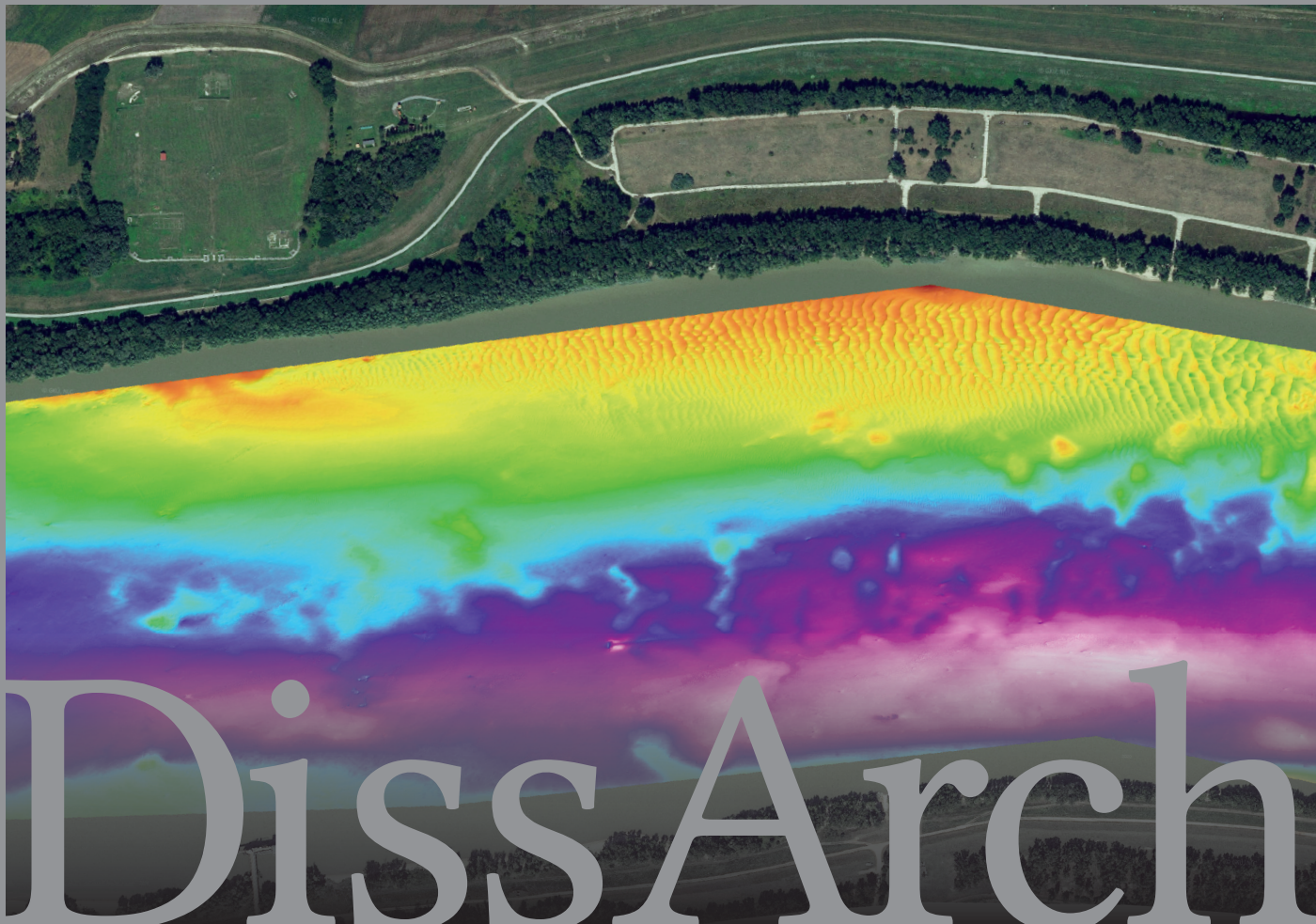


# DISSERTATIONES ARCHAEOLOGICAE

ex Instituto Archaeologico

Universitatis de Rolando Eötvös nominatae



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Change and transformation during the transition from the Middle to the Late Bronze Age along the capital region of the Danube: Settlement structure analyses based on particular sites from the Vatyá III – Koszider Period and the Early Tumulus Culture

# The vegetation of the Roman province of Pannonia based on wood charcoal, pollen, anthracological and carpological studies (1st–5th century AD)

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**Abstract:** The Roman Empire ruled Pannonia—largely corresponding to today’s Transdanubia in Hungary—for nearly 500 years. This study reconstructs Roman-era vegetation and land use around Lake Balaton using pollen analysis, carpology, and anthracology. Pollen-based reconstruction from the sediment of Lake Balaton, with a >100 km source radius, reveals intensive agriculture during the Roman period (1st–5th century AD), supported by high LUP index values (60–100). Oak (*Quercus* sp.) forests declined significantly from the Celtic period (5th century BC–1st century AD) onward, with further loss under Roman rule. Pollen of cereals and anthropogenic indicators (*Secale cereale*, *Artemisia* sp., Chenopodiaceae) increased markedly. Comparative data from five Roman sites (farmsteads, towns, villa granary) align with these trends. Anthracological results reveal oak as the dominant wood (55–100%), though urban sites like Gorsium/Tác used more diverse species, including imported spruce (*Picea abies*) and fir (*Abies alba*), while rural vicus sites relied solely on local species. Charcoal from shrubs (e.g., *Frangula alnus*, *Sorbus* sp.) suggests nearby open forests.

Carpological finds at Szabadbattyán and Tác were dominated by wheat (*Triticum aestivum*) and rye (*Secale cereale*), while vicus sites showed more emmer (*Triticum dicoccum*), spelt (*Triticum spelta*), and millet (*Panicum miliaceum*), indicating indigenous traditions. Evidence of hemp cultivation (*Cannabis sativa*) is strong in both pollen and macro-remains. Weed types suggest autumn and spring sowing, reflecting advanced Roman farming. Modern vegetation and soil maps corroborate these reconstructions.

