Buxus*), ki sicer pripadata različnim družinam, dren družini drenovk, pušpan pa družini pušpanovk, je identifikacija lesa, ohranjenega v kamniti sekiri zahtevala primerjavo z recentnim lesom.

Ugotovili smo, da je bilo toporišče približno 5300 let stare kladivaste sekire s Starih gmajn narejeno iz lesa drena (*Cornus* sp.), ki je uspeval v bližini kolišč in ima izjemno trdnost in žilavost ter je zelo primeren za tako uporabo. Slednje ponovno potrjuje, da so bili koliščarji dobri poznavalci lesnih lastnosti.

Glede na izbrani les je bilo toporišče verjetno narejeno v domačem okolju, medtem ko je bila sekira oz. kamnina zanjo prinesena od drugod.

Zahvala

Študija je nastala v okviru raziskovalnih projektov Inštituta za arheologijo ZRC SAZU, ki jih financirata Ministrstvo za visoko šolstvo, znanost in tehnologijo in Agencija za raziskovalno dejavnost Republike Slovenije. Zahvaljujemo se strokovnemu sodelavcu Martinu Zupančiču z Oddelka za lesarstvo BF za vsestransko pomoč pri delu v laboratoriju in pripravo fotografij ter Tamari Korošec z ZRC SAZU za izdelavo risbe.

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The wooden handle of a stone hammer-axe from the Eneolithic pile-dwelling settlement Stare gmajne near Verd in the Ljubljansko barje, Slovenia

Summary

INTRODUCTION

While excavating the pile-dwelling settlement Stare gmajne from the second half of the 4th millennium BC, a stone hammer-axe (*fig. 1:* 1,2) was found that was made from a type of stone not native to Slovenia, meaning it had been brought from elsewhere. A fragment of the wooden handle (helve) of the axe was also preserved, which is quite rare. We were interested in finding out from what type of wood the handle had been made and whether this might indicate that the axe had arrived in the settlement as a finished product.

The first anatomic examination of the wood showed that it had the characteristics of dogwood or cornel (*Cornus* sp.), or boxwood (*Buxus* sp.), which have a very similar wood structure. As dogwood existed in the vicinity of the pile-dwelling settlement, while boxwood is native to the Mediterranean, and hence also parts of Italy from which the stone for the axe could have come, it was necessary to analyze in detail the anatomy of the wood. This included macroscopic and microscopic examination of the wood using a key for identifying wood and the proper reference literature. As the wood of cornel and box today is not used commercially, and descriptions of them are scarce, it was even necessary to prepare reference material in the form of wood samples and microscopic slides from modern trees and bushes.

MATERIAL AND METHODS

Description of the wooden find

A wet fragment of wood was discovered in the shaft of a stone axe (*fig. 1:* 2) in 2004 by the excavation team of the Institute of Archaeology of the Scientific Research Centre of the Slovenian Academy of Science and Art (ZRC SAZU) at the pile-dwelling settlement Stare gmajne in the Ljubljansko barje (see Velušček 2002, 51 ff.; 2004, 77 f.).

The axe with the partly preserved handle weighed 0.97 kg and was found in the western part of the pile-dwelling settlement, which represents the oldest part of the settlement in terms of the results of dendrochronological analysis.[1] In absolute terms this would be the period around approximately 3300 BC (see Velušček 2005, 209 f.).

According to the geologist A. Horvat, who macroscopically identified the stone from which the axe was made, this was a magmatic stone, whose source should be sought beyond Slovenia: probably in Italy, Germany, the Czech Republic or in France.[2]

The remnant of the handle measures 4.6 cm in length with a diameter of 2.1 cm. Despite its considerable age, the wood is relatively well preserved, as in the moist and loamy soil no oxidation or biotic decay of the organic material occurred.

Methodology

Macroscopic and microscopic methods were used to identify the wood. For examination under a magnifying glass, the wet archaeological wood was first frozen and then the surfaces of three anatomic planes were smoothed. Thin slides were prepared for microscopic examination.

For light microscopy we placed a sample of the archaeological wood measuring: 0.5 × 0.5 × 1 cm in polyethylene glycol (PEG) 1500. When the infiltration was finished, the sample was dried in the open at room temperature. Then with the help of a Leica SM 2000R sliding microtome thin segments were cut of cross, radial, and tangential sections, 20 μm thick. Observations were made using a Nikon Eclipse E800 light microscope, and photographs were taken with the corresponding digital camera Nikon Coolpix 995.

Keys for the macroscopic and microscopic identification of wood were utilized to determine the type of wood (Schweingruber 1990; Torelli 1991; Richter, Dallwitz 2002). As many species within the same genus, such as the dogwood and cornel of the same genus *Cornus*, cannot be distinguished based on features in the wood, we decided to prepare wood samples and microscopic slides of cornelian cherry (*Cornus mas*) and bloodtwig dogwood (*Cornus sanguinea*), and from the common boxwood (*Buxus sempervirens*).

The size of the cells and tissues in the wood were measured with the *Lucia G* computer program for image analysis connected to the Nikon Eclipse E800 light microscope. We measured 50 randomly chosen vessels and calculated the basic statistics.

RESULTS AND DISCUSSION

The macroscopic identification of the excavated fragment of wood from the handle of the stone axe was impossible as insufficient anatomic features could be seen because of poor preservation, the waterlogged condition, and the juvenile nature of the sample (the wood of the handle also contained pith). The microscopic examination (*fig. 2*) showed wood elements characteristic for dogwood or boxwood.

To make a more detailed determination, we first examined microscopic slides of the wood of dogwood and cornel and common box from dendrologically determined trees or bushes, and then compared them to descriptions in the basic reference sources of Schweingruber (1990) and Torelli (1991), while the computer key *Intkey* (Richter, Dallwitz 2002) contained only a description of boxwood. We further consulted all available descriptions and illustrations from the internet sources *Inside wood*[3] and Schoch et al.[4] The wood of Cornelian cherry (*fig. 3a*) and bloodtwig dogwood (*fig. 3b*) usually cannot be distinguished (Schoch et al.), and hence we further refer only to dogwood or cornel in general (*Cornus* sp.). A table of the identification features of the archaeological sample and the samples of modern dogwood/cornel and boxwood is presented (*tab. 1*).

It was established that the wood of box and dogwood/cornel are similar. Boxwood can be distinguished as having only up to 10 bars on the scalariform vessel perforation plates, opposite

[1] K. Čufar, unpublished report on the dendrochronological resarch at the pile-dwelling Stare gmajne, 2008.

[2] A. Horvat, unpublished report on the petrographic analysis of two stone axes from the site Stare gmajne, 2008.

[3] *Inside Wood.* 2004 onwards. Published on the Internet. http://insidewood/lib.ncsu.edu/search [date of accession Aug. 19, 2008].

[4] W. Schoch, I. Heller, F. H. Schweingruber, and F. Kienast, *Wood anatomy of central European Species.* - Online version 2004: www.woodanatomy.ch

Tab. 1: Comparison of wood anatomic features of wood from the handle of the stone hammer-axe with modern cornel (*Cornus* sp.) and boxwood (*Buxus sempervirens*).

IDENTIFICATION FEATURES	Handle sample	Cornelian cherry (*Cornus mas*) / Dog-berry (*Cornus sanguinea*)	Boxwood (*Buxus sempervirens*)
Tangential diameter of vessels (average measurement in µm) *figs. 2:* a and *3:* a–c	36.51	32.12	14.63
Scalariform perforations (average number of bars) *fig. 2:* b	above 20	above 20	5 to 10
Heterogeneous rays (on radial section) *fig. 2:* e	multiseriate rays contain several rows of marginal upright cells	multiseriate rays contain several rows of marginal upright cells	multiseriate rays contain 1–2 rows of marginal upright cells
Heterogeneous rays *fig. 2:* c,d	uniseriate rays composed exclusively of upright cells	uniseriate rays composed exclusively of upright cells	-
Height of rays *fig. 2:* c,d	18 to 34 cells	19 to 41cells	3 to 13 cells

or alternating small intervascular pits (diameter < = 4 µm), vessels without helical thickenings, and 1–3 rows of rays without procumbent or upright cells. The tangential diameter of vessels in cross-section is in boxwood (*fig. 3c*) less (< 50 µm) than in dogwood/cornel (*fig. 3a,b*) (< 100 µm) (Brazier, Franklin 1961; cited from Torelli 1991). The keys also mention various inclusions in cells (crystals and starch), which are not preserved in archaeological wood of such an age. Dogwood grows in central Europe (but not in the Mediterranean), while boxwood is native to the Mediterranean (*Inside wood*; Schoch et al.).

On the basis of the results presented in *tab. 1* and *fig. 2*, particularly the measured dimensions of the vessels and the number of bars in the scalariform perforations and the type of heterogeneous rays, it was established that the handle of the hammer-axe was made from cornel or dogwood (*Cornus* sp.).

Cornel wood has a high to exceptionally high density to 1000 kg/m^3 and is consequently hard, solid, and strong (Horvat 1959, 245). Due to fine texture (small vessels) and high density it can be worked very smoothly. These properties are optimal for wood intended to be used for the handle of a tool.

The cultural strata of the pile-dwelling settlements contained the seeds of dogwood/cornel in addition to wood and charcoal remains (e.g. Šercelj, Culiberg 1978, 104; Culiberg 1984, 92; Jeraj 2004, 58 ff.; Velušček et al. 2004, 44 f.). Hence it is not strange that the wood of these species (and their properties) were well known and that they were widely used (cf. Velušček et al. 2004, 44), even for such specific purposes as making a handle for a stone axe weighing almost 1 kg.

CONCLUSION

The great similarities in the anatomy of the wood of dogwood/cornel (*Cornus*) and box (*Buxus*), which otherwise belong to different families, cornel to the Cornaceae family, and box to the Buxaceae family, meant that the identification of the wood preserved in the stone axe was somewhat difficult.

It was established that the handle of the 5300 year old hammer-axe from the site Stare gmajne had been made from cornel wood (*Cornus* sp.), which is exceptionally hard and strong and is highly suitable for such a purpose. This once again confirms that the pile-dwelling settlers had great knowledge of various wood properties.

The correct identification of the wood in this case is important both from the archaeological and the biological points of view, as it indicates that the wood for the handle probably came from the local environments, while the stone for the axe head or the already manufactured axe had been imported from elsewhere.

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2.5 NAJSTAREJŠI MAKROOSTANKI VINSKE TRTE IZ SLOVENIJE (THE OLDEST MACROREMAINS OF VITIS FROM SLOVENIA)

Tolar T., Jakše J., Korošec-Koruza Z. 2008. The oldest macroremains of *Vitis* from Slovenia. Vegetation History and Archaeobotany 17: 93-102

Najdene so bile najstarejše pečke vinske trte (*Vitis vinifera* ssp.) iz Slovenije s pozno neolitskega (eneolitskega) kolišča Hočevarica z Ljubljanskega barja. Datirajo v 37./36. stoletje pr. n. št. Na odkritih pečkah so bile opravljene različne biometrične meritve, da bi ugotovili, ali pečke pripadajo divji ali gojeni obliki vinske trte. V raziskavo je bila vključena tudi primerjava meritev na pečkah s Hočevarice s pečkami z rimskodobnega najdišča na Vrhniki (datirano v 1. stoletje n. št.) in s pečkami današnjih gojenih sort vinske trte. Izračuni standardnih indeksov so pokazali, da so bile neolitske pečke s Hočevarice najverjetneje še plod divje vinske trte, medtem ko za rimskodobne pečke tega ni bilo mogoče potrditi, saj so bili indeksi nekje vmes, med divjimi in gojenimi, čeprav je šlo tu najverjetneje že za gojeno obliko. Morfološke značilnosti pečk vinske trte namreč izredno variirajo, zato morfološki znaki pogosto niso dovolj zanesljiv dokaz za identifikacijo gojenih ali divjih oblik. Zato smo v tej raziskavi prvič v Sloveniji poskusili uvesti analizo DNK, ki velja za najbolj zanesljivo metodo odkrivanja sorodnosti vrst. Izveden je bil začetni poskus ekstrakcije arheološke DNK in amplifikacija kloroplastne regije.

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ORIGINAL ARTICLE

The oldest macroremains of *Vitis* from Slovenia

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Abstract The oldest *Vitis vinifera* ssp. L. (grape) pips (seeds) from Slovenian archaeological sites were found at the late Neolithic (Copper Age) pile-dwelling settlement of Hočevarica on the Ljubljansko barje and date to the 37th/36th century B.C. Various biometric studies were carried out to establish whether the grapes were wild or cultivated. A comparison of several morphological characteristics of grape pip samples was performed. Neolithic pips from Hočevarica, Roman pips from Vrhnika (1st century A.D.) and recent Slovenian cultivated grape pips were included in the study. According to the standard indices, the Neolithic *Vitis* pips were wild. In the case of the Roman pips, it was impossible to determine whether they were wild or cultivated, although they had most probably been cultivated. Since the morphology of grape pips varies considerably (as it did in the Neolithic, as well), the attempted identification of the subspecies *Vitis vinifera* ssp. *sylvestris*/*vinifera*, based on morphological characteristics alone, was unsatisfactory. Therefore, an attempt was made to analyse the DNA, which could help to resolve this question. Initial experiments on extraction of archaeological DNA and amplification of the chloroplast region were performed, but further optimization steps are needed to achieve successful amplification.

Keywords Grape pips · Neolithic · Roman · Morphological features · Biometric studies · DNA extraction

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Introduction

The area of present-day Slovenia is highly suitable for grape growing because of its geological and climatic conditions. Slovenia is considered to be a traditional viticulture land, where many European prehistoric events took place, and there is abundant cultural evidence to prove that. The temperate climate with sunny sand hills on the margins of the Pannonian lowland, the littoral or karst region with its sub-Mediterranean climate and marl terraces—both are very suitable for viticulture.

Slovenia lies within the natural distribution area of *Vitis vinifera* ssp. *sylvestris* (wild grapevine) (for example, Zohary and Hopf 2000); however, because of extensive viticulture in Slovenia, no more natural wild populations of *Vitis* are to be found there. Pejkić (1980) denotes the sandy river banks along the southern stream of the river Sava in Bizeljsko (a region in Slovenia) as the natural habitat for wild *Vitis* plants.

Grapevine, a plant with excellent physiological potential as a sugar collector, was an ideal plant for extensive cultivation by the Neolithic people, who were farmers as well as gatherers of native wild fruits. The genetic centres of the *Vitis* genus (west European group *Proles occidentalis* and

Mare Pontico group *Proles pontica*) (Branas 1974; Pejkić 1980; Rivera Nunez and Walker 1989) provide an eloquent evidence of how grapevines spread to suitable lands. Moreover, the main Slovenian rivers, the Drava and Sava flowing from the north and the Ljubljanica from the southwest, with their sandy river banks or floodplain woods were the best trading routes, through which the grapes or the knowledge of cultivation of the grapevines reached our prehistoric land.

All major lacustrine and marshland prehistoric settlements in Slovenia are to be found within Ljubljansko barje (the Ljubljana Moor) (Velušček 2004a). Since the first discovery of ancient settlements in this location in the second half of the 19th century, Ljubljansko barje has undergone extensive research study, which has produced extremely well preserved archaeological as well as archaeobiological evidence.

Ljubljansko barje is situated at the edge of the south-eastern Alps in central Slovenia (Fig. 1) and covers an area of 163 km^2 (Lah and Adamič 1992). The bog was formed by subsidence about 2 million years ago. Water, sediments and various other deposits subsequently filled the depression that was formed by subsidence (Pavšič 1989).

The sequence of sediments in Ljubljansko barje, which was determined with the help of corings, aided the reconstruction of the dynamically changing circumstances: first the area of the bog was a large gravel plain with individual small ponds, later it was a shallow lake with a rich flora and fauna, then an impassable swamp, and finally it became a peat bog (Pavšič 1989). The stratigraphy of pile-dwellings and other archaeological sites such as the Roman ones on the shores of Ljubljansko barje, revealed that the peat was formed after the period of pile-dwellings and perhaps even during the Roman period (Pavšič 1989).

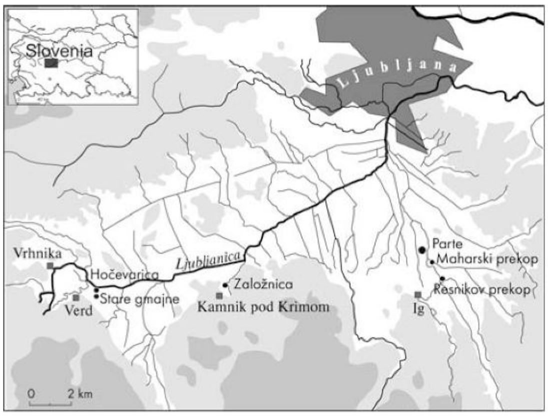

Fig. 1 Ljubljansko barje (Ljubljana Moor), Slovenia, with the most important Neolithic pile-dwelling settlements

The area of the Ljubljansko barje is rich in Neolithic pile-dwelling settlements (Fig. 1). Resnikov prekop (Fig. 1) is the most important site from the first half of the fifth millennium B.C. (Čufar and Korenčič 2006) (all the following dates are calibrated ^{14}C dates, partly verified by dendrochronology). It is a small, dispersed pile-dwelling settlement, which was probably located near the shore of the lake (Velušček 2004a). The next traces of human settlement in Ljubljansko barje date to the second and third quarters of the fourth millennium B.C. The Hočevarica site (Fig. 1) belongs to the second quarter of the fourth millennium B.C. (Čufar and Velušček 2004). Somewhat later settlements dating to the second half of the fourth millennium B.C. have also been discovered in other parts of Ljubljansko barje (Velušček and Greif 1998). In the middle of the fourth millennium B.C., a small pile-dwelling settlement referred to as Maharski prekop (Fig. 1) was located not far from the present-day village of Ig (Velušček 2004a). The site called Stare gmajne is a pile-dwelling settlement from a more recent period than the settlement at Maharski prekop. It is situated near the village of Verd (Fig. 1). The remains of a pile-dwelling settlement from approximately the first half of the third millennium B.C. have also been discovered. Dendrochronological research revealed that several locations on Ljubljansko barje were occupied simultaneously at that period (Velušček and Čufar 2002; Velušček and Čufar 2003; Čufar and Velušček 2004). The settlements at Parte near Ig and Založnica near Kamnik pod Krimom (Fig. 1) co-existed for about 40 years (Velušček and Čufar 2002).

In 1998, a team from the Institute of Archaeology at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts re-excavated a small trench in Ljubljansko barje, in the region of the Hočevarica pile-dwelling site. The main goal of sample trenching was to use excavation methods that had already been tested on the Neolithic wetland settlements in Switzerland, Germany and France, but never used in Ljubljansko barje. The new method brought enough applicable data for a team of 16 researchers from Slovenia and abroad. For several of them, co-researching the Hočevarica site and working in the field of archaeology was a new experience, although they were well recognized professionals in their own fields (Velušček 2004b). For the first time in Slovenia, the sediment from the cultural layer was washed over through three different sieves.

More than 30,000 seeds, fruits and their fragments larger than 3 mm, and even more seeds smaller than 3 mm were found in the cultural layer of the sampled quadrants (Jeraj 2004). Generally, they were well preserved, and—with the exception of cereal grains—almost completely non-carbonised waterlogged subfossils (Jeraj 2004; Jeraj et al. 2008). In most cases, seeds with lignified tissues were preserved, and grape pips (seeds) formed some of the most frequent remains, representing 27% of the seeds in the large fraction of 3 mm and above (Jeraj 2004). Some of the grape pips were also AMS radiocarbon dated. The radiocarbon date of grape pips found at a depth between 159 and 142 cm (the latest settlement phase) (Velušček 2004c) is 4780 ± 40 B.P. (3640–3520 cal B.C., 1 σ range, 3650–3380 cal B.C., 2 σ range) (Jeraj 2004).

Since such an extensive quantity of grape pips was found, the question arises whether they belonged to the *Vitis vinifera* ssp. *sylvestris* (wild grapevine) or cultivated *V. vinifera* ssp. *vinifera*. Grape pips in the Neolithic pile-dwelling settlements in Ljubljansko barje (Fig. 1) are numerous (for example, Culiberg 1980 (Parte); Jeraj 2004 (Hočevarica); Tolar, unpublished (Stare gmajne)) and the oldest in Slovenia so far. To find out what subspecies (wild or cultivated) they belong to, we performed various biometric measurements on the earliest grape pips which have been found in Slovenia, from the Hočevarica site. In addition, measurements of the Roman grape seeds from Vrhnika, Slovenia, dated to the 1st century A.D. (Horvat and Mušič 2006), and of modern grape pips of *Vitis vinifera* varieties were taken into account.

Since the morphological identification of the wild subspecies, with morphologically rounded pips, or the cultivated subspecies with morphologically pyriform pips (Stummer 1911) is questionable (for example Facsar 1972; Jacquat and Martinoli 1999; Schlumbaum et al. 2008), we decided to additionally use molecular methods that could help resolve our questions. The DNA analysis was performed on six grape pips (three morphologically rounded and three pyriform ones) from the Stare gmajne site, since these were preserved in better condition than the seeds from the Hočevarica site (see below, methods).

The objective of this article is to present the first results of morphological measurements and preliminary testing of the DNA isolation from Neolithic and Roman grape pips of Slovenian archaeological and modern *Vitis*, to find out whether the oldest grape pips found in Slovenia belong to the wild or cultivated *V. vinifera*.

Materials and methods

Archaeobotanical methods

The excavated trench at the Hočevarica site was 2 m wide and 4 m long. It was divided into 8 quadrants of 1 × 1 m^2. The sediment from the cultural layer in the quadrants 1, 4, 5, and 8 was washed through metal sieves with 3.0, 1.0 and 0.5 mm mesh sizes (Velušček 2004c). The collected fractions were dried, and the plant remains were sorted (Jeraj 2004; for a critical view of the methodology applied, see Jeraj et al. 2008).

The Stare gmajne site is located about 250 m south of the Hočevarica site (Fig. 1) and dates to the second half of the fourth millennium B.C. (Velušček 2004a). In 2006 and 2007, a team of experts from the Institute of Archaeology excavated two trenches of 15 m^2. Similarly to the Hočevarica site (see above), each excavated trench at Stare gmajne was divided into 15 quadrants of 1 × 1 m^2. The whole cultural layer was wet-sieved, and the collected sieve samples were dried in order for the inorganic materials (pottery, bones and stones) to be sorted. For analysing the organic remains (mostly non-carbonised plant remains), special archaeobotanical samples were taken for the first time: two samples of 2 l each were taken randomly from the trench in 2006; 15 samples of 2 l each were taken systematically from quadrants 1, 9 and 13 (horizontal sampling) and separately from each of the five layers (vertical sampling) from the trench in 2007. Afterwards, the samples were washed over (for example Hosch and Zibulski 2003) and hand sorted in water. Grape pips were found in these very rich macrobotanical samples as well, but not as many as at the Hočevarica site (Tolar, unpublished). All macrobotanical remains larger than 0.355 mm from Stare gmajne are stored under wet conditions to prevent decay and deformation.

Morphological material

For this study, 142 grape pips from the Neolithic pile-dwelling settlement of Hočevarica in Ljubljansko barje, approximately 5,600 years old (Fig. 2a) and 73 grape seeds from the Roman settlement at Vrhnika, approximately 2,000 years old (Fig. 2b) were measured. All remains come from waterlogged layers, and their preservation is as

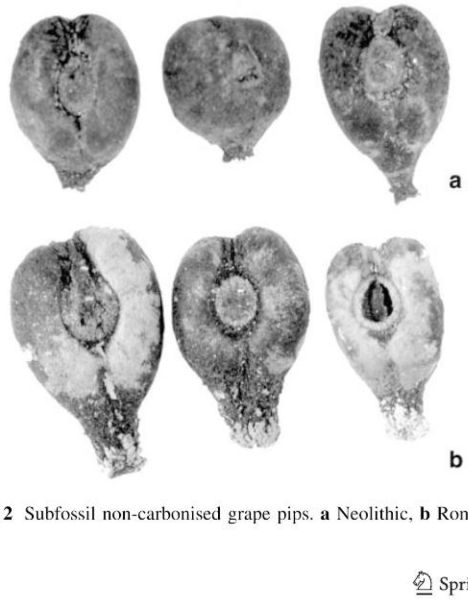

Fig. 2 Subfossil non-carbonised grape pips. **a** Neolithic, **b** Roman

non-carbonised subfossils, but they were dried after sieving (see above; Fig. 2; Jeraj 2004; Jeraj et al. 2008).

The cultivated modern populations of *Vitis vinifera* that were used for comparison comprised 50 seeds from five varieties (Fig. 3) used for wine making in Slovenia: Vrtovka (a seedling of unknown *Vinifera* origin) (Fig. 3a), an American variety originated from *V. labrusca* (Fig. 3b), Rebula (a local variety from Primorje) (Fig. 3c), Štajerska belina (Heunisch) (Fig. 3d) and Laški rizling (Welschriesling) (Fig. 3e).

Seeds of various shapes (more rounded, pyriform and in between) were taken at random from each group of Neolithic, Roman and modern (Figs. 2, 3).

Morphological methods

Identification of either wild or cultivated grape pips was first based on morphological features (Fig. 4; Stummer 1911; Terpo 1976, 1977; Mangafa and Kotsakis 1996; Jacquat and Martinoli 1999; Kohler-Schneider 2001).

Since the work of Stummer (1911), it has been generally accepted that domestication has caused changes in the dimensions and other morphological characteristics of the seeds. Therefore, it is generally possible to distinguish cultivated from wild grape pips. Stummer (1911) described the pips of wild vines as small, robust and with a rounded outline, or cordate with short stalks. On the other hand, the pips of domesticated vines were described as large, elongated, oval or pyriform, with a longer stalk. These distinguishing shape characteristics can be shown numerically, so the index $B/L \times 100$, also called the Stummer index, shows that wild grape seeds have larger Stummer indices because of their rounded shape, which is the result of their greater breath and shorter length.

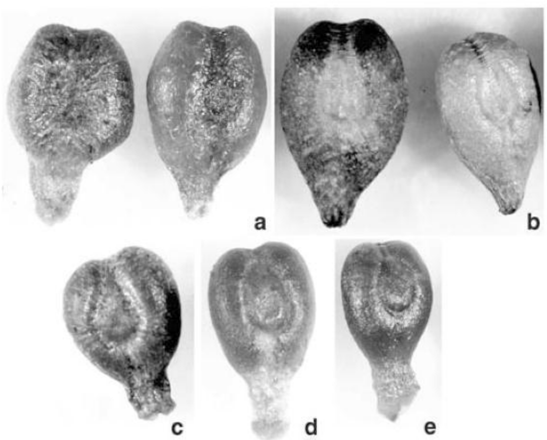

Fig. 3 Pips of modern cultivated *Vitis vinifera*. **a**Vrtovka, **b** *Vitis labrusca*, **c** Rebula, **d** Štajerska belina, **e** Laški rizling

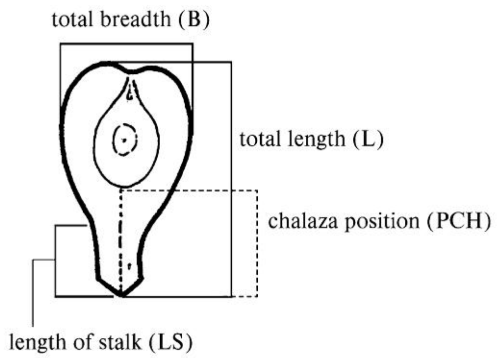

Fig. 4 Morphology measurements of the *Vitis* seed

Stummer index:

$$SI = B/L \times 100$$

Because many grape pips do not clearly fit into one of the two typical Stummer groups (for example Logothetis 1970, 1974; Smith and Jones 1990; Mangafa and Kotsakis 1996; Jacquat and Martinoli 1999; Kohler-Schneider 2001; see also the results section), several other indices and formulae for determining the *Vitis* subspecies were developed (Mangafa and Kotsakis 1996), the key to the codes used is below:

Formula 1:

$$-0.3801 + (-30.2\mathrm{LS}/L + 0.4564\mathrm{PCH} - 1.386L + 2.88\mathrm{PCH}/L + 9.4239\mathrm{LS})$$

Formula 2:

$$0.2951 + (-12.64\mathrm{PCH}/L - 1.6416L + 4.513\mathrm{PCH} + 9.63\mathrm{LS}/L)$$

Formula 3:

$$-7.491 + (1.7715\mathrm{PCH} + 0.49\mathrm{PCH}/L + 9.56\mathrm{LS}/L)$$

Formula 4:

$$0.7509 + (-1.5748L + 5.297\mathrm{PCH} - 14.47\mathrm{PCH}/L)$$

The morphological method (O. I. V. descriptors: OIV 241–OIV 244), which requires precise measuring of morphological characteristics of the grape pip, was used for our material (OIV Descriptiors 1984). The following measurements were taken (Fig. 4): length (L), breadth (B), thickness (T), length of stalk (from the tip of the stalk to its base—edge of the seed corpus) (LS), placement of the chalaza (the distance from the base of the chalaza to the tip of the stalk) (PCH) (Terpo 1977; Mangafa and Kotsakis 1996; Jacquat and Martinoli 1999; Kohler-Schneider 2001).

For precise measurements, we used an *Olympus PROVIS* stereomicroscope connected to the computer and the computer programme *analysis by Soft Imaging System GmbH*.

The following indices were calculated from the measurements: breadth to length ($B/L \times 100$), thickness to breadth ($T/B \times 100$), thickness to length ($T/L \times 100$), length of stalk to total length ($LS/L \times 100$), placement of chalaza to total length ($PCH/L \times 100$) (Terpo 1977; Mangafa and Kotsakis 1996; Jacquat and Martinoli 1999; Kohler-Schneider 2001), and an attempt to distinguish between wild or cultivated *Vitis* was made using the Stummer (1911) index and the four Mangafa and Kotsakis (1996) formulae (see above).

The four Mangafa and Kotsakis formulae are for charred grape seeds, since the archaeological finds are often carbonised. The effects of carbonisation on the dimensions of the grape seeds were investigated several times by experimental charring of seeds (Logothetis 1970, 1974; Rivera Nunez and Walker 1989; Smith and Jones 1990). The investigations revealed that after carbonisation, the seeds of both wild and cultivated subspecies became smaller and more rounded, since length decreases more than breadth which, in turn, decreases more than thickness. Consequently, the *B*:*L* indices (Stummer index) increased (Logothetis 1970, 1974; Rivera Nunez and Walker 1989; Smith and Jones 1990). For that reason, Mangafa and Kotsakis (1996) suggest that the second and the third formulae (see above) are more appropriate for the identification of charred archaeological grape pips, because fewer simple size variables are used with less contribution than ratio variables.

Material for our research was not charred, but preserved wet and subsequently dried. We are aware of the possible problems in treatment of our material (Jeraj et al. 2008), but we do not know if drying of wet archaeological seeds may cause damage and changes in the dimensions of grape seeds and DNA degradation. After having seen many *Vitis* pips, we assume that drying does not influence their shape (*B*:*L* indices) (see also Rivera Nunez and Walker 1989), because the outer tissue of grape pips is highly lignified and rigid. Therefore, we calculated all known indices and formulae (Stummer; Mangafa and Kotsakis) for distinguishing wild subspecies from the cultivated ones. The results are shown in Table 1.

Since there are no pure natural wild populations of *Vitis vinifera* ssp. *sylvestris* any more in Slovenia, Table 1 also includes the results of Kohler-Schneider (2001), who measured modern cultivated *Vitis* pips from France and wild ones from the Danube floodplains in Niederösterreich (Lower Austria).

The morphological characteristics of *Vitis* seeds (both cultivated and wild) are very variable (Table 1). The seeds can be rounded, pyriform or intermediate in both groups (wild and cultivated) (Facsar 1970, 1971, 1972, 1975; Jacquat and Martinoli 1999; Kohler-Schneider 2001).

Table 1 The average of measurements and calculated formulae (indices) (according to Mangafa and Kotsakis 1996; Stummer 1911) for morphological characteristics of grape pips from the Slovenian Neolithic and Roman settlements, and modern cultivated grape pips from Slovenia, all non-carbonised but dried; and, for comparison, morphological characteristics of modern charred grape pips—cultivated ones from France and wild ones from the Danube floodplains (according to Kohler-Schneider 2001)

Measurements and indices (formulae)	Neolithic, wild	Roman, wild/cult.	Modern, cult., Slovenia	Modern, cult., France	Modern, wild, Danube
Preservation	Non-carb.	Non-carb.	Non-carb.	Carb.	Carb.
Number of measured seeds	142	76	50		
Length (*L*)	4.82	5.37	6.13	7.1	3.8
Length of stalk (LS)	0.73	1.31	1.76	2	0.4
Placement of chalaza (PCH)	2.35	2.82	3.17	3.9	1.7
Breadth (*B*)	3.7	3.45	3.6	4.9	3.3
Thickness (*T*)	2.73	2.58	2.71		
B/*L*	77.27	64.48	58.92		
T/*L*	57.3	47.9	44.49		
LS/*L*	14.85	23.9	28.71		
PCH/*L*	48.26	52.01	51.77		
T/*B*	74.23	74.66	75.87		
Formula 1 (>0.8: cultivated); (<−0.2: wild)	−2.18	0.09	1.94	3.48	−2.99
Formula 2 (>0.9: cultivated); (<−0.2: wild)	−1.73	−0.08	0.77	2.01	−2.91
Formula 3 (>0.9: cultivated); (<0: wild)	−1.67	0.08	1.13	2.38	−3.25
Formula 4 (>1.4: cultivated); (<−0.9: wild)	−1.43	−0.28	0.41	2.28	−2.7
Stummer index (44–53: cultivated); (76–83: wild)	77.27	64.48	58.92	69	87

Therefore, the identification of grape pips as far as subspecies is problematic, and morphological features (described above; Fig. 4) that are generally used to distinguish between the wild and the cultivated subspecies are not satisfactory (Jacquat and Martinoli 1999; Kohler-Schneider 2001; Schlumbaum et al. 2008). We therefore completed the classical morphological methods (described above) and used molecular DNA methods as well.

An attempt to extract and amplify ancient grape DNA was made, details (material, methods) are available as Electronic Supplementary Material (ESM).

Results and discussion

Morphological results

Both the Neolithic grape pips from the Hočevarica site and the Roman ones from the Vrhnika site were found in wet conditions, non-carbonised and later air-dried. The seeds were very well preserved. The Neolithic grape pips, despite being older, were in considerably better condition, because the Neolithic cultural layer is deeper, and the Hočevarica site is situated more in the interior of the Ljubljansko barje (Fig. 1) where the clay soil is anoxic and contains more moisture, which slows down the degradation of organic material.

The morphological characteristics such as the chalaza and stalk of all measured archaeological seeds were easily visible and recognizable (Fig. 5). The computer measurements are expressed to five decimal places.

The variable morphological characteristics in each examined group are shown in Figs. 6 and 7, where box-plot graphs show the maximum, minimum and median values (the extremes), where half of the measurements is larger and the other half is smaller than the median. The grey boxes represent two quarters (or half) of the measurements.

The majority of the measured Neolithic grape seeds (83) fall into the wild range (76–83), as proposed by Stummer (Fig. 7). The rest of the measured seeds (59) fall into the intermediate range, and none of them falls into the cultivated range (Stummer 1911). Therefore, they could be considered as representing wild grapevines. However, when we compare the graphs of all three examined groups (Fig. 7), the result is not so convincing. It suggests that the values of Stummer indices of the Neolithic group also vary, and that a quarter of the Neolithic seeds (43) fall into the range of the modern group. This is not a strong enough result for identifying the Neolithic seeds as wild *Vitis*.