**Keywords:** Roman period, Pannonia, Pollen analysis, Carpology, Anthracology

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## Introduction

### Pannonia province/provinces

Before the Roman occupation, the Carpathian Basin was a politically and militarily highly fragmented Celtic community.<sup>1</sup> The territorial distribution of the Celtic population followed the physical environment and settlements were established along the main roads between the tribal areas.<sup>2</sup> There were scattered villages and farmsteads linked to land ownership, and fortified, urban settlements, the so-called oppidiums, in which residential areas, industrial and trading districts and religious sites were already isolated from each other.<sup>3</sup> Agricultural activity was likely concentrated near urban settlements due to the higher population densities which, along with deforestation and the iron and pottery industries, resulted in intensive land use in these areas.<sup>4</sup> This is supported by the presence of large amounts of Celtic agricultural tools from oppidiums,<sup>5</sup> the pollen data from the Velem-Szent Vid site<sup>6</sup> and the large amount of carbonized macro botanical remains found near the Gellért Hill oppidium in the Budapest-Corvin Square.<sup>7</sup> According to the scattered macro botanical remains from the Celtic period<sup>8</sup> the main crops in the La Tène period (5th century BC and 1st century AD) were emmer (*Triticum dicoccum*), spelt (*Triticum spelta*), barley (*Hordeum vulgare*), millet (*Panicum miliaceum*), and by the end of the period mainly common wheat (*Triticum aestivum*). The animal bone material found in settlements suggests that the Celts also raised domestic animals in addition to hunting and fishing. According to the animal bone finds from the 1st century BC Eraviscus settlements, they kept small horses and cattle, pigs, sheep, poultry and dogs (also for food).<sup>9</sup> The composition of the archaeozoological material from the period B2–C1 of La Tène in Sajópetri was dominated by cattle remains, followed by sheep/goat, pig and horse, with red deer being almost equal in number to the domestic pig.<sup>10</sup>

The Romans occupied the area up to the Danube River in several stages between 35 BC and 46–49 AD (Fig. 1). The area west of Lake Balaton came under Roman authority as early as 15 BC, and the whole of Transdanubia around the middle of the 1st century AD.<sup>11</sup> From this period, the province received the name Pannonia, and then at the beginning of the 2nd century it was divided into Pan-

1 JEREM 2003, 193.

2 SZABÓ 2005, 15.

3 SZABÓ 2005, 84.

4 SZABÓ 2005, 87.

5 SZABÓ 2005, 87.

6 JUHÁSZ 2007a, 275–276.

7 DÁLNOKI – JACOMET 2002, 9–13; SZABÓ 2005, 87.

8 DÁLNOKI – JACOMET 2002, 9–13; GYULAI 2010, 142–146.

9 SZABÓ 2005, 88.

10 BARTOSIEWITZ – GÁL 2010, 116.

11 FITZ 2003, 205.

nonia Inferior and Pannonia Superior provinces (Fig. 1)<sup>12</sup> along the border in the NE–SW direction. Finally, at the end of the 3rd century into four provinces (Prima, Savia, Secunda and Valeria) reorganized the former two provinces.<sup>13</sup>

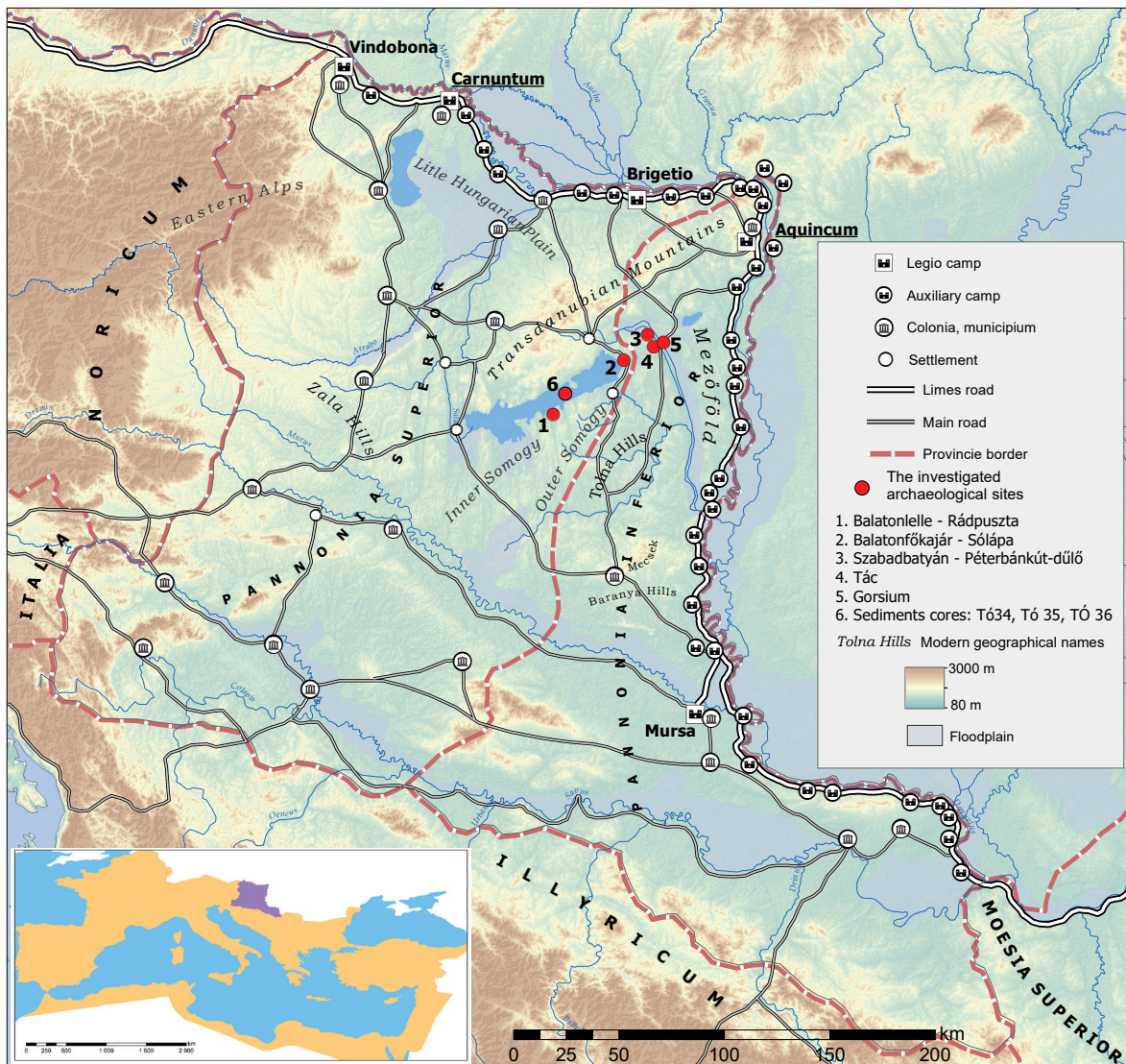


Fig. 1. Pannonia provinces in the 2nd century AD with road system of the province; study sites 1–6 are shown in the lake and in the vicinity of Balaton. 1 – Balatonlelle-Rádpusztá, 2 – Balatonfőkajár-Sólápa, 3 – Szabadbattyán-Péterbánkút-dűlő, 4 – Tác, 5 – Tác-Gorsium/Herculia, 6 – Sediments cores.