Identification of the Roman grape seeds, which are assumed to be cultivated, remains uncertain after calculating the Stummer index, and the majority of their indices are somewhere in between; the range (57–70) is closer to the cultivated modern grapevines (Fig. 7). Only four of 66 measured seeds fall within the cultivated range, and six seeds within the wild range. It is possible that our sample contained two or three types of seeds, wild (rounded and

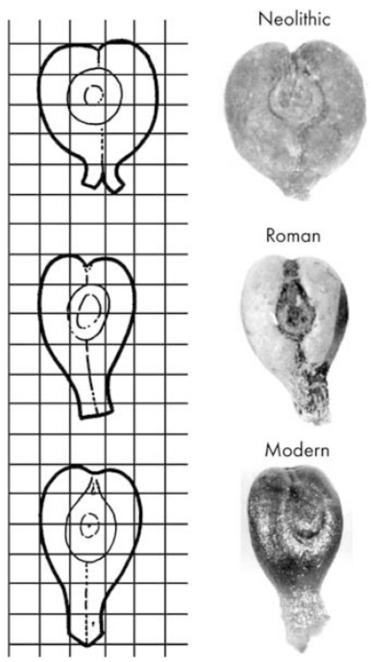

Fig. 5 Examples of Neolithic, Roman and modern grape pip

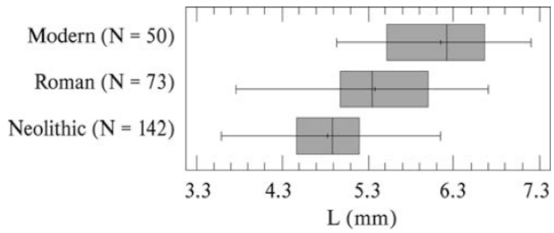

Fig. 6 Length (*L*) of grape pips (mm)

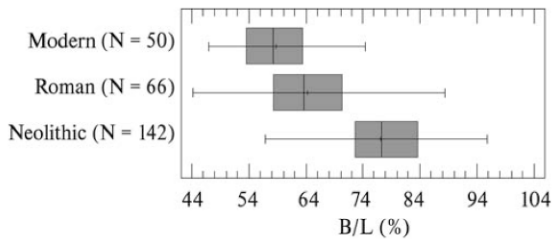

Fig. 7 Index $B/L \times 100$ of grape pips (%)

short), half-domesticated and domesticated (pyriform and elongated).

Based on the Stummer index, the majority of the modern grape seeds falls into the intermediate range too (54–64) (Fig. 7). Only 11 of the 50 measured grape seeds fall within the cultivated range (44–53), and none of them falls within the wild range. We have taken quite a diverse population of five modern varieties of *Vitis vinifera* (Fig. 3), and the variability of cultivars is notably great (Facsar 1970, 1972, 1975). So, some seeds fulfil the criteria for the cultivated range completely, but the rest to a minor extent. Moreover, in our case, it has turned out that the Stummer index is unreliable for the modern cultivated group as well. This means that there are also cultivars with round seeds (Facsar 1970, 1972), which should be, according to Stummer, a characteristic of wild grapes. Having calculated the Stummer index, we discovered that it is inconvenient (Mangafa and Kotsakis 1996; Jacquat and Martinoli 1999; Kohler-Schneider 2001), because it does not allow or consider the variability of seeds within one group (wild, cultivated or cultivars) or even within one grape (Facsar 1970, 1971, 1972; Terpo 1976, 1977). The seeds with an intermediate Stummer index (and they outnumber the other examined group) are impossible to attribute to a subspecies. Therefore, several other researchers have produced new formulae and indices for distinguishing wild from cultivated subspecies (Mangafa and Kotsakis 1996). Since we had carried out all the important measurements, we could apply them to the formulae proposed by Mangafa and Kotsakis (1996), and we compared the results obtained from these four formulae with the results of the Stummer index (Table 1). The formulae of Mangafa and Kotsakis (1996) include an error probability of imprecise measurement of the stalk length, because of difficult recognition of the stalk base or because of a frequently truncated tip, that are appropriate for dealing with archaeological seeds. The results are presented in Table 1. For comparison, we also took the average measurements and calculated indices and formulae of modern wild and cultivated grape seeds, cited in Kohler-Schneider (2001).

The values of the Mangafa and Kotsakis formulae are interpreted in the following way (according to Mangafa and Kotsakis 1996): values lower than −0.2 for Formula 1 and Formula 2, values of 0 for Formula 3, and −0.9 for Formula 4 indicate wild grape seeds. Values between −0.2 and 0 for Formula 1, between −0.2 and 0.4 for Formula 2, between 0 and 0.5 for Formula 3, and between −0.9 and 0.2 for Formula 4 indicate wild grape seeds with great probability. Values higher than 0.8 for Formula 1, 0.9 for Formula 2 and Formula 3, and 1.4 for Formula 4 indicate cultivated grape seeds. Values between 0.2 and 0.8 for Formula 1, between 0.4 and 0.9 for Formula 2, between 0.5 and 0.9 for Formula 3, and between 0.2 and 1.4 for Formula 4 indicate cultivated grape seeds with great probability.

Using all four of these formulae, it can be seen, similarly to the result obtained by the Stummer index, that the Neolithic grape pips are wild (Table 1). Only two out of the 142 measured seeds can be identified as cultivated. The values obtained using the first and the third formulae for one seed are around 0.9, and the values obtained using the second and the fourth formulae of the other seed are higher than 1, which can be considered as cultivated according to Mangafa and Kotsakis (1996). It is possible that two other seeds are cultivated according to the second (63.8% probability), third (63.3% probability) and fourth (91% probability) formulae. Since this is a common biological variability within one group, our conclusion is that the Neolithic grape pips belong to wild *Vitis*.

None of the 4 formulae can identify the Roman pips in general as either cultivated or wild (Table 1). The average calculations fall into the intermediate range with some probability of being wild. 20 out of the 66 measured Roman pips can be identified as cultivated using the first and the third formula. Using the second formula, 17 pips are identified as cultivated, and using the fourth formula, only 5 out of the 66 measured pips are identified as cultivated, and 18 other pips can be identified as belonging to cultivated vines with a 91% probability. As with the Stummer index, the four Mangafa and Kotsakis formulae cannot determine whether the Roman pips are cultivated, yet all formulae and indices show the same affinity towards the cultivated range (Table 1).

More than half the 50 measured modern cultivated grape pips can be identified as cultivated using the first three Mangafa and Kotsakis formulae. The fourth formula identifies only 8 out of the 50 measured pips as cultivated, and 19 other seeds as such with a 91% probability. The average calculations identify modern grape pips mostly or, at least, with a high probability as cultivated (Table 1).

DNA results

Fruits, seed tissues and especially archaeological samples represent unfavourable material for DNA extraction. In our first attempt at DNA extraction from recent grape seeds, a large amount of polysaccharides precipitated with the DNA and omitted the subsequent polymerase chain reaction (PCR) reactions (data not shown). After extraction, the introduction of the glass beads cleaning step to the recent seed DNA samples revealed DNA of adequate quality to be used for the PCR reaction.

Although there are numerous reports on successful extraction of amplifiable DNA from archaeological samples (Manen et al. 2004; Regner et al. 2004; Halasz et al.

2005), the first attempt at PCR (preserved chloroplast region) analysis from archaeological samples produced no successful outcome. The plastid organellar DNA exists in numerous copies per cell, and is thus more likely to survive the process of degradation and the effects of damage that follow the death of the organism, compared to single-copy nuclear sequences. Therefore, amplification of the preserved chloroplast region trnL–trnF was chosen for our analysis. The chloroplast region was successfully amplified in modern cultivated seed samples and three putative *V. sylvestris* samples, while amplification from the archaeological samples yielded no results even after several attempts under optimized conditions of amplification (data not shown). One reason for that could be the expected length of the trnL–trnF amplicon, which is up to 800 bp. Such a length can exceed the length of the archaeological DNA remains, and thus the region cannot be amplified. The problem of possible contamination of samples with modern *Vitis* DNA still remains, although several precautions were taken during extraction (see also the methods in ESM).

Conclusions

The oldest Neolithic *Vitis* pips from Slovenia are considered to be wild, according to the Stummer index (1911) and to the four formulae by Mangafa and Kotsakis (1996). The variability of the 142 grape seeds from the Neolithic pile-dwelling settlement is quite large (Fig. 7). Various results were obtained when comparing the modern wild *Vitis* pips from the Danube floodplains, measured by Kohler-Schneider (2001), with the Neolithic *Vitis* pips from Ljubljansko barje, which are considered to be wild (Table 1). The Stummer index and the four formulae show slightly smaller values for the modern wild *Vitis* seeds from the Danube floodplains, which provide more convincing evidence of their being wild.

The Roman *Vitis* seeds from Vrhnika can be determined neither as wild nor as cultivated, although the probability leans in favour of the latter option. The four formulae and indices showed that the Roman pips could not be confidently placed in either of the wild or cultivated groups, but that they were somewhere in between (Table 1). Variability among the 66 measured Roman grape seeds is also extensive (Fig. 7). It is possible that our sample contained two or three types of seeds: rounded and short wild ones, half-domesticated ones, and pyriform and elongated domesticated ones, because some individual seeds do fall into the cultivated range, according to the Stummer index and the four formulae of Mangafa and Kotsakis.

The reference seed material of modern cultivated grapes from Slovenian vineyards is considered cultivated when using the first and the third formulae by Mangafa and Kotsakis (1996), but unconvincing when using the second and the fourth formulae and the Stummer index (Table 1). However, the values obtained by using all four formulae and the Stummer index are higher in comparison to the Roman ones, which is more convincing evidence that they are cultivars.

The measurements and results of the calculated index and formulae of the modern cultivated *Vitis* seeds from France, measured by Kohler-Schneider (2001) show higher values in comparison to the modern Slovenian *Vitis* seeds; this is more convincing evidence of their being cultivars (Table 1). The great polymorphism of pips among grape varieties (Facsar 1970, 1971, 1972) can again be confirmed.

Again, the study of morphological characteristics of grape pips shows considerable variation in values within one measured group (Fig. 7). This confirms that classification into a *Vitis* subspecies based only on morphological characteristics is unsatisfactory. Therefore, an attempt to analyse the DNA was made.

PCR has transformed most areas of molecular biology; in fact, studies of DNA from archaeological remains have created an entirely new field (Pääbo 1991). We have successfully tried a method for the analysis of such remains; however, a modification of the DNA isolation procedure and PCR amplification must be carried out in order to obtain amplifiable DNA. Precautions must also be taken at the time of sample discovery to prevent them from drying out; this may be an additional reason for more rapid degradation of the DNA remains. In future, we aim to use redesigned primers to yield shorter DNA fragments to overcome the problem of ancient DNA degradation and fragmentation.

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3 POVEZOVALNA RAZPRAVA IN SKLEPI

Po skrbni primerjavi različnih metod dela v arheobotaniki smo, po zgledu švicarskega IPNA v Baslu, predlagali in uporabili naslednjo opremo in pripomočke: oprema za spiranje sedimenta v laboratoriju z 0,355 mm in 2 mm sitoma, stereomikroskop Leica MZ75 z do 50x povečavo, potrošni laboratorijski material (pincete, merilne posodice, kemikalije za shranjevanje vzorcev, plastične posodice za sortiranje in shranjevanje), literatura za identifikacijo makrorastlinskih ostankov ter referenčna zbirka recentnih in arheoloških makrorastlinskih ostankov (les, oglje, mikroskopski anatomski preparati lesa, semena in plodovi, vejice z brsti) (glej priloge: 5-10). Poleg samega načina dela (spiranja, shranjevanja in pregledovanja vzorcev) smo prilagodili tudi dokumentacijo (delovne liste), za beleženje pri odvzemu in analizi arheobotaničnega materiala (glej priloge: 1-4), kar bo omogočilo primerljivost slovenskih rezultatov s tistimi, ki jih pridobijo v laboratorijih severno od Alp.
Optimalen postopek opisan v članku 1 (Tolar in sod., 2010), ki vključuje odvzem vzorcev s terena, spiranje sedimenta v laboratoriju s polflotacijo, podvzorčenje ter pregledovanje in identifikacijo mokrih makrorastlinskih ostankov pod stereomikroskopom, je omogočil, da smo pridobili reprezentativne rezultate, ki so predstavljeni v 2. članku (Tolar in sod., 2011).

Na natančno datiranem kolišču Stare gmajne z dendrokronološko in radiokarbonsko wiggle matching metodo (članek 3: Čufar in sod., 2010) smo identificirali 93 različnih rastlinskih taksonov (članek 2: Tolar in sod., 2011). Identificirali smo rastlinske vrste, ki jih pred tem na slovenskih koliščih še nismo odkrili. To so na primer: lan (*Linum usitatissimum*), kopriva (*Urtica cf. dioca*), meta (*Mentha arvensis/aquatica*), krvenka (*Lythrum*), konjska griva (*Eupatorium cannabinum*), alge (*Characeae*), lučnik (*Verbascum*)/črnobina (*Scrophularia*), riček (*Camelina microcarpa*) in peščenka (*Arenaria serpyllifolia*).

Poleg novo odkritih vrst smo z uporabo ustrezne metode ugotovili tudi bolj realno sliko pogostnosti določenih rastlinskih vrst. Predvsem manjši, tanjši in bolj krhki nezogleneli rastlinski ostanki so bili tako prisotni v veliko večjem številu (oz. koncentraciji, izraženi v št. semen/liter sedimenta) kot smo bili prepričani doslej, na primer: semena lanu (*Linum)*, maka (*Papaver*), ogrščice (*Brassica*), ter plev žit (*Cerealia*) in perikarpov jabolk/hrušk (*Maloideae*), želodov (*Quercus*). Na drugi strani pa smo zabeležili manjše relativne količine vrst z lignificiranimi in trpežnimi zunanjimi tkivi semen/plodov, kot so: dren (*Cornus*), leska (*Corylus*), robida (*Rubus*), hrast (*Quercus*) - želodova kapica, metlika (*Chenopodium*) in biček (*Shoenoplectus*).

Uporaba reprezentativne metode nam je omogočila tudi prvo odkritje nezoglenelih ostankov nekaterih pomembnih kulturnih rastlin: semen in ostankov plodnih glavic lanu (*Linum usitatissimum*) ter zrn in plev žit: pšenice (*Triticum*) in ječmena (*Hordeum*) iz koliščarskih naselbin v Sloveniji.
Poleg naštetega smo zbrali tudi ostanke malih živali, kot so: hišice mehkužcev, ostanki žuželk, ribje kosti, zobe in luske, kosti in iztrebki malih sesalcev ter večji iztrebki (koproliti) koz in ovc ter goveda. Ti ostanki še niso bili raziskani in bodo za natančnejše analize shranjeni v mokrem in hladnem mediju (t. j. v destilirani vodi z dodanimi protiglivičnimi kemikalijami ter v hladilniku).
Za identifikacijo smo uporabili lastno arheobotanično referenčno zbirko, ki smo jo sestavili v okviru priprave disertacije na IPNA v Baslu. Ta vsebuje vse potencialne dele več kot 90

rastlinskih vrst, ki bi se lahko ohranile v arheoloških plasteh. Omenjena zbirka je skupaj z recentno referenčno zbirko (glej priloge 5-10) nujno potrebna za arheobotanične raziskave na barjanskih koliščih.
Del zbirke predstavlja tudi lesno-anatomska referenčna zbirka (priloga 6), ki jo priložnostno dopolnjujemo z odkritji novih lesenih najdb. Tako smo v sklopu doktorske naloge za identifikacijo lesenega toporišča (članek 4: Tolar in sod., 2008a) ter ostalih lesenih najdb s kolišča Stare gmajne (Tolar in Zupančič, 2009) v zbirko vključili 9 trajnih preparatov lesa različnih vrst.

Dendrokronologija, podprta z radiokarbonskimi analizami in metodo wiggle-matching, je omogočila, da smo naselbino Stare gmajne absolutno datirali. Ugotovili smo, da je bila dvakrat poseljena, prvič pred letom 3332 pr. n. št. in drugič, po pribl. 170-letni prekinitvi, do okoli 3109 pr. n. št. (članek 3: Čufar in sod., 2010).
Kronologijo širin branik hrastovega lesa s Starih gmajn smo sinhronizirali s kronologijami sedmih kolišč z Ljubljanskega barja, ki so bila naseljena v dveh naselitvenih obdobjih, prvo med 3600 – 3332 pr. n. št. in drugo med 3160 – 3071 pr. n. št. Definirali smo tudi čas največjih aktivnosti v smislu poseka lesa za gradnjo bivališč na posameznih koliščih.
Ugotovili smo, da je bila naselbina Hočevarica (glej članek 3: Čufar in sod., 2010: sl. 1c) najstarejša med raziskanimi. Obstojala je v 37. stoletju pr. n. št. Poseljena je bila zelo kratek čas, zadnja poselitvena faza se je končala okoli leta 3547 pr. n. št. Iz te naselbine izvirajo najstarejše pečke vinske trte, ki smo jih raziskali v članku 5 (Tolar in sod., 2008b).
Kmalu po opustitvi te naselbine, je bila na drugem koncu Ljubljanskega barja (članek 3: sl. 1c) ustanovljena nova naselbina Maharski prekop, ki je bila poseljena od leta 3510 – 3489 pr. n. št.
Približno 60 let kasneje je bila v bližini Maharskega prekopa (ca. 200 metrov stran) ustanovljena nova naselbina, Spodnje mostišče, ki je imela več gradbenih faz, zadnja se je končala okoli leta 3353 pr. n. št. V istem času je na nasprotni, jugozahodni strani Ljubljanskega barja (članek 3: sl. 1c) obstojala tudi naselbina Črešnja pri Bistri, kjer smo ugotovili eno samo gradbeno fazo, ki se je končala okoli leta 3409 pr. n. št.
Za slednjima pa je sledila naselitev Starih gmajn, kot že rečeno do pribl. 3332 pr. n. št. Po 170-letnem obdobju, za katerega nimamo nobenih najdb, je sledila še mlajša naselbinska faza s Starih gmajn in skupine drugih kolišč, ki smo jih datirali z natančnostjo ± 14 let. Sočasno z mlajšo naselbino Starih gmajn je živela komaj 1 km oddaljena naselbina Veliki Otavnik Ib (članek 3: sl. 1c). Les zanjo je bil večinoma posekan okoli leta 3108 pr. n. št., oz. 1 leto po zadnji datirani fazi na Starih gmajnah.
Najmlajša med dendrokronološko raziskanimi kolišči iz 4. tisočletja pr. n. št. pa je naselbina pod imenom Blatna Brezovica (članek 3: sl. 1c), le 500 metrov oddaljena od Starih gmajn, ki pa je bila najverjetneje opuščena okoli leta 3071 pr. n. št.
Po tem obdobju na Ljubljanskem barju ni znanih naselbin, vse do 29. oz. 28. stoletja pr. n. št., ko je bila naseljena naselbina Parte-Iščica z jugovzhodnega dela Barja (članek 3, sl. 1c). Nekaj o mlajših naselbinah, t. j. tistih iz 3. tisočletja pr. n. št., je bilo že objavljeno (Čufar in sod., 1997; Velušček in sod., 2000; Čufar in Velušček, 2003; Velušček in Čufar, 2003).
Dendrokronološke datacije, podprte z radiokarbonsko metodo, so bistvena osnova za interpretacijo rezultatov interdisciplinarnih raziskav na Ljubljanskem barju in za primerjave slovenskih kolišč z drugimi istočasnimi v Evropi.