### Geographical features of Pannonia between the 1st and 5th centuries

The Danube, the border of the empire, was the defining geographical feature of Pannonia and later of the Pannonian provinces, and its geographical structure was essentially determined by its basin position. The Roman Empire organized the province in the western part of the Carpathian basin between the eastern range of the Alps, the Carpathians and the northern range of the Dinaric Alps, delimited by the Danube. The greater part of which is now the western half of Hungary (Transdanubia), with smaller parts in Austria, Slovenia and Croatia. The province can be divided into three

12 TÓTH 1975, 237.

13 TÓTH 1975, 238.

main parts based on topography and hydrography (Fig. 1). This tripartite division was shaped on the one hand by structural movements and on the other hand by the particularities of the river network.<sup>14</sup> In the middle of Transdanubia, a central mountain range with a height of 400–800 m above sea level, divided by trenches and valleys, stretches in the NE–SW direction, the surface rocks of which are mostly carbonate rocks, including ancient sedimentary rocks and younger, Pliocene basalts.<sup>15</sup> To the south of the central mountains is the parallel depression, the ‘Balaton-trench’, in which there are two lakes, Lake Balaton and Lake Velencei. In the southern part of the province, on the northern edge of the Balkans and the Dinaric Alps, the present-day landscape is characterized by small central mountains with a decreasing height towards the east, between the Drava and the Sava valley, running in a NE–E depression.<sup>16</sup>

Thus, the first major unit between the central mountains and the Alps is the plain filled by the Danube, the Rába and their tributaries, the Kisalföld (Fig. 1). The second is the ‘Balaton-trench’ and the hilly areas stretching west and south of it, covered by Quaternary loess and sand, Tertiary clayey and gravelly sediments, stretching towards the Danube.<sup>17</sup> While the third is Drava-Sava interfluvium, south of the floodplains of the Mura and Drava, including the right bank plains of the Sava and extending to the mountains of Illyricum (Fig. 1).

Rivers and hydrographic features played an important role in the environmental characteristics of the Pannonian landscape, in addition to topographical factors. The waters of the province were collected by the Danube through four larger rivers originating in the Alps, these are the Rába, Mura, Drava and Sava (Fig. 1). The five main rivers were accompanied by extensive floodplains in the lower hilly areas, but smaller floodplains also developed alongside the smaller watercourses, mainly in the valleys of the hilly areas south-east of Lake Balaton.<sup>18</sup>

The different arrangement of the geological, relief and hydrographic environmental components (Fig. 2) also meant partly different climatic, micro-climatic characteristics, which, together with the altitude, influenced the formation of Quaternary soils and the appearance of different vegetation zones. In the Danube region of Transdanubia, a temperate continental climate<sup>19</sup> became dominant, while in the foothills of the Alps, a more humid version of this, and in the southern region, a sub-Mediterranean climate, which increased in intensity from the 1st century AD and stretched northwards, became dominant.<sup>20</sup>

The Roman conquest was based on the territorial and settlement system and the use of roads by the Celtic and other peoples living in their surroundings, but at the same time it organised the province according to imperial goals and needs, taking into account the environmental conditions for the functions it needed to perform, so that the Roman settlement network and economy were built up to different degrees and with different emphasis in different areas and landscapes. It was concentrated along three main lines: the most important was the Danubian frontier, the Limes, where the various large military camps and their associated settlements were established.<sup>21</sup> The second was the area of the Amber Road running along the foothills of the Alps (Fig. 1), where the

14 HAAS *et al.* 2018, 30–31; GÁBRIS *et al.* 2018, 46–47.

15 MBFSZ Maps.

16 GÁBRIS *et al.* 2018, 50–51.

17 MBFSZ Maps.

18 VARGA *et al.* 2018, 71–75.

19 Cf-based on the Köppen climate typ system; ÁCS – BREUER 2013, 18; <https://koeppen-geiger.vu-wien.ac.at>

20 VADAS – RÁCZ 2010, 42.

21 VISY 2003, 215.

major Romanised cities were established. The third in the south was the northern Balkan route between the Drava and Sava rivers to Sirmium and the Danube border, with centres mostly linked to the rivers.<sup>22</sup> The Roman period brought greater and more intensive environmental transformation than the Celtic period. Not only the growing population, but also the higher level of organisation, the imperial trade, the significant military population and its continuous supply, the growth of industry, the settlement areas and their technical content required more and more environmental resources for almost four centuries. The expansion of settlements, military camps, roads, bridges, locks, dams, aqueducts, canals and farmland affected the environment, primarily vegetation and water networks.<sup>23</sup>

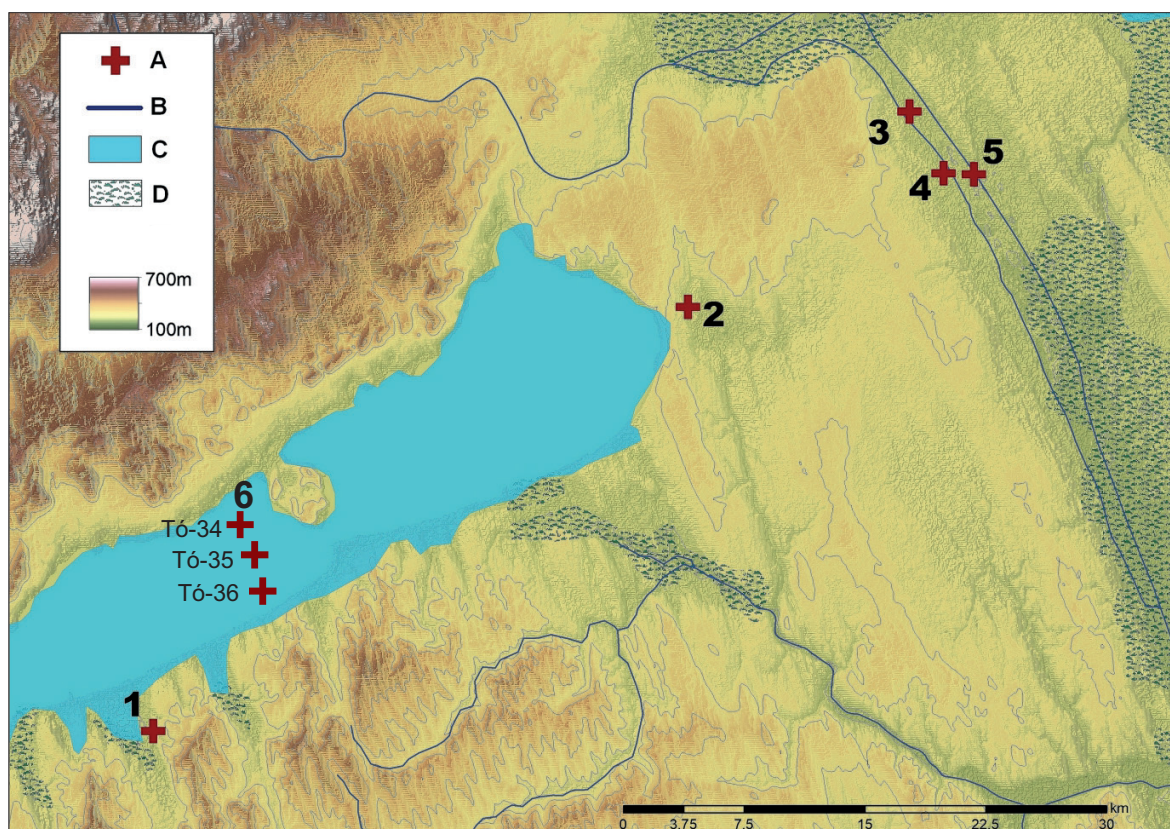


Fig. 2. The topography and hydrography of the area around the sites before the 18 th century water controls. A) sites: 1 – Balatonlelle-Rádpusztá, 2 – Balatonfőkajár-Sólápa, 3 – Szabadbattyán-Péterbánkút-dűlő, 4 – Tác, 5 – Tác-Gorsium/Herculia, 6 – Pollen coring sites (Tó-34, Tó-35, Tó-36); B) watercourse; C) lake; D) floodplain, marsch, wet meadow.

### Lake Balaton and its surroundings in the Roman period

By the 2nd century AD, the area around Lake Balaton in the interior of the province, far from the major centres, was romanised by settlements, and the establishment of villa farms can be dated to this period,<sup>24</sup> with the appearance of atrium houses.<sup>25</sup> However, the Roman settlement network and farming on the north–west and south–east sides of Lake Balaton show a different picture, partly due to the geography of the area.

22 TÓTH 2003, 218.

23 FIRNIGL 2012, 24.

24 MÜLLER 1996a, 86.

25 FIRNIGL 2012, 20–21.

No settlements of urban status were established northwest of Lake Balaton, and archaeological evidence suggests villa-type and village settlement elements.<sup>26</sup> Villa farms have been identified at Baláca, Gyulafirátót-Pogánytelek, Szentkirályszabadja-Romkút and Örvényes, of which the 9 ha Baláca is the earliest built.<sup>27</sup> In the Balaton highlands, the Romans had a well-developed network of roads that followed the topography (Fig. 1). One of the main routes ran along the northern shore of Lake Balaton up to Szigliget and from there to Keszthely, while the other main route was the Veszprém–Nagyvázsony–Tapolca section of the Balaton highlands, which was part of the Poetovio–Salla–Gorsium–Aquincum road network (Fig. 1). From these main road networks branched off secondary and local roads of local interest, which connected the main routes to the farms and villages.<sup>28</sup> In the 4th century AD the fortress of Fenékpuszta<sup>29</sup> was built, mainly for military purposes. In addition to its military function, it also served as a storage base, as indicated by the large number of archaeobotanical remains and the agricultural iron tools found. According early 5th century finds, a Romanised population may have lived within the walls of the fortress until the Huns arrived in mid-430s.<sup>30</sup> On the southern and south-eastern shores of Lake Balaton, several Roman sites and settlement traces are known from the 1st to 3rd centuries AD.<sup>31</sup> In the second half of the 2nd century AD, the Roman settlements around Lake Balaton were destroyed by the Marcomanic–Quad–Sarmatian wars and invasions.<sup>32</sup> From the 3rd century AD, we know of the existence of villa farms and small villages around Lake Balaton.<sup>33</sup> According to the research data available so far, Gorsium (Tác) is the closest settlement to Lake Balaton with urban status.<sup>34</sup> On the southern shore of Lake Balaton, current research suggests fewer villa farms compared to the northern shore. Archaeological evidence suggests that the fortress of Ságvár<sup>35</sup> was built in the 4th century AD.<sup>36</sup> The Roman road connecting the sites under study, running along the southern shore of Lake Balaton, dates back to the 1st century AD.<sup>37</sup>

#### Plant use of the Romans in Pannonia

With the arrival of the Romans, a major change can be observed in the archaeobotanical finds of Hungary.<sup>38</sup> The carpological remains show a more varied picture compared to previous periods. The archaeological sites have been found to contain seeds of apricot (*Prunus armenica*), peach (*Prunus persica*), pear (*Pyrus communis*), plum (*Prunus* sp.), walnut (*Juglans regia*), grape (*Vitis vinifera*), olive (*Olea europaea*) and fig (*Ficus carica*).<sup>39</sup> The biggest change in cereals is that common wheat (*Triticum aestivum*) with higher yield, but also with higher susceptible to diseases was replacing hulled wheats (*Triticum dicoccum*, *Triticum spelta*). The agricultural technology was still mixed, the Celtic characteristics can be observed through the further but smaller scale cultivation of hulled

26 MÜLLER 1996a, 86.

27 PALÁGYI 2003, 238–241.

28 FIRNIGL 2012, 62.

29 Valcum or Volgum.

30 MÜLLER 1996a, 87–88.

31 FIRNIGL 2012, 58–59.

32 MÜLLER 1996a, 86.

33 MÜLLER 1996a, 86.

34 FIRNIGL 2012, 56.

35 Tricciana or Quadriburgium.

36 NÉMETH 2007, 44–45.

37 NÉMETH 2007, 41.

38 GYULAI 2010, 152–153.

39 GYULAI 2010, 157–159.

cereals, millet (*Panicum miliaceum*) and barley (*Hordeum vulgare*).<sup>40</sup> In the Roman period, peas (*Pisum sativum*), bitter vetches (*Vicia ervilia*), small and large-grain lentils (*Lens culinaris*) and broad beans (*Vicia faba*) were also grown as a food source.<sup>41</sup> Among the vegetable crops, black mustard (*Brassica nigra*), carrots (*Daucus carota* subsp. *sativus*), summer savory (*Satureja hortensis*), and opium poppy (*Papaver somniferum*) were known.<sup>42</sup> According to the written sources, the province of Pannonia was dependent on wine imports until the 4th century AD.<sup>43</sup> F. Gyulai,<sup>44</sup> on the other hand, reports a high level of Pannonian viticulture and wine culture.

Contrary to carpology results, very little anthracological<sup>45</sup> data are available from the Roman period in Hungary. The results of the processed sites show that the Romans preferred oak (*Quercus* sp.) for everyday life, but to a smaller degree ash (*Fraxinus* sp.), alder (*Alnus* sp.),<sup>46</sup> willow (*Salix* sp.), poplar (*Populus* sp.), beech (*Fagus sylvatica*) and hazel (*Corylus* sp.) can be found among the remains.<sup>47</sup> Similar results were obtained from the barbarian areas based on the research of Náfrádi,<sup>48</sup> where oak (*Quercus* sp.) dominates, but the plants used by the Sarmatians include elm (*Ulmus* sp.), ash (*Fraxinus* sp.), silver fir (*Abies alba*), apple (*Pomoideae*), beech (*Fagus sylvatica*), poplar (*Populus* sp.) and willow (*Salix* sp.).