Ker so bili članki objavljeni v mednarodnih revijah, kjer je dolžina člankov strogo omejena, v diskusijah le teh nismo mogli podrobneje razpravljati o ekoloških in klimatskih razmerah v času obstoja proučenega kolišča in o pomenu določenih rastlinskih vrst na naših tleh, zato se bom tej temi posvetila v nadaljevanju razprave.

S svojimi raziskavami smo pripomogli k spoznanju, da koliščarska poselitev na Barju v času bakrene dobe ni bila konstantna, pač pa so bile vmes ugotovljene poselitvene vrzeli. Tako smo raziskali in datirali 8 kolišč iz obdobja 3600 – 3071 pr. n. št. (glej: članek 3), ki so bila poseljena v dveh naselitvenih obdobjih, prvo med 3600 – 3332 pr. n. št. in drugo med 3160 – 3071 pr. n. št. Vmes je torej zaznati 170-letno poselitveno prekinitev. Ta pojav smo ugotovili prav pri raziskani naselbini Stare gmajne (članek 2), poselitveno vrzel pa so neodvisno potrdile različne interdisciplinarne raziskave. Zastavlja se vprašanje, zakaj v omenjenih 170-tih letih Barje najverjetneje ni bilo poseljeno? Arheobotanične raziskave pričujoče naloge na to vprašanje ne morejo odgovoriti, bi pa lahko, v sodelovanju s palinološkimi, geološkimi in klimatološkimi raziskavami, v prihodnosti pripomogle k primerni razlagi.

Klimatsko-geološko obdobje holocena je v času obstoja bakrenodobnih kolišč trajalo že okoli 6000 let. To je obdobje, ki je sledilo zadnji ledeni dobi in traja še danes. V predhodnih ledenih dobah je bilo ozemlje Slovenije le delno pod ledom (Alpe, Snežnik). Nepoledenele površine pa so preraščale arktična parkovna tundra, tajga ali hladna stepa, le ob vodah so bili mogoči »galerijski gozdovi«. Tako je bilo vse do postopnega ogrevanja v poznem glacialu, ki se je začelo pribl. 15000 let pr. n. št. Vendar pa tla v Sloveniji verjetno niso bila erodirana, zato so takšne razmere omogočale naglo širjenje gozdnega drevja v postglacialu (Šercelj, 1996).
Na prostoru Slovenije je dokazano, da so v ledenodobnih klimatskih razmerah obstajali ugodni kotički, ekološke niše, in to predvsem ob kraških jezerih in rekah, ob kraških izvirih in proti jugu obrnjenih dolinah, kjer so se tudi v poledenitvenih fazah mogle obdržati skupine toploljubnih rastlin in živali (Šercelj, 1970). Takšne vrste zavetišč imenujemo mikrorefugiji. Ko pa so se začele klimatske razmere v poznem glacialu postopoma izboljševati, so ti mikrorefugiji postali žarišča, iz katerih se je na vse strani širila preživela drevesna vegetacija. Tako so se v holocenu že takoj na začetku razrasli strnjeni gozdovi in v prej kot 3000 letih so se zvrstile vse gozdne faze od pionirske do klimaksne (Šercelj, 1996).
S tega vidika lahko predvidevamo, da se v koliščarski dobi klima in z njo vegetacija v osrednji Sloveniji najverjetneje ni bistveno razlikovala od današnje. Rastlinstvo se je namreč v 6000 letih najverjetneje že vrnilo iz mikrorefugijev, kjer je našlo zatočišče med ledeno dobo, in se razširilo v okolje, tudi na Barje in v njegovo okolico. Z nekolikšnim časovnim zamikom, lahko tudi tisoč let in več, se je holocensko rastlinstvo počasi razširilo tudi preko Alp, kjer so severno od Alp tudi obstojala kolišča, ki jih omenjamo v članku 2 in jih arheobotanično primerjamo s slovenskim koliščem Stare gmajne. V kolikšni meri je bila vegetacija severno in južno od Alp v času kolišč podobna, je pomembno vprašanje, ki bi ga lahko v prihodnosti razrešilo tudi sodelovanje arheobotanikov z drugimi naravoslovnimi vedami.

Pri vprašanju pretekle vegetacije v okolici Barja so nam v pomoč pelodni diagrami z Ljubljanskega barja akademika dr. Alojza Šerclja (n. pr. Šercelj, 1996) in novejši diagrami

dr. Maje Andrič (n. pr. Andrič in sod., 2008). Palinologija namreč indirektno (po ohranjenem pelodu) omogoča registrirati najpomembnejše sestavine nekdanje vegetacije in njihovo medsebojno razmerje ter spreminjanje vegetacije v času. Po pelodnih diagramih je bilo ugotovljeno, da kasnoglacialno vegetacijo sestavljajo rastline, ki so sposobne prenašati ekstreme ledenodobnega podnebja kot na primer: *Pinus, Picea, Betula, Juniperus* ter zelišča in mahovi ter lišaji. Zelišča so bila poleg redkih dreves tipična pionirska zarast razgaljenih tal. Takšna, od podnebja odvisna vegetacija: tundra, tajga, hladna stepa in vmes borovo-brezovi gozdiči, je bila izrazito klimatogena. Sporadično se v kasnoglacialnih sedimentih pojavlja tudi pelod mezofilnih listavcev, kot so *Fagus, Quercus, Ulmus, Tilia, Ostrya, Corylus* in celo *Abies* (Šercelj, 1963; Culiberg, 1991). V tem primeru imamo dokaze, da je to drevje preživelo ohladitve v mikrorefugijih (Šercelj, 1996).
V številnih paleolitskih (ledenodobnih) naselbinah po Sloveniji so med obilico oglja iglavcev, bora in smreke, identificirali tudi oglje naslednjih drevesnih vrst: *Fagus, Tilia, Ulmus, Quercus, Fraxinus, Sorbus, Carpinus, Ostrya, Corylus, Acer, Taxus, Populus, Alnus* (Šercelj, neobj. poročila; Šercelj in Culiberg, 1985). To pomeni, da je omenjeno drevje raslo tam že v obdobju paleolitika. Šercelj (1996) razlaga, da so med bori, ki so prevladovali, posamično rasli tudi listavci.
Prehod hladnodobne (glacialne) vegetacije v toplodobno (holocensko) ni bil skokovit, temveč postopen. V pelodnem diagramu se kaže kot močno nazadovanje iglavcev in breze ter hitro širjenje elementov mešanega hrastovega gozda, kar naj bi se na Barju (oz. na področju Slovenije) zgodilo med ok. 9900 in 9400 pr. n. št. (n. pr. Andrič in sod., 2008).

Tudi za holocensko klimo in z njo vegetacijo je bilo ugotovljeno, da sta se v zadnjih 10000 letih spreminjali in nihali od toplejše in suhe do hladnejše in vlažne, kar bi lahko bil tudi eden izmed razlogov za večjo ali manjšo poselitev na določenih področjih v določenih obdobjih. Blytt in Sernander sta tako na podlagi klimatskih, geoloških in bioloških dogajanj v skandinavskih šotiščih vpeljala več časovnih odsekov v holocenu: boreal, atlantik, subboreal, subatlantik, pri čemer naj bi bil boreal najtoplejši in suh, atlantik topel in vlažen, subboreal topel in suh, subatlantik pa vlažen in hladnejši (po Lowe in Walker, 1997). Časovne meje med posameznimi obdobji niso jasno definirane. Tudi sama metodologija, na osnovi katere sta prišla do te razdelitve, je vprašljiva in nikakor ne more biti posplošena za celotno Evropo.
Firbas (1949) je to členitev prilagodil klimatsko-ekološkim zahtevam sukcesivnih gozdnih faz ob njihovi selitvi od Alp proti Balkanu in Skandinaviji. Za srednjo Evropo severno od Alp je tako na podlagi številnih pelodnih diagramov postavil razvojno shemo vegetacije po gozdnih fazah za pozni glacial (15000 – 10000 let pr. n. št.) in holocen. Te gozdne faze veljajo kot kronotipi in se še danes uporabljajo za določanje časa in podnebja na podlagi nastopa te ali one faze. Vendar pa se moramo zavedati, da je ta shema »tempirana« le za en, časovno in geografsko določen pas srednje Evrope. V južnejših pasovih je nastopila določena gozdna faza prej, v severnejših pa ustrezno kasneje.
Šercelj (1996) je prikazal paralelen prikaz kronologije naseljevanja gozdov (gozdnih faz) v Sloveniji in severno od Alp (po Firbas-u, 1949), kjer je jasno razvidno, kako so se v Sloveniji vse gozdne faze razvile hitreje in prej kot na območjih severno od Alp. Tako je n. pr. klimaksna faza Abies-Fagus v Sloveniji nastopila že v začetku atlantika (pred pribl. 7000 leti), medtem ko je v severni Evropi klimaksna faza Fagus dosegla svoj vrh šele v subatlantiku (pred pribl. 2000 leti), kar je pribl. 5000 let kasneje (Šercelj, 1996: str. 13, sl. 4).

Glede na raziskave pričujočega doktorskega dela nas zanimajo značilnosti vegetacije in klime v Sloveniji v času eneolitskih kolišč na Barju, ki naj bi okvirno sodile v prehodni čas med atlantikom in subborealom oz. v subboreal, ko naj bi se začelo tudi presihanje jezera in rast šote (Šercelj, 1996). V tem času naj bi vegetacija v Sloveniji (po Šercelj, 1996) že dosegla svoj vrh, torej zadnjo razvojno fazo, t. j. Abies-Fagus (tudi po diagramu Andrič in sod., 2008). Severno od Alp pa naj bi v časovno istem obdobju uspevala gozdna faza Quercetum mixitum, kar je dve razvojni fazi nižje kot v Sloveniji (po Firbas, 1949).

Že ob koncu boreala (zgodnji holocen) je na področju Slovenije v nižjih in gorsko ležečih gozdovih prevladovala bukev (*Fagus*). Le v alpskem delu se je s precejšnim deležem obdržala smreka (*Picea*). V prvi polovici atlantika se je bukovim gozdovom pridružila tudi jelka (*Abies*) in sta se povezali v fazo Abieti-Fagetum (od ok. 7300 do 5000 pr. n. št.; po diagramu: Andrič in sod., 2008). Od tedaj naprej je bil jelovo-bukov gozd v raznih variantah dominantna gozdna vegetacija vse do danes, torej tudi v obdobju eneolitskih kolišč na Barju. V alpskem prostoru se je vseskozi pojavljala tudi smreka. V nižjih legah pa so se neprestano izmenjavale gozdne faze nižje stopnje, pogosto tudi z gabrom. V subborealu se je bukev začela vrivati v hrastove gozdove in šele v subatlantiku (pred 2500 leti) je poselila tudi srednjeevropski prostor (Buchenzeit; po Šercelj, 1996).
Ker je Abieti-Fagetum v Sloveniji klimaksna gozdna formacija, je bil progresivni razvoj gozdov s tem končan. Nastopi recikliranje navzdol: na nižje stopnje (t. j. sukcesijsko zgodnejše stadije) in spet navzgor (t. j. klimaksne stadije). Alternirata bukev in jelka, lahko gre tudi še niže v Quercetum mixtum in se spet obrne navzgor. Vse te progresivne in regresivne stopnje se kažejo kot sekundarne gozdne faze.
Subboreal, v katerem naj bi obstojalo tudi raziskano barjansko kolišče Stare gmajne, velja za razmeroma toplo in suho obdobje. Sušnost naj bi se kazala v nihanjih vodne gladine nekaterih evropskih jezer in rek. Delno je vzrok tudi v listnati gozdni vegetaciji, ki z močnejšo transpiracijo vpliva na vodno bilanco ter na vedno gostejšo človekovo poselitev (Frenzel, 1983).
Tudi nekdanje jezero na Ljubljanskem barju je ob koncu eneolitika (pred pribl. 4300 leti) začelo presihati. Na to kaže tudi prehajanje jezerske krede v močvirsko blato organskega nastanka (gyttja) in začetek rasti šote (Šercelj, 1996). V teh prehodnih fazah je veliko ostankov eneolitskih koliščarskih naselbin, ki tudi kažejo na dinamiko krčenja holocenskega jezera v smeri proti središču Ljubljanskega barja (Velušček in Čufar, 2008). Gozdna vegetacija je bila v tistem času še v glavnem Abieti-Fagetum (Šercelj, 1996; Andrič in sod. 2008). Toda eneolitski človek je v svojem okolju že kar močno degradiral klimaksni gozd in ga spremenil v sukcesijsko zgodnejše stadije s pionirskimi gozdnimi združbami. To se prav izrazito kaže tudi na Barju (Culiberg in Šercelj, 1991; Andrič in sod., 2008), na Krasu in ob kraškem polju (Ajdovska jama). Abieti-Fagetum je v bolj ali manj neprizadetih pokrajinah sicer še naprej ostajal vodilna gozdna formacija. Le na skrajnem vzhodu Slovenije se jelka ni uveljavila (Šercelj, 1996).

Na podlagi zgornjega povzetka po Šerclju (1996) lahko torej zaključimo, da je bila naravna vegetacija v dobi eneolitskih slovenskih kolišč zelo podobna današnji. Verjetno tudi klima ni veliko odstopala od današnje, lahko pa so bila vmes kakšna bolj suha/toplejša ali vlažna/hladnejša obdobja (kot sta ugotovila Blytt in Sernander v Skandinavskih šotiščih), ki so tedanjim prebivalcem omogočila ali onemogočila bivanje na Barju. Kdaj točno je do teh klimatskih nihanj prišlo v Sloveniji (oz. v celotni Evropi), je za enkrat še vprašanje, ki si ga želimo skupaj z dendrokronologi in palinologi v prihodnosti razjasniti.

Zaradi že zgoraj omenjene biogeografske omejenosti pri interpretaciji rezultatov arheobotaničnih raziskav iz srednje in severne Evrope želim v nadaljevanju razširiti tudi razpravo o pomenu posameznih rastlinskih vrst, odkritih na najdišču Stare gmajne v okviru pričujoče disertacije.

Da bi se malce bolje seznanili in izpostavili prehrano koliščarskih prebivalcev in njihovo kulturo nabiranja oz. gojenja rastlin (članek 2), sem poglavje v nadaljevanju namenila sintezi najpomembnejših prehrambenih rastlin, ki smo jih našli na najdišču Stare gmajne (članek 2), ter jih grupirala v tri skupine, glede na domneven način pridobivanja. Omenjene rastline, predvsem nabirane vrste, nam lahko podajo tudi informacijo o vegetaciji (ev. tudi klimi) v času kolišč.

Kulturne, gojene rastlinske vrste (vse po: Zohary in Hopf, 2004)

Triticum monococcum (enozrna pšenica)

Enozrna pšenica je bila v času eneolitika eden osnovnih žitnih pridelkov na bližnjem vzhodu in glavna komponenta zgodnjih žit v Evropi. V bronasti dobi njen pomen drastično upade, najverjetneje zaradi pojava novih vrst žit, katerih zrna je bilo lažje ločiti od plev. Rastlina uspeva tudi na revnejših tleh.

Triticum dicoccum (dvozrna pšenica)

Tudi dvozrno pšenico je težko izluščiti iz plev, zato velja za primitivno obliko žit. Bolj napredna sorodnica dvozrne pšenice je trda pšenica (*T. turgidum* ssp. *durum*), ki je na slovenskih koliščih zaenkrat še nismo odkrili. Ima nežnejše pleve, zato je njena zrna lažje izluščiti. Trda pšenica velja za eno glavnih žit v Evropi v času eneolitika in zgodnje bronaste dobe.

Hordeum vulgare (navadni ječmen)

Ječmen velja za eno glavnih žit na območju Sredozemlja in osnovni pridelek starega sveta v eneolitiku. Je univerzalni spremljevalec pšenice, toda v primerjavi s pšenico velja za pridelek revnejših ljudi. Na številnih področjih Sveta je veljal za enega glavnih pridelkov, ker dobro prenaša sušna in revnejša tla ter tudi nekaj soli v tleh. Še dandanes predstavlja pomemben delež pri prehrani ljudi in domačih živali.

Papaver somniferum (vrtni mak)

Mak je bil v eneolitiku najverjetneje že gojen in sicer iz dveh razlogov: 1. kot vir opija, ki ga vsebujejo še nezrele plodne glavice in 2. kot vir olja, ki ga vsebujejo njegova semena. Semena lahko predstavljajo hrano ali pa iz njih ekstrahirajo olje. Zelo verjetno se je udomačevanje maka začelo, za razliko od žit, ki načeloma izvirajo iz bližnjega vzhoda, v Sredozemlju, kjer je avtohton tudi njegov divji prednik.

Linum usitatissimum (navadni lan)

Lan velja za glavno oljno in tekstilno surovino Starega sveta. Najverjetneje je bil prva kultivirana rastlina z namenom izdelovanja oblek (pridobivanja vlaken, sukanca). Njegova semena so bogata z oljem. Kot uporabna rastlina je bil še preden so ga začeli gojiti, saj najstarejši dokazi o njegovi uporabi segajo že v 10. tisočletje pr. n. št. Na evropskih eneolitskih in bronastodobnih koliščih so njegove najdbe stalno prisotne, medtem ko smo ga na slovenskih koliščih odkrili prvič s pričujočo raziskavo v tem doktorskem delu.