As with the charred wood remains, palynological data for Roman Hungary are scarce. Pollen analysis results from the sediments of Zalavár near Lake Balaton indicate a strong human impact on the catchment from the Celtic period which continued later into the Roman period.<sup>49</sup> The proportion of oak (*Quercus* sp.) in the pollen record is significantly reduced (from 10% to 2%) and beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*) became sporadic (under 1%). The proportion of cereals was high in the Roman layer, similar to the Iron Age.<sup>50</sup> In the sediments of Lake Baláta in Somogy County, pollen of rye (*Secale cereale*) and wheat (*Triticum* sp.) was found in the Roman period, indicating small-scale farming, while the higher proportion of hemp (*Cannabis sativa*) indicates cultivation during the Roman period.<sup>51</sup> The pollen data from the Velem-Szent Vid section indicate intensive agricultural activity in the Roman period, as indicated by a high proportion of cereals and a lower proportion of woody species.<sup>52</sup> There is no comparable literature available on the changes in vegetation and land cover in the Roman period for other Pannonian sites. Intensive land use and agriculture in the Roman period is indicated by the large quantity of remains of agricultural iron tools recovered from archaeological sites in Pannonia.<sup>53</sup> The finds show that the Romans used the ploughshare, the skife and the ploughing chain in Pannonia. They also used the spade, the shovel and the hoe. The rake was used to collect hay, forks were used as tools for collecting and moving fodder, and only sickles were used for harvesting crops. The presence of the scythe in Pannonia

40 GYULAI 2010, 153–155.

41 GYULAI 2010, 155.

42 KENÉZ 2014, 136.

43 MÓCSY 1990, 128.

44 GYULAI 2010, 158–159.

45 Fossil wood charcoal.

46 NÁFRÁDI 2011, 127–131.

47 GRYNAEUS 2001, 199–201; GRYNAEUS 2002, 208–211.

48 NÁFRÁDI 2011, 122–125.

49 JUHÁSZ 2007b, 42.

50 JUHÁSZ 2007b, 42.

51 JUHÁSZ 2007c, 244–245.

52 JUHÁSZ 2007a, 276.

53 RUPNIK 2014.

is known from the Late Iron Age, with two types (short and long).<sup>54</sup> The romans usually used the long scythe and took the extermination knives and the pruning knives for clearing, fruit and vine cultivation and fodder harvesting.<sup>55</sup> Traces of viticulture and grape processing are found in pruning knives, hoes and grape pips from Aquincum and its surroundings, as well as tubs found in farm buildings associated with villas, which may have been used for pressing grapes.<sup>56</sup>

### Aims of the study

As the above summary showed, we have some knowledge about the everyday life, plant husbandry regimes and woodland exploitation in Roman Age Transdanubia, but archaeobotanical studies are relatively scarce from this period. In particular, wood charcoal analyses, suitable to reconstruct past natural forest composition and the selective use of certain woody species for house construction, were done only at few sites. Therefore, our aims in this study are to analyse large volume bulk material from 5 archaeological site from the Lake Balaton area for wood charcoal and carbonized seed assemblage<sup>57</sup> composition along with the pollen analytical study of the Roman sediment layers of Lake Balaton. Using these records, we make inferences on the extent of land use, forest exploitation, wood-choice and plant husbandry in Pannonia Province during the Roman Age. Since Lake Balaton is a large lake, pollen assemblages from this lake allow the quantification of regional land cover using the REVEALS algorithm.<sup>58</sup> This technique was applied in this study to quantify the extent of deforestation in Pannonia during the Roman Age.

## Archaeological excavations, soil types and potential natural vegetation of the study sites

### Balatonlelle-Rádpusztá site

The site is located approximately four kilometres from the present-day southern shore of Lake Balaton, on the northern edge of a hill divided by meridional valleys, at the entrance to a valley open to Lake Balaton, at the bottom of a western part of a hill. Several similar valleys and ridges are present in the vicinity of the site.<sup>59</sup> The top of the ridges are covered with loess, the valleys of the small watercourses cutting into them, are mantled with debris, the larger longitudinal valleys between the ridges contain river sediments, and the flatlands near the shore of Lake Balaton contain lake and mire sediments (Fig. 3).<sup>60</sup> The most common soils within the site and its 15 km radius are various brown forest soils in loess. At lower terrain chernozem brown forest soils and peats developed (Fig. 4.1).<sup>61</sup>

The hydrography of the area was determined by the varying extent of the Lake Balaton shoreline following the fluctuations of the lake level and the watercourses of the NW–SE valleys.<sup>62</sup> The immediate environment of the site was shaped by the wetland area of the southern outflow of Lake Balaton and the Tetves stream flowing here. The present-day vegetation of the area is characterised by

54 RUPNIK 2014, 204–205.

55 RUPNIK 2014, 205, 210–211.

56 HAVAS 2008, 98–99.

57 Carpology.

58 SUGITA 2007a, 229.

59 GÁBRIS *et al.* 2018, 50–51.

60 MBFSZ Maps.

61 VÁRALLYAY *et al.* 1994.

62 VARGA *et al.* 2018, 74.

oak–hornbeam forests with beech forests on the northern slopes and continental oak woodland on the southern slopes.<sup>63</sup> In drier parts, patches of forest-steppe and sand-steppe beds are found. Along the watercourses, streamside reed beds are typical, and in more waterlogged areas, the presence of spring marshes is characteristic.<sup>64</sup>