Pisum sativum (navadni grah)

Grah velja za eno najstarejših gojenih stročnic. Njegovi začetki segajo približno tako daleč nazaj kot gojenje pšenice in ječmena. Rastlina se dobro prilagaja tako topli sredozemski klimi, kot tudi zmerni klimi osrednje Evrope. Semena so bogata s proteini, zato so zelo primerna za človeško prehrano. Na bližnjem vzhodu se pojavi že v 8. tisočletju pr. n. št., večje količine pa nekje sočasno z žiti, t. j. v 6. tisočletju pr. n. št. Semena divje in gojene oblike graha je težko ločiti, pa vendar predvidevajo, da naj bi se grah razširil v Evropo skupaj z žiti v neolitiku. Kako pomemben je bil grah v prehrani koliščarjev s Starih gmajn ne moremo oceniti, saj smo našli le 3 ostanke zoglenelih semen. Razloga za tako slabo zastopanost sta lahko dva: 1. da se grah slabše ohranja v mokrih tleh zaradi neznanih tafonomskih razlogov ali pa grah preprosto ni bil tako pomemben in priljubljen v prehrani koliščarjev. Pa vendar so skromni ostanki dokaz o njegovem zgodnjem gojenju na naših tleh, saj divji prednik graha v naših krajih ne velja za avtohtono vrsto.

Nabirane ali gojene rastlinske vrste (po: Zohary in Hopf, 2004; Martinčič in sod., 1999)

Camelina sp. (riček)

Camelina sativa iz družine Cruciferae oz. Brassicaceae (križnice) danes velja za poslednji ostanek oljne rastline, ki je na hitro izginila iz kultivacije. Še do leta 1940 je bila pomembna kot oljna vrsta v vzhodni in srednji Evropi. Pogosto je odkrita v arheoloških plasteh srednje in vzhodne Evrope, vendar ne prav iz zgodnjih plasti, saj se najzgodnejše najdbe pojavljajo šele v 3. in 2. tisočletju pr. n. št. Rastlina se je najverjetneje razvila sprva kot plevel na njivah lanu ter žit in je bila kasneje nabirana in kultivirana za pridobivanje olja, zato jo štejemo za sekundarni kultivar, torej vrsto, ki se je razširila zaradi gojenja drugih pridelkov. Tu se nam zastavi vprašanje, ali so jo koliščarji z Barja že poznali kot uporabno vrsto ali je veljala še za plevel na njivah. Glede na majhne količine najdenih ostankov te vrste (samo 3 semena), bi lahko bila bolj verjetna slednja trditev. V prihodnosti velja biti na to rastlino bolj pozoren.

Brassica rapa (repa, oljna repica)

Divja oblika te rastlinske vrste, ki ima z oljem bogata semena, ima zelo velik areal razširjenosti, ki sega od zahodne Azije pa vse do Evrope, kot plevel pa se je razširila tudi preko teh meja. Iz švicarskih in nemških koliščarskih naselbin poročajo o domnevni uporabi/nabiranju semen, najverjetneje še divje oblike (tako kot *Camelina*) kot vir olja (Schlichtherle, 1981). Medtem ko številne najdbe semen te vrste iz rimskega obdobja že kažejo na kultivacijo. Dokaj zaznavna prisotnost semen oljne repice iz sedimentov tako s Starih gmajn (234 nezoglenelih semen) kot tudi z več eneolitskih in bronastodobnih švicarskih jezerskih naselbin nakazuje na dokaj zgodnjo uporabo te rastline, najverjetneje še divje rastoče oz. plevelne vrste. Današnja slovenska flora ne pozna divjih vrst iz rodu Brassica, pač pa samo gojene (kapus, kamor štejemo: zelje, ohrovt, cvetača, brokoli, kolerabica; repa/oljna repica; navadna ogrščica in črna ogrščica), ki večkrat podivjajo (po MFS, Martinčič s sod., 1999), zato se tudi tu zastavi vprašanje, kako je rastlina prišla v okolico kolišč, zagotovo pa s človekovim posredovanjem: hote (kot gojena vrsta) ali nehote (kot plevel).

Chenopodium album (bela metlika)

Izjemno visoke vrednosti najdenih semen v kulturni plasti s Starih gmajn (preko 1300 semen) nakazuje njihovo uporabno vrednost v času koliščarjev. Čeprav gre za domnevno izrazito plevelno oz. vrsto ruderalnih in obdelanih tal, ne gre zanemariti, da so njena semena bogata z olji in je bila zato morda vrsta prav tako kot *Camelina* in *Brassica* pomembna v prehrani koliščarjev. Uporabni so tudi zeleni deli rastline kot zelenjava. Podobno domnevajo tudi za kolišča severno od Alp.

Fallopia dumetorum/convolvulus (hostni/navadni slakovec)

Med najdenimi semeni vrst, ki bi lahko bile kultivirane, sta zanimivi tudi hostni in navadni slakovec, bližnja sorodnika ajde (*Fagopyrum esculentum*) iz družine Polygonaceae (dresnovke). Medtem ko hostni slakovec raste med grmovjem in v logih, uspeva navadni slakovec tudi na obdelanih tleh in ruderalnih mestih. Semena vseh treh vrst se da razmeroma dobro ločiti, tako da smo lahko prepričani, da prave ajde med koliščarskimi botaničnimi ostanki nismo našli in da je najverjetneje v prehrani koliščarjev še ni bilo. Doslej je veljalo, da naj bi ajda v Evropo prišla šele v 15. stoletju n. št. (Simmonds, 1976).

Daucus carota (nav. korenje)

Rastlina, suhih travnikov in pripotij je bila najverjetneje prinešena v koliščarsko naselbino ob jezeru iz okoliških, sušnejših predelov, morda njiv. Ali je bila gojena ali zgolj naključno najdena in nabrana, pa zaenkrat ostaja neodgovorjeno.

Vitis vinifera ssp. *sylvestris* (divja vinska trta)

Vprašanju vinske trte smo namenili poseben članek (članek 5). Po raziskavi pečk, smo najdene koliščarske pečke uvrstili v skupino divje vinske trte. Ker so bile pečke številčne in pogosto najdene tudi na ostalih barjanskih koliščih, se nam je tudi tu zastavilo vprašanje o kulturi nabiranja oz. gojenja te vrste. Glede na to, da je bila klima in z njo tudi vegetacija v času kolišč najverjetneje podobna današnji, bi lahko sklepali, da obsežnih rastišč, idealnih za uspevanje divje vinske trte, v okolici kolišč ni bilo. Če pa upoštevamo, da trta dobro uspeva v mikroklimatskih razmerah termofilnih vlažnih gozdov in nabrežij, Piltaver (2007) opisuje nedavno odkrito rastišče divje vinske trte v Sloveniji: vzdolž prisojnih melišč, pogosto pred odprtimi skalnatimi stenami tam, kjer se v tleh pojavlja obilica vode, prisojne lege pa nudijo veliko sonca, bi morda lahko podobne kotičke našli tudi v Krimskih in Mokrških gozdovih v bližini barjanskih kolišč (n. pr. v Iškem vintgarju). Po botanični literaturi naj bi bila divja vinska trta nekoč pogostejša rastlina evropskih gozdov in je njeno izginotje (uničenje) povzročil človek. Z odkritjem Amerike je v Evropo prinesel mnoge nove vrste rodu Vitis, z njimi pa tudi številne škodljivce in bolezni, ki so povzročile popolno uničenje nekaterih evropskih sort vinske trte (Piltaver, 2007). V zadnjem času pa je človek uničil tudi večji del trtinega življenjskega okolja, ki je kot vemo zelo specifično. Tako je vrsta, ki je bila do 19. stoletja pogosta rastlina poplavnih ravnic Donave v Avstriji ter Rena v Nemčiji in Franciji, postala dandanes zelo redka in jo srečamo samo še ponekod v naplavnih in meliščnih gozdovih (Kohler-Schneider, 2001). Danes so rastišča samonikle vinske trte v Sloveniji prava redkost in vprašljiva, obstajajo namreč samo še posamezne populacije, ki so zelo razdrobljene. Če bi znali odgovoriti na vprašanji: ali je bilo temu tako tudi v času kolišč in kje v bližini kolišč bi lahko uspevala tako ozko habitatna vrsta, bi lahko odgovorili tudi na vprašanji ali so koliščarji vrsto srečevali v bližnjem gozdu (kar pomeni, da bi je moralo biti v gozdu precej, glede na količino najdenih pečk), ali pa so koliščarji grozdje prinesli od drugod. Še vedno pa obstaja manj verjetna možnost, da so divjo vinsko trto, kot rastlino pripeljali od drugod in jo gojili v bližini kolišč. Vendar, kot navaja Piltaver (2007), je vzgoja divje vinske trte zelo zahtevna in po pripovedovanju domačinov iz Vinj, kjer so nedavno odkrili še zadnje ostanke te rastlinske vrste v Sloveniji, to za enkrat ni uspelo še nikomur, ki je poskusil. Poleg tega z barjanskih kolišč, razen pečk, zaenkrat še nismo odkrili ostalih ostankov vinske trte, n. pr. lesa ali zaznavnejših količin peloda (Andrič, osebna komunikacija, navaja po 1-2 pelodni zrni v kulturni plasti nekaterih kolišč, tudi Starih gmajn; tudi Jeraj, 2002). Tako ostaja vprašanje o prvih gojenih vinskih trtah na naših tleh še vedno odprto (članek 5).

Nabirane rastlinske vrste

Med nabiranimi rastlinskimi vrstami, prinesenimi v naselbino iz gozda oz. njegovega obrobja, so najpogosteje najdena semena/plodovi naslednjih vrst: *Quercus* sp. (hrast, želod), *Corylus avellana* (leska, lešnik), Maloideae (jablana, hruška), *Fragaria vesca* (jagodnjak), *Rubus fruticosus* agg. (robida), *Physalis alkekengi* (nav. volčje jabolko), *Cornus mas* (rumeni dren), *Crataegus monogyna* (enovrati glog), *Prunus spinosa* (črni trn) in *Rosa* sp. (šipek).

Zanimivo, da so bili ostanki plodov *Fagus sylvatica* (bukev, žir) zelo redki, medtem ko ostankov plodov/semen *Prunus avium* (divja češnja) in *Castanea sativa* (pravi kostanj) zaenkrat sploh še nismo odkrili, čeprav so vse tri vrste v Sloveniji avtohtone in so tako najverjetneje uspevale tudi v bližnji ali daljni okolici kolišč. Rastišča bukve in divje češnje še danes najdemo na bližnjem pobočju Krima, nedaleč stran od kolišč, medtem ko so najbližja rastišča pravega kostanja malo odmaknjena, n. pr. na Golovcu nad Rudnikom. Da koščic divje češnje ne bi ločili od koščic črnega trna, je skoraj nemogoče, saj imajo koščice češnje bolj gladko površino in so nekoliko bolj okrogle oblike, ter manjše. Za žir pa je zelo verjetna razlaga, da se v mokrih tleh, kjub anoksičnosti tal, slabše ohrani kot drugi plodovi/semena s trdnejšo lupinico in je zato v zbitem barjanskem sedimentu slabše zastopan. Za bukev tako ne moremo trditi, da med koliščarji ni bila priljubljena nabirana vrsta. Zakaj ni najdb divje češnje, lahko zaenkrat samo ugibamo, medtem ko za pravi kostanj obstaja razlaga, da vrsta v bližini kolišč verjetno še ni uspevala, saj tudi pelodne analize kostanja ne zaznajo v večjih količinah (Andrič, osebna komunikacija) in ga

koliščarji najverjetneje še niso poznali. Šercelj sicer omenja domnevno kostanj med lesenimi najdbami na najdišču Blatna Brezovica (Šercelj, 1981-82), vendar pri tem poudarja, da bi bila potrebna revizija identifikacije lesa, saj terenski mikroskop ni dopuščal razpoznave ločilnega znaka kostanjevega in jesenovega lesa. Novejše raziskave lesa z barjanskih kolišč kostanja ne omenjajo (Čufar; Tolar, osebna komunikacija). Kostanj namreč izvira iz Sredozemlja in so ga po Evropi razširili Rimljani, skupaj z vinsko trto (Brus, 2004). Kljub temu *Castanea sativa* v Sloveniji velja za samoniklo vrsto, saj je bil odkrit pelod te vrste izpred nekaj tisoč let, vendar pa so bila rastišča sprva omejena na dve glavni območji: spodnje Posavje in ob spodnjem toku Soče (vse po Brus, 2004).
Med kaloričnimi oreški je omembe vreden tudi *Trapa natans* (vodni orešek), ki je bil očitno med koliščarji zelo priljubljen, saj so njegovi ostanki v sedimentu redno prisotni v večjih količinah. Gre za plavajočo rastlino stoječih vod, torej so jo koliščarji najverjetneje nabirali v bližnjem jezeru. Rastlina danes velja za redko in ranljivo vrsto. Na večini severno alpskih koliščih vrsta ni tako zelo pogosta (članek 2), kar bi lahko pomenilo, da so v barjanskem jezeru vladali drugačni ekološki pogoji. Vrsta namreč preferira plitva mezo- do evtrofna jezera, ki se poleti segrejejo (n. pr. Karg, 2006). O domnevni plitvosti in z njo segretosti jezerske vode (nad 18 stopinj) pričajo tudi najdbe divjega krapa (*Cyprinus carpio*) iz sedimentov kolišča Hočevarica na Ljubljanskem barju, za katerega je znano, da se drsti samo v topli vodi, nad 18 stopinj celzija (Govedič, 2004).
Med najdbami jagodičja pa na Starih gmajnah pogrešamo maline (*Rubus idaeus*), ki jih danes pogosto srečamo v gozdovih in na posekah ter grmovnatih mestih in borovnice (*Vaccinium myrtillus*), ki uspevajo v zakisanih gozdovih ter med resjem in rušjem. Semena robide (*Rubus fruticosus* agg.), ki so pogosto najdena v koliščarskih sedimentih (n. pr. Jeraj, 2004), so zelo podobna semenom maline, toda z malo večjo pozornostjo lahko opazimo tudi rahle razlike v obliki in velikosti semen. Semena robide so nekoliko večja in so ledvičaste do okroglo-trikotne oblike, medtem ko imajo semena maline vrh kljukasto zaključen in so manjša. Današnja razširjenost robide v Sloveniji je večja kot maline, saj jo najdemo od nižine pa vse do montanskega pasu (Kosmač, 2010). Kar se tiče rastišča, malina preferira rodovitna in vlažna tla, medtem ko lahko robida poseljuje tudi zelo revna rastišča, kakršna so tudi ilovnata barjanska tla, ter uspeva tako na suhih kot tudi na vlažnih (dobro drenažnih) tleh (Kosmač, 2010). Danes na Barju srečamo le robido, medtem ko na gozdnih jasah bližnjega Krimskega in Mokrškega hribovja lahko naletimo tudi na malino. Glede na zgornja dejstva so koliščarji z Barja verjetno pogosteje srečevali robido kot malino.
Borovnica (*Vaccinium myrtillus*) pa je vrsta, ki je v južnem delu Slovenije (Dinarskem gorstvu) resda redkeje prisotna kot v severnejših predelih. Zelo ji prijajo zakisana tla, ki jih ustvarjajo smrekovi in kostanjevi gozdovi, rušje ter resje. Slabo prenese sušna tla (Kosmač, 2010). Tudi danes jo v okolici barjanskih kolišč redko najdemo, saj zanjo ni primernih rastišč. V nižinskem barju sploh ne, medtem ko v bližnjem Dinarskem hribovju samo na določenih mestih. Ali so koliščarji rastlino kljub temu poznali še ne vemo, saj njenih semen, velikosti razreda od 1 do 1,5 mm, zaenkrat še nismo uspeli odkriti.

Glede na spekter nabiranih vrst, z izjemo vinske trte, ki je verjetno uspevala tudi v bližini kolišč, in vodnih-jezerskih rastlin, lahko sklepamo na zelo podobno vegetacijo in z njo tudi primerljivo klimo v dobi kolišč in danes.

Dosedanji rezultati in izzivi za prihodne raziskave

Članek 1 te doktorske disertacije opisuje metodologijo, ki je trenutno edina, ki v arheobotaničnih raziskavah zagotavlja reprezentativne in primerljive rezultate. Še vedno pa se moramo zavedati, in seveda to tudi upoštevati, da velika večina rastlinskih ostankov, kljub primerni metodologiji spiranja in vzorčenja, v tisočletjih propade oz. se ne ohrani. Zato je rezultatom semi-kvantitativnih analiz, ki jih pridobimo v arheobotaniki iz arheoloških sedimentov zelo nevarno pripisovati zanesljivo kvantitativno vrednost in je tako na osnovi zgolj arheobotaničnih rezultatov, pridobljenih iz površinsko zelo omejenega najdišča (sonda 3 x 3 m), težko opisovati tedanjo vegetacijo na in v okolici najdišča. So pa nam ti rezultati lahko v veliko pomoč pri ugotavljanju prvih kulturnih rastlin, opisovanju prehranskih navad naseljencev in nenazadnje, v sodelovanju s palinologijo ter drugimi naravoslovnimi vedami, tudi pri ugotavljanju pretekle vegetacije, okolja in klime.

V 2. članku poskušamo arheobotanične rezultate s slovenskega kolišča Stare gmajne primerjati z rezultati s kolišč severno od Alp. Pri tem se moramo zavedati, da je biogeografija Slovenije (južno od Alp) drugačna od pokrajin severno od Alp. Alpe so namreč predstavljale veliko naravno oviro pri širjenju rastlinskih vrst iz ledenodobnih mikrorefugijev nazaj v območja severno od Alp, ki so bila med ledenimi dobami večkrat pokrita s snegom in ledom. Dandanes je vegetacija severno in južno od Alp verjetno bolj primerljiva kot je bila pred pribl. 5300 leti, ko so obstojala kolišča na območju Starih gmajn. Zato se ekološka opredelitev nekaterih rastlin, n. pr. v članku 2 (Tab. 4, str. 27) nekoliko razlikuje od slovenske. Rod *Sparganium* sp. (ježek) n. pr. v Sloveniji v glavnem poseljuje mokra, s hranili bogata rastišča v nižinah in montanskem pasu, le dve vrsti lahko najdemo tudi v plitvinah manjših jezerc in počasi tekočih voda (po MFS, Martinčič in sod., 1999). Po flori severno od Alp pa jo uvrščajo med vodne rastline (članek 2). *Eupatorium cannabinum* (konjska griva) v Sloveniji velja za rastlino posek ter svetlih in vlažnih gozdov, medtem ko ga severno od Alp uvrščajo med močvirne rastline. *Physalis alkekengi* (volčje jabolko) v Sloveniji poseljuje tako gozdove kot tudi grmovja in obdelana tla, medtem ko severno od Alp velja za bolj gozdno rastlino. *Epilobium hirsutum* (dlakavi vrbovec) v Sloveniji poseljuje bregove voda, vlažne travnike in grmovja, severno od Alp pa gozdno obrobje in jase. *Ranunculus repens* (plazeča zlatica) je v Sloveniji značilna rastlina vlažnih travišč, njiv ter gozdnih obronkov, tudi jarkov. Severno od Alp jo uvrščajo med plevelne in ruderalne rastline. *Sambucus ebulus* (smrdljivi bezeg) je rastlina tako obdelanih in ruderalnih rastišč, kot tudi vlažnih travnikov in gozdnih obronkov, zato jo težko uvrstimo v eno samo skupino (o slovenskih rastiščih vse po MFS).

Članek 3 postavlja barjanska kolišča iz 4. tisočletja pr. n. št. v kronološko sosledje z absolutnimi datacijami s pomočjo dendrokronologije in radiokarbonske analize ter metode wiggle matching. Natančne datacije so zelo pomembne za nadaljno delo, saj bomo samo tako lahko primerjali sočasna kolišča med seboj ter s poslednimi.
Poleg samih datacij pa raziskava lesnih pilotov podaja tudi informacijo o izbiri in posredno o razpoložljivosti lesnih vrst. Koliščarji s Starih gmajn so za konstrukcijske namene v veliki večini uporabljali odporen ter trden hrast (36 %) in trden a neodporen les jesena (pribl. 44 %). Naša kolišča se od sočasnih kolišč severno od Alp, n. pr. Arbon Bleiche 3 v Švici, razlikujejo po slabši zastopanosti ali v nekaterih primerih odsotnosti jelke (*Abies alba*) za gradbeni material. Na najdišču Arbon Bleiche 3 jelka namreč s 27 % celo prevlada

nad jesenom (14 %) in hrastom (5 %). Zanimivo sta med pogosto uporabljenimi vrstami tudi manj odporni in manj trdni jelša (*Alnus glutinosa*) s 16 % in leska (*Corylus avellana*) s 5 % (Sormaz, 2004). Obe vrsti sta redno prisotni tudi na naših koliščih, pri čemer je veliko bolj pogosta jelša, a z zgolj 3 % na Starih gmajnah.
Če pogledamo še eno najdišče severno od Alp, Hornstaad-Hörnle ob Bodenskem jezeru v Nemčiji (po Billamboz, 2006), ki je bilo z vmesnimi prekinitvami naseljeno v 5 fazah od 40. do 27. stoletja pr. n. št. V najzgodnješih fazah poselitve tudi tu jesen in hrast nista predstavljala tako velikega deleža med uporabljenim gradbenim materialom kot pri nas. Najpogostejši sta bili vrba in topol, vsaka s po 22 %, sledi leska z 21 %, nato pa še hrast s 16 % in jesen s 15 %. Raziskana je bila veliko večja površina kot pri nas, pri čemer so prišli do ugotovitve, da je bila naselbina po požarih večkrat na novo poseljena, z različno postavitvijo hiš in da so za gradnjo v različnih fazah uporabljali različne tipe lesnih vrst. V najstarejši fazi HOIA so uporabljali različne vrste: bukev, hrast, jesen, leska, topol, vrba, javor in jelša, v pribl. 30 let mlajši fazi HOII so dominirale jesenove konstrukcije, čez 300 let v fazi HOIB pa hrastovo-jesenove. Te spremembe v uporabi različnih drevesnih vrst Billamboz (2006) razlaga s spremembo tradicije in z inovacijami v gospodarjenju z gozdom med tedanjimi prebivalci. Opaža pa tudi veliko interakcijo med naselbinsko aktivnostjo in spremembami v okolju. V določenih gradbenih fazah so zaznali uporabo serije mladih dreves, kar pomeni, da je takrat človek izsekaval predvsem v predelih, kjer se je gozd regeneriral. Medtem ko je bilo v finalni fazi zaznati veliko starih hrastovih dreves, kar kaže na izrazito izsekavanje gozda, ko je mlajših dreves (z manjšimi premeri debel) začelo primanjkovati.

Na omenjenih primerih je torej med severnoalpskimi in barjanskimi kolišči opazna razlika v uporabi lesa za izgradnjo hiš na kolih. To je posledica različne vegetacije v bližini kolišč, zaradi različnih geografskih danosti in verjetno tudi zakasnelega vračanja vegetacije na rastišča severno od Alp (Šercelj, 1996).

Članek 4 govori o uporabi lesa za toporišče sekire, ki je bilo narejeno iz lesa drena (*Cornus* sp.).

V članku 5. smo razpravljali o pomenu vinske trte v času kolišč. V koliščarski naselbini Hočevarica, ki je bila sicer skoraj 200 let starejša od Starih gmajn, je bila odkrita večja količina grozdnih pečk, ki so najverjetneje pripadale še divji vinski trti (*Vitis vinifera* ssp. *sylvestris*). Še vseeno pa ostaja odprto vprašanje, kje so koliščarji dobili grozdje in kaj so počeli z njim? Teoretično bi grozdje divje vinske trte lahko: 1. nabirali sami nekje v bližnjem gozdu, 2. ga prinesli od drugod ali 3. celo gojili nekje v bližini kolišč. Vse to so za enkrat še možni odgovori. Po 1. hipotezi bi moralo biti vinske trte v bližnjem gozdu kar precej, toda glede na to, da rastlina uspeva na zelo specifičnih, danes v Sloveniji zelo redkih rastiščih, ostaja ta hipoteza še vedno vprašljiva, 2. hipoteza bi bila zelo verjetna, saj je znano, da so koliščarji izmenjevali n. pr. gradivo za kamnita orodja po trgovskih poteh, ki so prepletala evropski prostor, še posebej s Sredozemljem (n. pr. Pavšič in Dirjec, 2004). Izključiti pa za enkrat ne moremo niti 3. hipoteze, da bi koliščarji sami gojili trto, saj bi tako vsako leto najenostavneje prišli do grozdja. Toda v prid tej teoriji za enkrat še nismo odkrili zaznavnejših količin peloda (Andrič, osebna komunikacija) niti lesnih ostankov trte.

3.1 SKLEPI

Primerjava metod (M1-grobo spiranje in sušenje, M2-grobo spiranje in M3-nežno spiranje s polflotacijo) za pripravo arheobotaničnih vzorcev iz mokrih arheoloških sedimentov je pokazala, da je M3 najbolj primerna.
Z uporabo metode M3 se je ohranilo več nežnejših vegetativnih rastlinskih ostankov (ostanki mahov, lističev, iglic, stebelc, epidermov), fragilni reproduktivni deli rastlin (semena in plodovi z nežnejšimi tkivi), nezoglenele pleve žit in perikarpi nekaterih plodov ter fragilni živalski ostanki (delci insektov, moluskov, ribjih lusk ter koprolitov), ki jih pri uporabi M2 in še posebej M1, izgubimo.
Za uspeh raziskav je pomembna tudi velikost najmanjšega sita. Sito s premeri por 0,355 mm, na katerem se ujamejo tudi manjša semena, se je izkazalo za primernejše kot dosedanje 1 mm sito.
Pri uporabi metod M2 in M1 so manjkali ali bili prisotni v manjšem številu krhki ostanki rastlin. Trdnejši in lignificirani ostanki pa so bili ohranjeni v večjem številu. Razmerja med nežnimi in trdnimi ostanki niso odražala dejanskega pomena najdb.
Le z metodo M3 smo dobili realno sliko deležev gospodarsko pomembnih rastlin in ugotovili glavne prehranske rastline prazgodovinskih prebivalcev s Starih gmajn. Prvič v Sloveniji smo odkrili nezoglenele, z vodo prepojene ostanke semen in plodnih glavic lanu (*Linum usitatissimum*) in nezoglenele pleve različnih vrst pšenice (*Triticum* sp.). Ugotovili smo tudi večji pomen maka (*Papaver somniferum*) kot je bilo mišljeno doslej.
Raziskava je pokazala, da je metode v arheobotaniki potrebno standardizirati, da bomo lahko primerjali rezultate različnih/sorodnih študij.

Primerjava uporabe kulturnih rastlin na Ljubljanskem barju in drugod po Evropi kaže na odsotnost trde pšenice (*Triticum durum/turgidum*) na slovenskem kolišču. Lan (*Linum usitatissimum*) je bil s pričujočo raziskavo pri nas odkrit prvič. Izbor nabiranih rastlin je na kolišču z Barja podoben kot na severno alpskih sočasnih koliščih, le vinska trta (*Vitis vinifera* ssp. *sylvestris*), rumeni dren (*Cornus mas*) in vodni orešek (*Trapa natans*) so prisotni v večjem številu na Starih gmajnah kot na koliščih severno od Alp.

Predstavili smo doslej najbolj natančno datiranje eneolitskih kolišč z Ljubljanskega barja iz 4. tisočletja pr. n. št. Ugotovili smo poselitvene aktivnosti na Barju od pribl. 3600 do 3071 pr. n. št. in poselitveno vrzel od pribl. 3332 do 3160 pr. n. št. Natančno datiranje kolišč je bistveno za primerjave sočasnih naselbin.

Identifikacija ostanka lesenega toporišča v kamniti sekiri s Starih gmajn je pokazala, da je bilo toporišče pribl. 5300 let stare kladivaste sekire narejeno iz lesa drena (*Cornus* sp.), ki je uspeval v bližini kolišč in ima izjemno trdnost in žilavost ter je zelo primeren za tako uporabo. To potrjuje, da so bili koliščarji dobri poznavalci lesnih lastnosti. Les za toporišče so verjetno dobili v domačem okolju, sekira pa je bila, glede na izbor kamnine, prinesena od drugod.

Pečke vinske trte (*Vitis vinifera*) s kolišča Hočevarica so najstarejše tovrstne najdbe pri nas in so najverjetneje plod divje vinske trte.

4 POVZETEK

Cilji doktorske disertacije, ki temelji na 5 člankih, so bili:

- preveriti uveljavljene metode arheobotaničnih raziskav na Ljubljanskem barju in v skladu s trenutno splošno sprejetimi svetovnimi standardi uvesti metodologijo, ki bo omogočila pridobitev reprezentativnih rezultatov, primerljivih rezultatom raziskav na podobnih najdiščih severno od Alp,
- podati ugotovitve in rezultate arheobotaničnih raziskav na primeru kolišča Stare gmajne ob uporabi standardiziranih metod in jih primerjati z rezultati, pridobljenimi na drugih evropskih koliščih iz istega obdobja,
- absolutno datirati slovenska kolišča iz 4. tisočletja pr. n. št. s pomočjo dendrokronoloških in radiokarbonskih raziskav,
- vpeljati in ovrednotiti nekatere specifične raziskave v arheobotaniki, ki nam lahko podajo pomembne informacije o preteklih dogodkih.

Primerjava metod (M1-grobo spiranje in sušenje, M2-grobo spiranje in M3-nežno spiranje s polflotacijo) za pripravo arheobotaničnih vzorcev iz mokrih arheoloških sedimentov je pokazala, da je M3 najbolj primerna metoda. Z uporabo te metode z nežnim spiranjem in ohranjanjem frakcij s sit v mokrem stanju, se je ohranilo mnogo nežnejših vegetativnih rastlinskih ostankov, kot so na primer ostanki mahov, lističev, iglic, stebelc, različnih epidermov i. pd., ki jih pri uporabi M2 in še posebej M1, izgubimo. Poleg le teh se zelo dobro ohranijo tudi nekateri krhki/nežnejši reproduktivni deli rastlin, torej semena in plodovi z nežnejšimi tkivi, pa tudi nezoglenele pleve žit in perikarpi nekaterih plodov. Fragilni živalski ostanki kot so n. pr. delci insektov, moluskov, ribjih lusk ter koprolitov so se ob uporabi M3 pravtako zelo lepo ohranili. Poleg samega načina spiranja vzorcev in shranjevanja, se je izkazalo, da je pomembna tudi velikost najmanjšega sita, ki ga pri delu uporabljamo. Zelo primerno je sito s premeri odprtin 0,355 mm, na katerem se ujamejo tudi manjša semena, n. pr. mak. Z raziskavo smo potrdili priporočila za tretiranje mokrih arheoloških sedimentov, ki so jih predlagali že Kenward in sod. (1980). V kolikor so sedimenti s terena močno zbiti, kot n. pr. v ilovici, predlagamo predhodno zamrznjenje (Vandorpe in Jacomet, 2007), kar povzroči kasnejše odstopanje organskih delcev od ilovice in s tem lažje in posledično nežnejše spiranje.
Pri tretiranju vzorcev z M2 in M1 metodama so očitno manjkali krhki ostanki rastlin, oziroma so bili prisotni v manjšem številu, kar pa ne velja za trdnejše in lignificirane ostanke, ki so bili prav nasprotno, bolj koncentrirani, torej prisotni v večjem številu, saj jih grobo spiranje in sušenje ni prizadelo.
Med tremi metodami so bile očitne tudi razlike v sami diverziteti identificiranih rastlinskih ostankov. Ob uporabi M3 in najmanjšega sita 0,355 mm je bila diverziteta, po pričakovanju, največja in hkrati je bilo samo s to metodo mogoče dobiti realno sliko deležev gospodarsko pomembnih rastlin in tudi ugotoviti glavne prehranske rastline tedanjih prebivalcev. Z uporabo M3 je bilo prvič v Sloveniji mogoče najti nezoglenele, z vodo prepojene ostanke lanu (*Linum usitatissimum*) – tako semen, kot tudi ostanke plodnih glavic. Prvič smo identificirali tudi nezoglenele pleve različnih vrst pšenice (*Triticum* sp.) iz eneolitskega najdišča v Sloveniji.

Čeprav je sediment s kolišč z Ljubljanskega barja zelo bogat in so rastlinski ostanki v njem dobro ohranjeni in koncentrirani, v bodoče priporočamo odvzem vsaj 3 litrov sedimenta/vzorec, saj bo tak volumen ob uporabi M3 zagotovo zadostoval minimalnemu standardu števila identificiranih rastlinskih ostankov za dosego reprezentativnih rezultatov, na obeh, 2 mm in 0,355 mm, sitih. Ta rezultat sovpada tudi s priporočili s severnoalpskih jezerskih naselbin (Hosch in Jacomet, 2001).
Naša raziskava kaže na potrebno standardizacijo primerne metodologije v arheobotaniki, ki bi omogočala primerjave podobnih študij z različnih delov Evrope, in tudi Sveta. Jasno pokaže, kako lahko neprimerna metoda dela z arheološkimi sedimenti privede do nereprezentativnih (okrnjenih) rezultatov, tako v kvalitativnem (spektru vrst) kot tudi v kvantitativnem (številčnem) smislu. S to raziskavo smo jasno pokazali, koliko in katere vrste so manjkale v preteklih arheobotaničnih raziskavah s slovenskih kolišč, kjer je bila uporabljena metoda M1.

Po novi arheobotanični metodologiji M3 nam je uspelo eneolitsko najdišče s Starih gmajn na Ljubljanskem barju, ki je bilo tudi zelo natančno dendrokronološko datirano, analizirati tako, da so rezultati prvič reprezentativni in primerljivi ostalim evropskim. Rezultate smo primerjali s sočasnimi kolišči severno od Alp, to je s kolišči, datiranimi med leti 3500 in 3000 pr. n. št., iz tega obdobja naj bi bil tudi nedavno odkriti ledeni mož – Ötzi.
Naša raziskava je pokazala veliko podobnosti v uporabi rastlin med slovenskim in severno alpskimi sočasnimi kolišči. Odkrili pa smo tudi nekaj razlik. Med kulturnimi rastlinami smo opazili odsotnost trde pšenice (*Triticum durum/turgidum*) na slovenskem kolišču. Omembe vredna je tudi velika količina maka (*Papaver somniferum*). Pred našo raziskavo je bil mak na slovenskih koliščih omenjen le enkrat (Jeraj, 2004). Pomembno je tudi prvo odkritje lana (*Linum usitatissimum*) na slovenskih koliščih, torej iz eneolitskega obdobja. Pred tem je bil v Sloveniji odkrit le v mlajših obdobjih: bronasti in železni dobi (Culiberg, 1999). Vse to podaja nov pogled na zgodnjo zgodovino oz. razširjanje kulturnih rastlin po Evropi. Tudi med nabiranimi rastlinami smo odkrili veliko podobnosti in nekaj razlik med slovenskim koliščem in severno alpskimi sočasnimi kolišči. V sedimentu zgodnje faze naselja Starih gmajn smo pogosto naleteli na vinsko trto (*Vitis vinifera* ssp. *sylvestris*), rumeni dren (*Cornus mas*) in vodni orešek (*Trapa natans*) – vse to so rastline, ki niso prav pogosto odkrite na ostalih koliščih severno od Alp, medtem ko so na slovenskih koliščih redno prisotne. Najverjetneje razlog za to tiči v ekoloških razlikah med regijami severno in južno od Alp. Prebivalci s Starih gmajn so vplivali na rastlinstvo v svoji okolici s pridelovanjem kulturnih rastlin, nabiralništvom in pašništvom, prav tako tudi prebivalci kolišč severno od Alp (Jacomet in sod., 2004). Potrebne bodo nadaljnje raziskave z uporabo primerne metode na slovenskih koliščih, da bi lahko izboljšali realno sliko o prehranskih navadah barjanskih prebivalcev, njihovih aktivnostih in organizaciji, ter sliko o tedanjih ekoloških razmerah v okolici slovenskih kolišč.