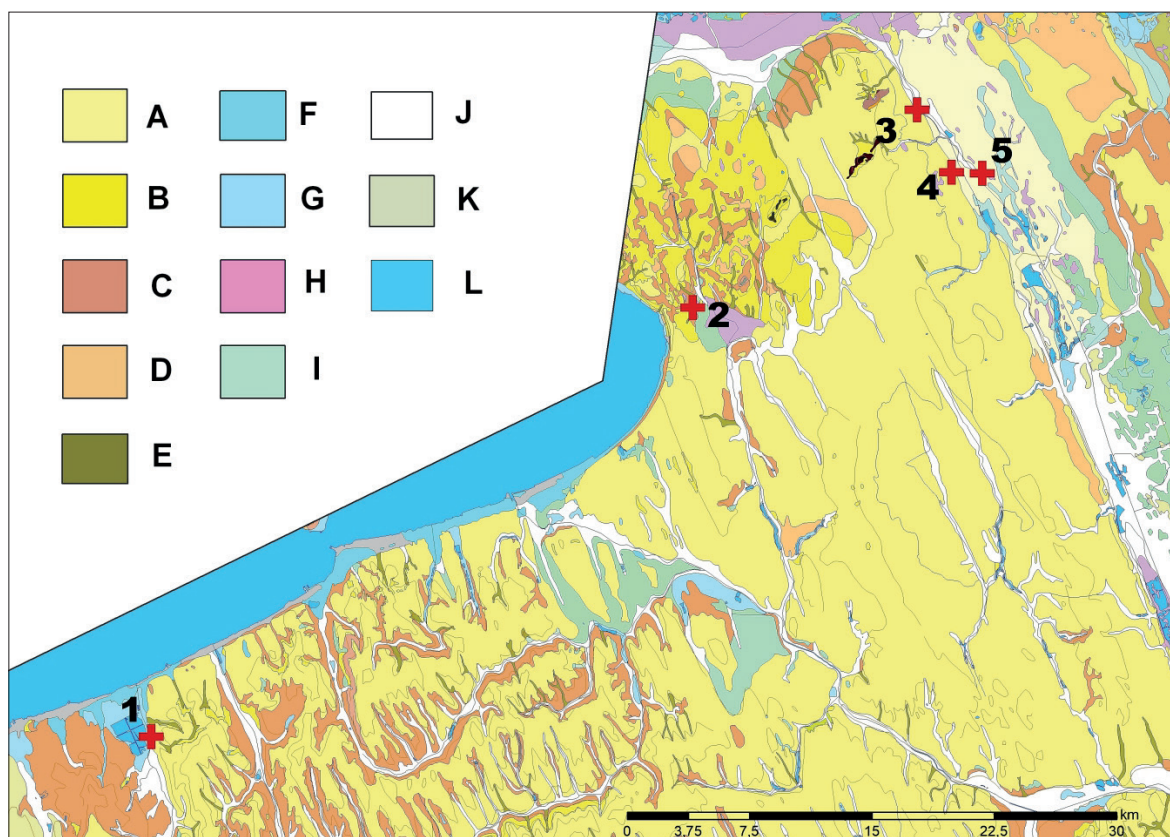


Fig. 3. Main surface rocks in the vicinity of the sites A) loess; B) lime marl, lime mud, aleurit; C) deluvial sediment; D) eluvial–deluvial sediment; E) pro-deluvial sediment; F) lake sediment; G) lake, marsh sediment; H) marsh sediment; I–J–K) river sediment; L) water surface. 1 – Balatonlelle–Rádpusztá, 2 – Balatonfőkajár–Sólápa, 3 – Szabadbattyán–Péterbánkút–dűlő, 4 – Tác, 5 – Tác–Gorsium/Herculia.

The potential vegetation (natural vegetation without human impact) in 15 km radius around the site, as defined by Zólyomi (Fig. 5.1)<sup>65</sup> is dominated by turkey-oak zonal forests (– 49%), followed by Illyric downy-oak scrub (– 11%), carr (– 8%), floodplain woodlands and marshes (– 3.5%). Mountain hornbeam woodlands account for 3% and lowland oak–hornbeam woodlands for 0.5%. Comparison of the actual and potential natural vegetation suggest that most of the floodplain, turkey-oak and beech woodlands were cleared, and today we see higher proportion of hornbeam in the secondary forest.

Szilvia Honti carried out the first archaeological excavation in 1986 at Balatonlelle–Rádpusztá. In 2004, Honti recorded a 1500 m long site on the east side of the Tetves stream. In 2005, Gábor Serlegi excavated at the site (67/3), documenting archaeological finds from the Copper Age, Bronze Age, Roman Age, and Migration Period from 15,000 m<sup>2</sup> area of the site. In 2005 István Molnár and in 2006 Szilvia Honti excavated the site, the Árpád period part was summarized by István Molnár and

63 DÖVÉNYI 2010, 459.

64 DÖVÉNYI 2010, 459–460.

65 ZÓLYOMI 1989.

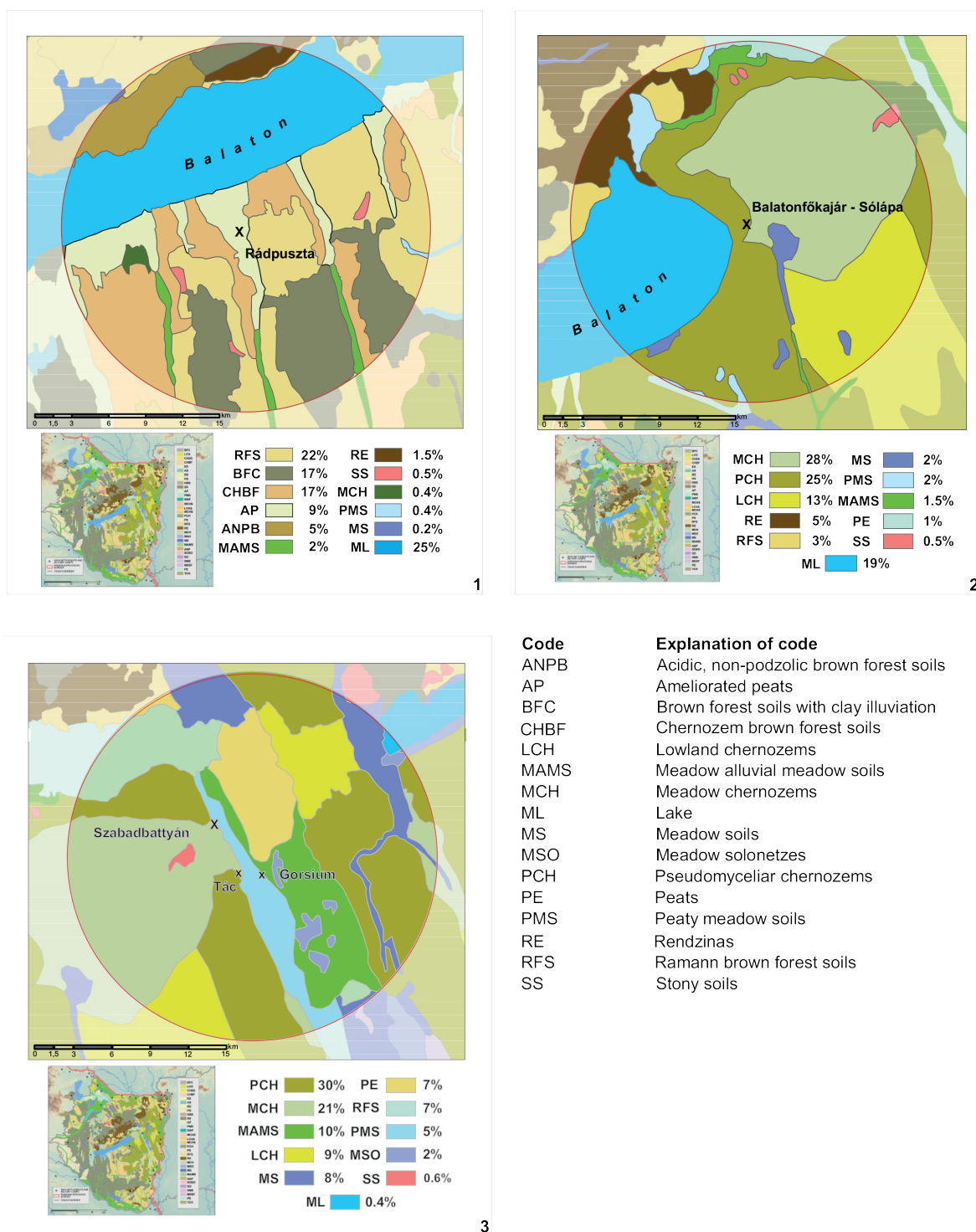


Fig. 4. Soil maps of the studied site in the 15 km radius of the settlements. 1 – Balatonlelle-Rádpusztá, 2 – Balatonfőkajár-Sólápa, 3 – Szabadbattyán-Péterbánkút-dűlő, Tác, Tác-Gorsium/Herculia.