Eden izmed temeljnih predpogojev za uspešno primerjavo kolišč z Ljubljanskega barja z ostalimi arheološkimi najdišči je absolutna in natančna datacija posameznih kolišč. Datacije z Ljubljanskega barja, objavljene v 3. članku, so trenutno najbolj točne datacije prazgodovinskih kolišč na tem območju. Ugotovili smo poselitvene aktivnosti na Barju od pribl. 3600 do 3071 pr. n. št. in poselitveno vrzel od pribl. 3332 do 3160 pr. n. št.

Tudi možne naselitvene prekinitve zaslužijo posebno pozornost, saj so bile v 4. tisočletju pr. n. št. odkrite na več mestih zahodno-centralne Evrope (n. pr. v Švici, JV Franciji in JZ Nemčiji). Opisane so bile kot posledica klimatskih sprememb (zaradi hladnejšega in vlažnejšega podnebja), ki se zdi, da je bilo še posebno turbulentno v centralni Evropi v 2/2 4. tisočletja pr. n. št. (Magny in Haas, 2004). Zato je obdobje od 3332 do 3160 pr. n. št., ko na Ljubljanskem barju ni najdb, ki bi nakazovale človeške aktivnosti (podiranja dreves), še posebej zanimivo, saj bi lahko šlo za poselitveno vrzel (hiatus). Nadaljne raziskave bodo razjasnile, ali je v resnici šlo za to in ali ima kaj zveze s hiatusi po ostali Evropi okoli Alp.

Raziskave arheološkega lesa, poleg dendrokronologije in radiokarbonskega datiranja, zajemajo tudi samo identifikacijo lesnih vrst, ki nam lahko ob primerni interdisciplinarni interpretaciji, veliko pove o človekovih dejavnostih, vedenju, znanju kakor tudi o samem okolju v katerem je človek bival in se gibal.
Identifikacija lesenega ostanka toporišča v kamniti sekiri s Starih gmajn je zaradi podobnosti anatomskih znakov lesa drena (*Cornus*) in pušpana (*Buxus*), ki sicer pripadata različnim družinam, zahtevala primerjavo z recentnim lesom. Ugotovili smo, da je bilo toporišče pribl. 5300 let stare kladivaste sekire narejeno iz lesa drena (*Cornus* sp.), ki je uspeval v bližini kolišč in ima izjemno trdnost in žilavost ter je zato zelo primeren za tako uporabo. Slednje ponovno potrjuje, da so bili koliščarji dobri poznavalci lesnih lastnosti. Glede na izbrani les je bilo toporišče verjetno narejeno v domačem okolju, medtem ko je bila sekira oz. kamnina zanjo prinesena od drugod.

Da je arheobotanika veda s širšim pogledom na preteklo vegetacijo, nam dokazuje zadnji članek, ki se zelo specifično ukvarja z doslej najstarejšimi ohranjenimi pečkami vinske trte pri nas.
Pečke iz eneolitskega obdobja so najverjetneje semena divje vinske trte, tako vsaj kažejo izračuni Stummerjevega indeksa (1911) in formul (Mangafa in Kotsakis, 1996), čeprav je variabilnost 142 izmerjenih pečk s kolišča Hočevarica kar precejšna. V primerjavi z današnjimi pečkami divje vinske trte s porečja Donave (Kohler-Schneider, 2001) imajo koliščarske pečke nekoliko višje vrednosti omenjenih indeksov, kar kaže na dvom o njihovem divjem poreklu.
Rimske pečke iz Vrhnike je, na podlagi izračunanih indeksov, še težje umestiti v divjo ali gojeno skupino, čeprav po vsej verjetnosti že pripadajo gojenim sortam. Večina izmerjenih rimskih pečk namreč pade v nekakšno vmesno skupino, med priporočenimi indeksi za divjo in gojeno skupino. Tudi 66 izmerjenih rimskih pečk kaže na veliko variabilnost znotraj skupine. Možno pa je tudi, da je rimski vzorec vseboval dva ali tri tipe pečk vinske trte: 1. okrogle in kratke, torej divje; 2. poldomestificirane; ter 3. hruškaste in podolgovate, torej gojene. Nekatere individualne pečke namreč zelo dobro in nedvomno padejo v rang gojenih oblik.
Za primerjavo smo izmerili tudi pečke nekaterih sort današnjih slovenskih gojenih trt in ugotovili, da po 1. in 3. formuli Mangafa-e in Kotsakis-a (1996) dobro padejo v rang gojenih oblik, medtem ko izračuni 2. in 4. formule ter Stummerjev indeks ne rangirajo pečk k gojenim oblikam, čeprav vemo, da so v resnici gojene. So pa vseeno izračunani indeksi na pečkah današnjih gojenih sort višji od indeksov, izračunanih na rimskih pečkah, kar je dokaz, da so med vsemi izmerjenimi pečkami najbližje kultivarjem.
Z raziskavo smo potrdili velik polimorfizem med pečkami vinskih trt (Facsar, 1970, 1971, 1972) – tako znotraj treh skupin (divja, poldomestificirana, gojena), kot tudi znotraj

posameznih kultivarjev (sort). S tem ponovno potrjujemo, da je klasifikacija na podlagi morfoloških značilnosti pečk negotova in nezadostna (n. pr. Jacquat in Martinoli, 1999). Zato je bil prvič v Sloveniji narejen tudi poskus izolacije DNK, ki je v tem primeru edina možna pot za ločevanje divje od gojenih oblik. Nadaljni poskusi bodo še potrebni za uspešen rezultat.

5 SUMMARY

The main aims of the PhD thesis that is based on five articles were:

- to check the established archaeobotanical research methods used at the Ljubljansko barje pile-dwellings and introduce, in accordance with the current generally accepted global standards, a methodology on the basis of which it will be possible to obtain representative results, which will be comparable to the results of similar researches on sites north of the Alps;
- to make conclusions and results of archaeobotanical research using standardized methods and compare them with results obtained at other European settlements from the same period;
- to define absolute dates of Slovenian pile-dwellings from the 4th millennium BC with the help of dendrochronology and radiocarbon analyses;
- to introduce and evaluate some specific research in archaeobotany that can be used to provide important information about the past events.

The comparison of methods (M1 - rough washing and drying, M2 - rough washing and M3 - gentle washing with halfflotation) for the preparation of archaeobotanical samples from the wet archaeological sediments showed that M3 is the most suitable method. With this method, combined with gentle washing and keeping the fractions in wet state, many fragile vegetative plant remains, such as the remains of moss, leaves, needles, stems, different epiderms etc., that are lost when method M2 and especially method M1 are used, are very well preserved. Furthermore, some fragile reproductive plant parts (seeds and fruit) with smooth tissue, as well as uncarbonised chaff and pericarp of some fruits, are well preserved. Fragile animal remains such as fragments of insects, mollusks, fish scales and coprolites were very well preserved also with the method M3. Besides the method of sieving and storage of samples, also the size of the smallest sieve used is very important. It was found that sieve with a pore diameter of 0.355 mm, which captures small seeds as well, eg. *Papaver somniferum,* is the most appropriate. The research confirmed the suggested recommendations for the treatment of wet archaeological sediments, which were already proposed by Kenward et al. (1980). If the sediments from the field are tightly packed, for example in clay, we suggest pre-freezing (Vandorpe in Jacomet, 2007), which leads to subsequent separation of organic matter from the clay and therefore enables easier and consequently gentle washing.
When M1 and M2 methods were used fragile plant remains were obviously missing or were underrepresented. On the other hand, stronger and lignified plant residues were more concentrated and present in greater numbers, because rough washing and drying did not adversely affect them. Huge differences between these three methods were identified also in the field of diversity of the identified plant remains. When the method M3 and the

smallest sieve with 0.355 mm mesh size were used the diversity was, just as it was expected, the largest and at the same time this method is the only one that can provide a realistic picture of economically important plant shares and that can be used to determine the main food crops of the researched settlement. With the method M3, uncarbonised residues of flax (*Linum usitatissimum*) from the Eneolithic site were found for the first time in Slovenia – i.e. seeds, as well as remnants of the capsules. We also identified different types of uncarbonised chaff of wheat (*Triticum* sp.) from the Eneolithic site.
Although the sediment from pile-dwellings at Ljubljansko barje is very rich and plant remains are very well-preserved and concentrated, we recommend that in the future the size of the sediments used per sample should be at least 3 liters, since such volume is definitely sufficient to obtain minimum standard number of identified plant remains in order to achieve representative results using method M3 for both, 2 mm and 0.355 mm, mesh-size sieves. This result confirms the recommendations of the northern Alpine lake settlements (Hosch and Jacomet, 2001). Our study shows the need to standardize the appropriate methodology in archaeobotany that would allow comparison between similar studies from different parts of Europe and other parts of the world. It clearly shows that inappropriate methods of work used with archaeological sediments lead to unrepresentative (truncated) results, both in qualitative (spectrum of species) and in quantitative (numerical) sense. With this study we clearly show how many and what types of plant remains were missing in the previous Slovenian archaeobotanical researches, where the method M1 was used.

With the help of the new methodology M3, a late Neolithic (resp. Eneolithic) site of Stare gmajne, which was also dendrochronologically dated, was analyzed in such a way that the results are representative and comparable with the rest of Europe for the first time. The results were compared to contemporaneous settlements north of the Alps (dated between 3500 and 3000 cal BC). The recently discovered ice man – Ötzi also comes from this period. Our study showed many similarities between the plants used in Slovenia and in the contemporaneous settlements north of the Alps. However, a few differences were also discovered. As far as crops are concerned, we noticed the absence of durum wheat (*Triticum durum / turgidum*) at the Slovenian pile-dwelling. The fact that large quantities of poppy (*Papaver somniferum*) were discovered at Stare gmajne site should also be mentioned. Prior to our study, poppy was mentioned only once in the Slovenian late Neolithic settlements (Jeraj, 2004). The first discovery of flax (*Linum usitatissimum*) at Slovenian lake dwellings from Eneolithic period is also very important. Prior to our research, it was only discovered in the Bronze and Iron Ages in Slovenia (Culiberg, 1999). All this gives a new perspective on the early history of dissemination of crops in Europe. Gathered plants that we found at Stare gmajne also show many similarities as well as some differences between the Slovenian and the contemporaneous pile-dwellings north of the Alps. In the sediments from early stages of the settlement, we often found grapevine (*Vitis vinifera* ssp. *sylvestris*), cornelian cherry (*Cornus mas*) and a water chestnut (*Trapa natans*) – these plants are not often found at other lake settlements north of the Alps but they are regularly present in the Slovenian lake settlements. The most likely reason for this lies in the ecological differences between the regions north and south of the Alps. The cultivation of crops, gathering of wild plants and pasturing affected the vegetation in the vicinity of settlements at Stare gmajne site, similarly as at the pile-dwellings north of the Alps (Jacomet et al., 2004). Further researches using appropriate methods are necessary at

Slovenian lake settlements in order to get a more realistic picture of the dietary habits of dwellers, their activities and organization, and also to get a picture of the ecological conditions in the vicinity of the Slovenian piles.

One of the fundamental prerequisites for a successful comparison of Ljubljansko barje pile-dwellings with other archaeological sites is the absolute and precise dating of individual settlement. Datings published in the third article are currently the most accurate datings of the prehistoric lake dwellings in Slovenia. Settlement activities at Ljubljansko barje were found from approx. 3600 to 3071 cal BC as well as a settlement hiatus of ca. 3332 to 3160 cal BC.
The possible interruption in settling (hiatus) deserve a special attention, because they were found in several parts of west-central Europe (eg. Switzerland, SE France and SW Germany). They were described as a result of climate changes (due to a colder and wetter climate) that seem to be particularly turbulent in the central Europe in the second half of the 4th millennium BC (Magny and Haas, 2004). Therefore, the period from 3332 to 3160 cal BC, when no findings that would indicate human activities (tree falling) were found at Ljubljansko barje, is particularly interesting since this could indicate a settlement hiatus. Further studies will clarify whether this is actually true and if it has anything to do with the hiatus in the rest of Europe around the Alps.

Studies of archaeological wood, besides dendrochronology and radiocarbon dating, include also the identification of wood species that can, with the appropriate interdisciplinary interpretation, tell us a lot about human activities, behavior, as well as their knowledge about their living environment. Identification of a wooden handle of a stone hammer-axe from Stare gmajne site required a comparison with the recent wood because of the similarities of wood anatomical characteristics between dogwood (*Cornus*) and boxwood (*Buxus*), which belong to different families. We found that the handle of approx. 5300-year-old hammer was made from dogwood (*Cornus* sp.), which grew in the vicinity of the settlement and its wood is known for its tremendous strength and toughness what is very suitable for such use. The latter reaffirms that the dwellers were very familiar with wood properties. The wooden handle most probably comes from the local environment, while the axe or rock was most probably brought from elsewhere.

The last article proves that archaeobotany is a science which gives a broader view on the past vegetation. It very specifically deals with the oldest grapevine seeds in Slovenia. Seeds from the Eneolithic period most probably come from a wild grapevine, which is shown by the calculations of Stummer index (1911) and 4 formulas (Mangafa and Kotsakis, 1996). The measurements of 142 grape pips from Hočevarica pile-dwelling are considerably variable. When comparing with today's seeded wild grapevine from the Danube River Basin (Kohler-Schneider, 2001), the pile-dwelling grape pips show slightly higher values of these indices what reflects doubts about their wild origin. Based on the calculated indices it is difficult to put Roman grape pips from Vrhnika either in the wild or in the cultivated group, although they most likely come from cultivated varieties. Most of the Roman seeds fall into a kind of intermediate group between the indices for the wild and the cultivated group. Also 66 measured Roman grape pips show a high variability within the group. It is also possible that the Roman sample contained two or three types of seeds: 1. the round and short, which are wild; 2. the halfdomesticated; and 3. the pear-shaped and

elongated, which are cultivated. Some individual pips fall very clearly into the group of cultivated forms.
For comparison, we also measured some pips of today's Slovenian cultivated sorts of vines and found out that they fall very clearly to the group of cultivated sorts if Mangafa and Kotsakis (1996) formulas 1 and 3 are used, while the formulas 2 and 4 and Stummer index do not classify the pips into the cultivated group, although we know that they are cultivated. However, indices of pips from the varieties grown today are higher than the indices calculated on Roman pips, what proves that, among all measured pips, they are the closest to the cultivars. The study confirms the high polymorphism among the grapevine seeds (Facsar, 1970, 1971, 1972) – within the three groups (wild, halfdomesticated, cultivated) as well as within individual cultivars (varieties). Thus, we reaffirm that the classification based on morphological characteristics of seeds is uncertain and insufficient (eg. Jacquat and Martinoli, 1999). Therefore, an attempt of DNA isolation was made for the first time in Slovenia, which is in this case the only possible way to distinguish the wild from the cultivated sorts. Further experiments will be necessary for a successful outcome.

6 VIRI IN LITERATURA

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PRILOGE

DELOVNI LISTI

Priloga 1: Postopek izpiranja sedimenta iz kulturne plasti za analizo makrorastlinskih ostankov

ident. št. vzorca:		datum odvzema vzorca na terenu:	
ime spiralca:		datum in čas izpiranja vzorca:	
arheološko najdišče:		tip naselbine:	
arheološko obdobje:		št. kvadranta:	
št. podvzorca:		stratigrafska enota plasti:	

TIP IZPIRANJA:		**TIP SEDIMENTA:**	
pol-flotacija		organsko	
gold-wash		ilovica	
mokro sejanje		polžarica	
flotacija		peščeno	
drugo:		drugo:	
VOLUMEN VZORCA:			
odvzem na terenu (kg):			
pred izpiranjem (l):			
po izpiranju (ml):	organsko	anorgansko	podvzorec - odvzem za analizo
2 mm frakcija			
0.355 mm frakcija			
SHRANJEVANJE VZORCA:		**VZOREC S TERENA:**	
mokro, hladilnik, temno		moker	
suho		suh	
PRISOTNOST MATERIALA:			**OPOMBE:**
oglje			
semena, plodovi			
les, veje, lističi			
keramika			
opeka			
kovina			
kosti			
moluski			
ribe			
drugo:			
LEGENDA:	**X**	posamezen	
	XX	nekaj	
	XXX	veliko	

Priloga 2: Klasifikacija materiala v vzorcu/podvzorcu št. ___________

		2 mm	0.355 mm
anorganski material			
	kamni		
	konkrecije		
	kepe ilovice		
	drugo:		
arheološke najdbe	keramika, opeka		
	kovinski predm.		
	steklo		
	obdelan les		
	tekstil, usnje		
	drugo:		
rastlinske najdbe			
a) mineralizirane	plodovi, semena		
	fragm. lesa		
	skup. org. material/iztrebki, hrana		
	drugo:		
b) karbonizirane	plodovi, semena		
	fragm. lesa		
	lubje, skorja		
	veje, lističi		
	amorfni objekti		
	drugo:		
c) subfosilne, nekarbonizirane	plodovi, semena		
	fragm. lesa		
	lubje, skorja		
	veje, lističi		
	korenine		
	skup. org. material/iztrebki, hrana		
	drugo:		
d) strohnele	ostanki:		
e) slano - konservirane	ostanki:		
f) kovinsko - konservirane	ostanki:		
živalske najdbe			
a) kosti	kosti, zobje velikih sesalcev		
	kosti, zobje malih sesalcev		
	ptice		
	dvoživke, plazilci		
	vretenca rib		
	luske rib		
b) moluski			
c) drugi žival. ostanki	insecta - odrasli		
	insecta - larve		
	drugo		

LEGENDA:		
	X	posamezno
	XX	malo
	XXX	veliko
	XXXX	prevladuje

Priloga 3: Arheobotanični rezultati

				VZOREC											
				KVADRANT		1	1	1	1	1	1	1	1	1	1
				KULTURNA PLAST		4	4	5	5	6	6	7	7	8	8
				VOLUMEN VZORCA											
				VOLUMEN ORGANSKIH OSTANKOV	VELIKA FRAKCIJA: 2 mm		X		X		X		X		X
RASTLINSKA VRSTA		RASTLINSKI OSTANEK			MALA FRAKCIJA: 0.355 mm	X		X		X		X		X	
Abies alba	Nav. jelka	fragmenti listov	N												
Alisma sp.	Porečnik	celo seme	N												
Alnus glutinosa	Črna jelša		N												
Apiaceae	Kobulnice		N												
Asteraceae	Košarnice		N												
Asteraceae	Košarnice	fragmenti semen	N												
Atriplex	Loboda	celo seme	N												
Brassica rapa	Oljna repica		N												
Carex sp.	Šaš	cel plod	N												
Carex sp.	Šaš	celo seme	N												
Cerealia	Žita	rahis fragment	N												
Cerealia	Žita		C												
Cerealia	Žita	pleva	N												
Cerealia	Žita		C												
Cerealia	Žita	fragmenti semen	N												
Cerealia	Žita		C												
Characeae (Chara, Nitella)	zelena alga	spore alg	N												
Chenopodium album	Bela metlika	celo seme	N												
Chenopodium album	Bela metlika		N												
Cladium mariscus	Navadna rezika		N												
Cladium mariscus	Navadna rezika	fragmenti semen	N												
Clematis	Srobot	celo seme	N												
skupno (total)															

Priloga 4: Analiza dendrokronoloških vzorcev

Lokacija	Vzorec	Merjen	Dodatni vz	Drev.vrsta	Premer	Klan	Št.branik	Beljava	WK	Skorja	Krono	Opombe

REFERENČNA ZBIRKA RECENTNIH RASTLINSKIH DELOV

Priloga 5: Seznam vrst za katere smo sestavili referenčno zbirko lesa in oglja

Navadna smreka (*Picea abies*)
Rdeči bor (*Pinus sylvestris*)
Vednozelena cipresa (*Cupressus sempervirens*)
Tisa (*Taxus baccata*)
Navadni češmin (*Berberis vulgaris*)
Navadna bukev (*Fagus sylvatica*)
Dob (*Quercus robur*)
Graden (*Quercus petraea*)
Navadna breza (*Betula pendula*)
Črna jelša (*Alnus glutinosa*)
Nav. beli gaber (*Carpinus betulus*)
Nav. leska (*Corylus avellana*)
Gorski brest (*Ulmus glabra*)
Navadni smokvovec (*Ficus carica*)
Češnja (*Prunus avium*)
Čremsa (*Prunus padus*)
Sliva (*Prunus domestica*)
Mandljevec (*Prunus dulcis*)
Jablana, lesnika (*Malus sylvestris*)
Hruška, drobnica (*Pyrus pyraster*)
Robinija (*Robinia pseudoacacia*)
Octovec (*Rhus typhina*)
Javor (*Acer* sp.)
Trta: divja, domača (*Vitis vinifera/sylvestris*)
Nav. bršljan (*Hedera helix*)
Vrba-iva (*Salix caprea*)
Črni topol (*Populus nigra*)
Lipa (*Tilia platyphyllos*)
Pušpan (*Buxus sempervirens*)
Rumeni dren (*Cornus mas*)
Rdeči dren (*Cornus sanguinea*)
Veliki jesen (*Fraxinus excelsior*)
Nav. oljka (*Olea sativa*)

Priloga 6: Seznam vrst za katere smo sestavili referenčno zbirko lesno-anatomskih preparatov

Vednozelena cipresa (*Cupressus sempervirens*)
Navadni češmin (*Berberis vulgaris*)
Navadna leska (*Corylus avellana*)
Gorski brest (*Ulmus glabra*)
Hruška, drobnica (*Pyrus pyraster*)
Trta: divja, domača (*Vitis vinifera/sylvestris*)
Pušpan (*Buxus sempervirens*)
Rumeni dren (*Cornus mas*)
Rdeči dren (*Cornus sanguinea*)

Priloga 7: Seznam vrst za katere smo sestavili referenčno zbirko semen/plodov lesnih in grmovnih vrst

Dvokrpi ginko (*Ginkgo biloba*)
Navadna jelka (*Abies alba*)
Navadna smreka (*Picea abies*)
Evropski macesen (*Larix decidua*)
Rdeči bor (*Pinus sylvestris*)
Rušje (*Pinus mugo*)
Zeleni bor (*Pinus strobus*)
Vednozelena cipresa (*Cupressus sempervirens*)
Navadni brin (*Juniperus communis*)
Rdečeplodni brin
Škrlatnoplodni brin
Tisa (*Taxus baccata*)
Lovor (*Laurus nobilis*)
Navadni srobot (*Clematis vitalba*)
Navadni češmin (*Berberis vulgaris*)
Thunbergerjev češmin (*Berberis thunbergii*)
Javorolistna platana (*Platanus x hispanica*)
Navadna bukev (*Fagus sylvatica*)
Graden (*Quercus petraea*)
Dob (*Quercus robur*)
Cer (*Quercus cerris*)
Evropski pravi kostanj (*Castanea sativa*)
Navadna breza (*Betula pendula*)
Puhasta breza (*Betula pubescens*)
Črna jelša (*Alnus glutinosa*)
Siva jelša (*Alnus incana*)
Zelena jelša (*Alnus viridis*)
Navadni beli gaber (*Carpinus betulus*)
Črni gaber (*Ostrya carpinifolia*)
Navadna leska (*Corylus avellana*)
Poljski brest (*Ulmus carpinifolia*)
Gorski brest (*Ulmus glabra*)
Navadni smokvovec (*Ficus carica*)
Navadni oreh (*Juglans regia*)
Črni ribez (*Ribes nigrum*)
Rdeči ribez (*Ribes rubrum* sp.)
Rumeni-beli ribez (*Ribes* sp.)
Divja češnja (*Prunus avium*)
Čremsa (*Prunus padus*)
Črni trn (*Prunus spinosa*)
Višnja (*Prunus cerasus*)
Ringlo-sliva (*Prunus* sp.)
Češnja (*Prunus avium*)
Rešeljika (*Prunus mahaleb*)
Sliva (*Prunus domestica* L.)
Mandljevec (*Prunus dulcis*)
Prava robida (*Rubus fruticosus* agg.)
Malina (*Rubus idaeus*)
Navadni šipek (*Rosa cannina*)
Prava japonska kutina (*Chaenomeles speciosa*)
Jablana (*Malus* sp.)
Lesnika (*Malus sylvestris*)
Hruška (*Pyrus* sp.)
Drobnica (*Pyrus pyraster*)
Jerebika (*Sorbus aucuparia*)
Mokovec (*Sorbus aria*)
Skorš (*Sorbus domestica*)
Enovratni glog (*Crataegus monogyna*)
Navadni glog (*Crataegus laevigata*)
Rožičevec (*Ceratonia siliqua*)
Alpski nagnoj (*Laburnum alpinum*)
Žuka (*Spartium junceum*)
Robinija (*Robinia pseudoaccacia*)
Navadni ruj (*Cotinus coggygria*)
Terebint (*Pistacia terebinthus*)
Citrus, pomarančevec (*Citrus sinensis*)
Navadni kloček (*Staphylea pinnata*)
Navadni divji kostanj (*Aesculus hippocastanum*)
Maklen, poljski javor (*Acer campestre*)
Gorski javor, beli javor (*Acer pseudoplatanus*)
Ostrolistni javor (*Acer platanoides*)
Navadna trdoleska (*Euonymus europaea*)
Bradavičasta trdoleska (*Euonymus verrucosa*)
Širokolistna trdoleska (*Euonymus latifolia*)
Navadna krhlika (*Frangula alnus*)
Čistilna kozja češnja (*Rhamnus catharticus*)
Vinska trta (*Vitis vinifera*)
Vinika (*Parthenocissus* sp.)
Bela omela (*Viscum album*)
Navadni bršljan (*Hedera helix*)
Vrba (*Salix* sp.)
Črni topol (*Populus nigra*)
Trepetlika (*Populus tremula*)
Lipovec (*Tilia cordata*.)
Lipa (*Tilia platyphyllos*)
Bodika (*Ilex aguifolium*)
Rumeni dren (*Cornus mas*)
Rdeči dren (*Cornus sanguinea*)
Borovnica (*Vaccinium myrtillus*)
Brusnica (*Vaccinium vitis – idaea*)
Jesenska vresa (*Calluna vulgaris*)
Spomladanska resa (*Erica carnea*)
Puhastolistno kosteničevje (*Lonicera xylosteum*)
Črno kosteničevje (*Lonicera nigra*)
Črni bezeg (*Sambucus nigra*)
Navadna brogovita (*Viburnum opulus*)
Dobrovita (*Viburnum lantana*)
Veliki jesen (*Fraxinus excelsior*)
Mali jesen (*Fraxinus ornus*)
Navadna kalina (*Ligustrum vulgare*)
Navadna oljka (*Olea europaea*)
Navadni zimzelen (*Vinca minor*)
Dateljnova palma (*Phoenix dactylifera*)
Bombaževec

Priloga 8: Seznam vrst za katere smo sestavili referenčno zbirko semen/plodov poljščin

PRAVA ŽITA
Enozrna pšenica (*Triticum monoccocum var. monoccocum*)
Trda pšenica (*Triticum turgidum var. durum*)
Turanska pšenica (*Triticum turgidum var. turanicum*)
Večzrna pira (*Triticum aestivum var. spelta*)
Navadna pšenica (*Triticum aestivum var. aestivum*)
Ozimini ječmen (*Hordeum vulgare*)
Goli ječmen (*Hordeum vulgare*)
Oves (*Avena sativa*)
Rž (*Secale cereale*)
Tritikala (*Triticosecale*)

PROSASTA ŽITA
Koruza sladkorka (*Zea mays*)
Proso (*Panicum miliaceum*)
Krmni sirek (*Sorghum vulgare*)
Sladkorni sirek (*Sorghum vulgare var. saccharatum*)
Sudanska trava (*Sorghum vulgare var. sudanense*)
Riž (*Oryza sativa*)
Facelija (*Phacelia tanacetifolia*)
Ajda (*Fagopyrum esculentum*)

OLJNICE
Soja (*Glycine max*)
Sončnica (*Helianthus annuus*)
Buča (*Cucurbita pepo*)
Oljna buča (*Cucurbita pepo var. oleifera*)
Buča velikanka (*Cucurbita maxima*)
Muškatna, dišeča buča (*Cucurbita moschata*)
Buča vodnjača (*Lagenaria siceraria*)
Oljna ogrščica (*Brassica napus var. napus*)
Repica (*Brassica rapa ssp. sylvestris*)
Rjava gorjušica (*Brassica juncea*)
Bela gorjušica (*Sinapis alba*)
Oljna redkev (*Raphanus satovus var. oleiferus*)
Riček (*Camelina sativa*)
Kloščevec (*Ricinus communis*)
Sezam (*Sesamum indicum*)
Vrtni mak (*Papaver somniferum*)

OLJNICE IN PREDIVNICE
Navadni lan (*Linum usitatissimum*)
Navadna konoplja (*Cannabis sativa var. sativa*)
Bombaževec (*Gossypium sp.*)

ZRNATE SROČNICE
Kitajski fižol (*Vigna sinensis*)
Fižol adzuki (*Vigna angularis*)
Fižol nizki (*Phaseolus vulgaris ssp. vulgaris var. nanus*)
Fižol visoki (*Phaseolus vulgaris ssp. vulgaris var. vulgaris*)
Vrtni grah (*Pisum sativum*)
Njivni, krmni grah (*Pisum arvense*)
Sladkorni grah (*Pisum sacharatum*)
Navadna grašica (*Vicia sativa*)
Rumen volčji bob (*Lupinus luteus*)
Bel volčji bob (*Lupinus albus*)
Vrtni bob (*Vicia faba*)
Krmni bob, konjski (*Vicia faba var. equina*)
Grahor (*Lathyros sativus*)
Soja (*Glycine max*)
Fižol mungo (*Vigna mungo*; *Phaseolus mungo*)
Leča (*Lens culinaris*; *L. esculenta*)
Čičerika (*Cicer arietinum*)

KORENOVKE
Sladkorna pesa (*Beta vulgaris ssp. vulgaris var. altissima*)
Krmna pesa (*Beta vulgaris ssp. vulgaris var. alba*)
Rdeča pesa (*Betula vulgaris ssp. v. var. conditiva*)
Repa (*Brassica rapa var. rapa*)
Njivna redkev (*Raphanus raphanistrum*)
Oljna redkev (*Raphanus sativus var. deiferus*)
Korenje (*Daucus carota*)

GOMOLJNICE
Krompir (*Solanum tuberosum*)

POSEBNE POLJŠČINE
Hmelj (*Humulus lupulus*)
Tobak (*Nicotiana tabacum*)
Paprika (*Capsicum anum*)
Lubenica

Priloga 9: Seznam vrst za katere smo sestavili referenčno zbirko semen/plodov trav, plevelov in ostalih zelišč

Trava (*Poaceae*)
Navadni trst (*Phragmites australis*)
Šaš (C*arex* sp.)
Laški muhvič (*Setaria italica* (L.) PB. (*Panicum italicum*)
Sabljasti triplat (*Trigonella foenum*)
Navadni regrat (*Taraxacum officinale*)
Velika kopriva *(Urtica dioica*)
Navadni plotni slak (*Calystegia sepium)*
Beli slizek (*Silene latifolia*)
Grozdasti lučnik (*Verbascum blattaria*)
Drobnocvetni lučnik (*Verbascum hlomoides*)
Velecvetni lučnik (*Verbascum densiflorum*)
Škrlatni naprstec (*Digitalis purpurea*)
Volnati ali dlakavi naprstec (*Digitalis lanata*)
Škrlatni ameriški slamnik (*Echinacea purpurea*)
Nav. rman (*Achillea millefolium*)
Nav. kamilica (*Chamomilla recutita*)
Vrtni ognjič (*Calendula officinalis*)
Pegasti badelj (*Silybum marianum*)
Pravi pelin (*Artemisia absinthium*)
Barvilni rumenik (*Carthamus tinctorius*)
Navadni srobot (*Clematis vitalba*)
Ozkolistni trpotec (*Plantago lanceolata*)
Bolhačica (*Plantago psilium*)
Spomladanski jeglič (*Primula veris*)
Gozdni slezenovec (*Malva sylvestris*)
Nav. Slez (*Althaea officinalis*)
Vrtni šetraj (*Saturea hortensis*)
Kraški šetraj (*Saturea montana*)
Nav. materina dušica (*Thymus vulgaris*)
Nav. dobra misel (*Origanum vulgare*)
Divja mačeha (*Viola tricolor*)
Rumeni svišč (*Genciana lutea*)
Šentjanževka (*Hypericum perforatum*)
Dvoletni svetlin (*Oenothera biennis*)
Zdravilna boraga (*Borago officinalis*)
Bolhač (*Chrysantheum cinerariaefolium*)
Vrtna redkev *(Raphanus sativus*)
Rukola (*Diplotaxis erucoides*)
Oljna repica (*Brassica rapa*)
Nav. komarček (*Foeniculum vulgare*)
Kumina (*Carum carvi*)
Janež (*Pimpinella sativum*)
Janež (*Pimpinella anisum*)
Koriander (*Coriandrum sat.*)
Nav. Koper (*Anethum graveolens*)
Čemaž (*Allium ursinum*)
Bazilika (*Ocimum bazilicum*)
Ožepek (*Hyssopus officinalis*)
Ozkolistna sivka (*Lavandula angustifolia*)
Melisa (*Melissa officinalis*)
Zdravilna špajka (*Valeriana officinalis*)
Žajbelj (*Salvia officinalis*)
Majaron (*Majarona hortensis*)
Artičoka (*Cynara scolymus*)
Volčja češnja (*Atropa belladona*)
Grenkoslad (*Solanum dulcamara*)
Volčje jabolko (*Physalis alkekengi*)
Gozdna jagoda (*Fragaria vesca*)
Vrtna jagoda (*Fragaria* sp.)
Vodni orešek (*Trapa natans*)
Ananas

Priloga 10: Seznam vrst za katere smo sestavili referenčno zbirko zimskih vejic z brsti

Evropski macesen (*Larix decidua*)
Azijski klek (*Thuja orientalis*)
Nav. češmin (*Berberis vulgaris*)
Navadna bukev (*Fagus sylvatica*)
Graden (*Quercus petraea*)
Črna jelša (*Alnus glutinosa*)
Siva jelša (*Alnus incana*)
Zelena jelša (*Alnus viridis*)
Beli gaber (*Carpinus betulus*)
Črni gaber (*Ostrya carpinifolia*)
Nav. leska (*Corylus avellana*)
Divja češnja (*Prunus avium*)
Čremsa (*Prunus padus*)
Črni trn (*Prunus spinosa*)
Sliva (*Prunus domestica*)
Robida (*Rubus fruticosus* agg.)
Malina (*Rubus idaeus*)
Šipek (*Rosa cannina*)
Divja hruška (*Pyrus pyraster*)
Hruška (*Pyrus* sp.)
Skorš (*Sorbus domestica*)
Enovratni glog (*Crataegus monogyna*)
Alpski nagnoj (*Laburnum alpinum*)
Žuka (*Spartium junceum*)
Robinia (*Robinia pseudoacacia*)
Divji kostanj (*Aesculus hippocastanum*)
Gorski javor (*Acer pseudoplatanus*)
Bradavičasta trdoleska (*Euonymus verrucosa*)
Navadna krhlika (*Frangula alnus*)
Čistilna kozja češnja (*Rhamnus catharticus*)
Pobešava vrba (*Salix x sepulcralis*)
Črni topol (*Populus nigra*)
Trepetlika (*Populus tremula*)
Lipa (*Tilia platyphyllos*)
Rumeni dren (*Cornus mas*)
Rdeči dren (*Cornus sanguinea*)
Brogovita (*Viburnum opulus*)
Dobrovita (*Viburnum lantana*)
Veliki jesen (*Fraxinus excelsior*)
Mali jesen (*Fraxinus ornus*)
Kalina (*Ligustrum vulgare*)
Bambus

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DOKTORSKA DISERTACIJA

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