Carmen Sipos in their joint publication.<sup>66</sup> In addition to the medieval monuments, a Roman grave and a settlement object dating from the 2nd to 3rd century AD were also found at the site during the two years of excavation. The processed soil samples were collected by István Molnár during his archaeological excavation from 20 October 2021 to 30 June 2022. A Roman village settlement existed

66 MOLNÁR – SIPOS 2013.

on the excavated site in the 1st–4th centuries AD, with most of the monuments dating from the 2nd–3rd centuries AD. The archaeological material has not yet been published.<sup>67</sup>

### Balatonfőkajár-Sólápa site

The site is located near Lake Balaton, on the northern edge of the Mezőföld, where loess is no longer the dominant surface sediment. The surface of its surroundings is poorly indented, with low, partly loess, partly loamy, partly clayey, marly, calcareous rocks, and wide valleys formed by structural movements and watercourses from the higher foothills of the Bakony Mountains (Fig. 3).<sup>68</sup>

According to the bedrock, the poor relief and the hydrography, the typical soil types of the site and its surroundings are pseudomyceliar chernozem, lowland chernozem and meadow chernozem. In small patches, meadow soils, meadow alluvial soils and peaty meadow soils also occur (Fig. 4.2).<sup>69</sup> Today, its semi-natural vegetation is only found in patches. The loess plateau is covered with loess oak forests, the lower parts with reeds and mires. The slopes of the valleys are characterised by dry and semi-dry loess-steppe and forest-steppe vegetation.<sup>70</sup>

In a 15 km radius of the site the potential natural vegetation (Fig. 5.2) consists of forest-steppe oak forest on loess with Tatar maple (– 58%), followed by floodplain woodlands and marshes (– 13%), and Illyric downy oak scrub (– 4%) and swamps with swamp woodlands (– 4%).

The 1969 volume of the Hungarian Archaeological Topography mentions a villa of the 2nd–4th centuries. In 2003, Szilvia Palágyi excavated an area of 8500 m<sup>2</sup>, she documented 192 objects, including a stone building with a preserved wall foundation. In 2005 Zsolt Gallina and in 2009 Máté Stribányi carried out field excavations at the site. In 2016 István Eke made a test excavation at the site, uncovering a total of 220 archaeological features. The soil samples were from the archaeological excavation in 2017–2018. A total of 28,339 m<sup>2</sup> was excavated and 1,692 archaeological features were documented by the staff of the Laczkó Dezső Museum. No archaeological publication has yet been produced on the results of the excavation, but the archaeological finds suggest that the period between the 2nd and 3rd centuries AD saw a higher intensity of settlement in the Celtic-rooted village settlement. The pottery recovered indicates the habitation of the area between the 1st and 4th centuries AD. No iron tools indicating Roman agricultural activity were found during the two years excavation.<sup>71</sup>

### Szabadbattyán and Tác-Gorsium/Herculia sites

The investigated sites are located at the terraced NW–SE running river valley between Lake Balaton and Lake Velence.<sup>72</sup> Its watercourses are the Séd and Sárvíz with large floodplains.

The high floodplains are covered with blown sand, the terraces with sandy loess, and the valley floor with river and mire sediments (Fig. 3).<sup>73</sup> The higher parts of the site are covered with meadow and pseudomyceliar chernozem soils, while the soils in the vicinity of the site are meadow soils,

67 Hungarian National Museum, Archaeological Database: <https://archeodatabase.hnm.hu/hu/node/42113> (Retrieved 25 June 2025).

68 MBFSZ Maps.

69 VÁRALLYAY *et al.* 1994.

70 DÖVÉNYI 2010, 116.

71 Hungarian National Museum, Archaeological Database: <https://archeodatabase.hnm.hu/hu/node/2611> (Retrieved 25 June 2025).

72 GÁBRIS *et al.* 2018, 50.

73 MBFSZ Maps.

meadow alluvial soils and lowland chernozem (Fig. 4.3). The alluvial deposits of the Sárvíz River nowadays present semi-natural vegetation, such as softwood and hardwood forests and marshy meadows, and saline vegetation further away from the river. Dry sand grasslands, forest-steppe oak forests and meadow steppes on loess can be found on the sandy soils of the higher levels.<sup>74</sup>

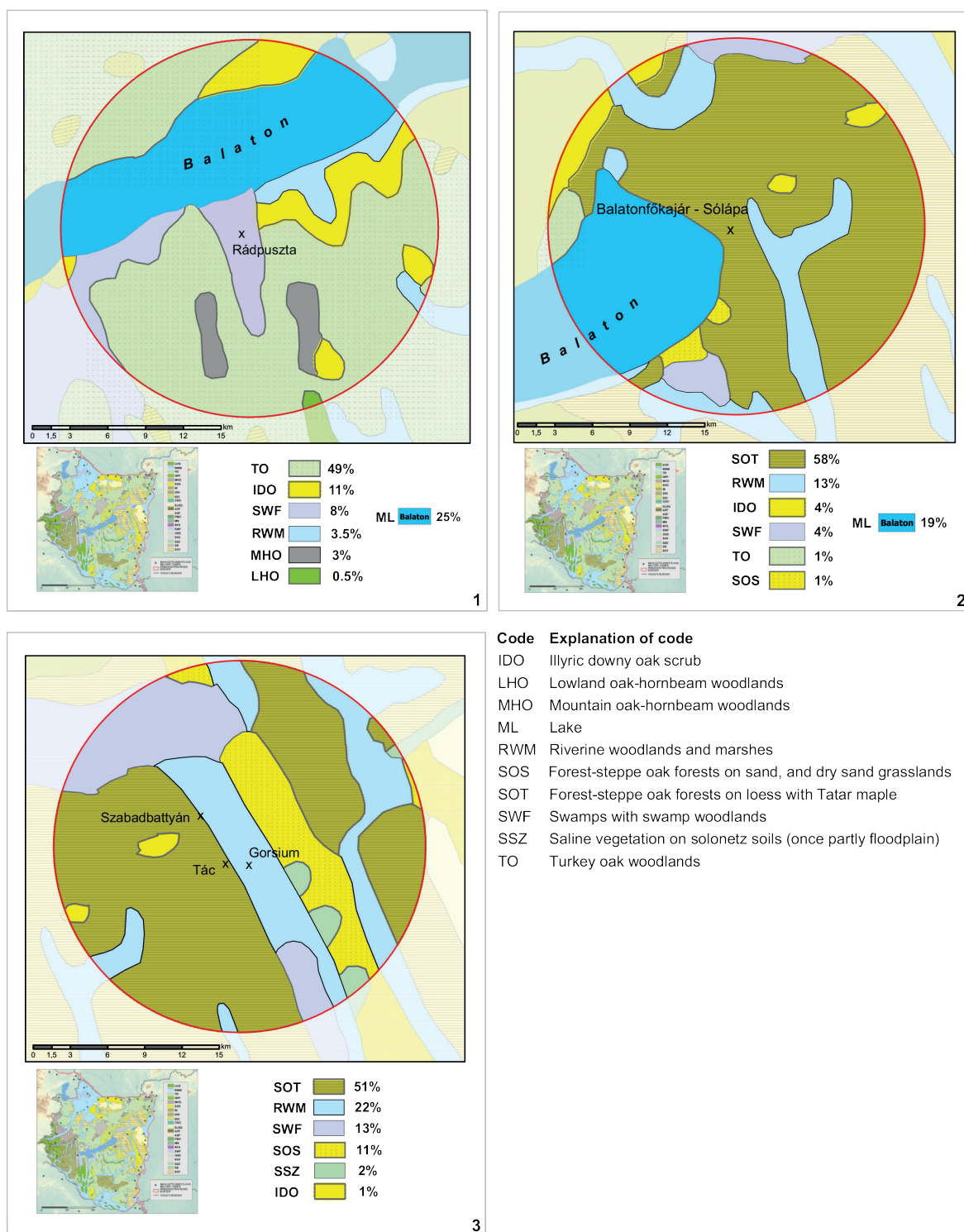


Fig. 5. Potential vegetation maps of the studied sites in 15 km radius of the settlements following the classification of ZÓLYOMI 1989. 1 – Balatonlelle-Rádpusztá, 2 – Balatonfőkajár-Sólápa, 3 – Szabadbattyán-Péterbánkút-dűlő, Tác, Tác-Gorsium/Herculia.

74 DÖVÉNYI 2010, 108–109.

The potential natural vegetation of the site (Fig. 5.3)<sup>75</sup> is mainly forest-steppe oak forest on loess with Tatar maple (– 51%) followed by alluvial woodlands (– 22%), swamps with swamp woodlands (– 13%) and forest-steppe oak forest on sand, and dry sand grasslands (– 11%). We also notice the presence of saline vegetation on solonetz soils (once partly floodplain) (– 2%) and Illyric downy oak scrub (– 1%).

Szabadbattyán-Péterbánkút-dűlő has been a protected archaeological site since 1994. Excavations in the area began in 1974, when archaeologists discovered the foundations of two large Roman buildings. Excavations continued in 1975, and between 1996 and 2002. In 1998, Gabriella Nádorfi excavated part of a 4th century building.<sup>76</sup> Excavations at the site continued in the following years, and in 2001 the remains of a building 35 m long and 17 m wide were found in the 13.000 m<sup>2</sup> building from which the charred plant remains were found. The samples were collected underneath the burnt charcoal layer of the building's mortared, terrazzo floor. According to the research of Gabriella Nádorfi and her colleagues, the building was used as a *horreum*.<sup>77</sup>

Excavations at the TÁC-Gorsium/Herculia site began in 1934 and continued from 1958 until 2006. Before the town, there was a Roman military camp on this site, which developed into a settlement established by the emperor Trajan<sup>78</sup> and the town was then given the status of municipium. It suffered its first major destruction during the Marcomannic Wars (167–180), when a major Sarmatian attack caused damage to several of its buildings. The next Sarmatian attack in 260 proved to be the final one in the life of the town. After that, there were no major changes in the barbarian-ravaged city for nearly three decades. Towards the end of the 3th century AD, rebuilding started again and from that time onwards the sources mention a new name for the city, Herculia. As a result of building and economic development, by the second quarter of the 4th century AD the size of the walled city reached 5 hectares.<sup>79</sup> The town reached its golden age towards the end of the 4th century AD, when the inhabited area increased to 45 hectares. After the Roman defeat at Hadrianopolis in 378 AD, the Huns and Goths conquered several areas of the Roman Empire, including Pannonia. The next decades in the life of Gorsium/Herculia were marked by wars and destruction, with the inhabitants leaving most of the town's buildings. In 430 AD, the Roman province of Valeria, to which Gorsium/Herculia belonged together with Aquincum, fell to the Huns.<sup>80</sup> The collected carpological samples are mainly from archaeological features dating from the 2nd to 4th centuries AD.

## Methods

### Sediment coring in Lake Balaton

The Tó-34 core together with two other cores (Tó-35 and Tó-36) (Fig. 2) were taken in the 2017 winter coring expedition supported by the GINOP-2.3.2-15-2016-00019 project. Three points were selected in the Szemesi sub-basin of the lake (N46°54'57.80", E17°48'55.38"), where sediment mixing was at its lowest and their seismic profiles were 3–4 m thick based on preliminary investigations.<sup>81</sup> The coring was carried out on January 27, 2017 on the frozen Lake Balaton with a modified Livingstone piston corer, between Balatonudvari and Balatonszárszó, 2 (Tó-34) – 4 (Tó-35) km from the shore. The sediment cores were 4.3–4.5 m in length each (Tó-34a, Tó-35a). Sediment depths are given relative to the water surface, so 420.68 cm represents the top of the core, while the bottom is 845 cm in the case of Tó-34a. The overlapping cores were also taken from a sediment depth of 50 cm (Tó-34b, Tó-35b).

75 ZÓLYOMI 1989.

76 NÁDORFI 2001, 215–216.

77 NÁDORFI 2012, 123.

78 FITZ 1996, 16.

79 FITZ 1996, 15–20.

80 FITZ 1996, 20.

81 VISNOVITZ *et al.* 2015, 2276–2278.

## Anthracology and carpology

In the vicinity of Lake Balaton, we selected the five Roman sites presented above, where the determination and analyses of seed, crop and charred wood remains were carried out. The aim of the macro-botanical analysis was to obtain information on the Roman environment, crop use and cultivation of the micro-regions under study. In the case of the Balatonfőkajár-Sólápa site, the samples were taken from the excavations of 2017–2018, with a total of 79 soil samples and charred wood remains from different archaeological sites, from ovens and from different types of pits (storage pit, working pit and post hole). Their weight varied between 1 g and 5 kg. We obtained a total of 6 Roman period soil samples from the Balatonlelle-Rádpusztá site, weighing 2.5–6 kg.<sup>82</sup> The samples came from oven, ash pits and pits. From the sites of TÁC-Gorsium/Herculia and Szabadbattyán-Péterbánkút-dűlő we received flotation material. From the 7.8 kg flotata sample from the *horreum* of Szabadbattyán, 57 g were randomly selected for processing. We analyzed 69 objects or layers from the TÁC-Gorsium/Herculia site, which, in terms of context, came from villa buildings, graves, wells, and pits. Macro-fossils were extracted from the soil samples by wet sieving using 0.5–1.0–2.0–4.0 mm mesh. This was followed by drying and the macro-charcoal remains were sorted. The TÁC and Szabadbattyán were provided to us in sorted form. Sorting was performed using an Olympus SZ-51 stereo type microscope. The identification of the carpological material was carried out using modern comparative reference material and standard identification manuals,<sup>83</sup> as well as the reference collections of the Kuny Domokos Museum in Tata and Maria Hajnalová. The taxonomic identification of the charred wood remains was done with a Nikon Eclipse LV100 POL scanning binocular microscope, using wood atlases and identification books.<sup>84</sup> In both cases we aimed at species-level determination wherever possible. For charred wood remains, at least 100 randomly selected remains were analyzed per sample if sample size allowed. Charred wood samples were identified at genus level in most cases due to the similar wood anatomical features of species within the genera.

## Sediment lithology, <sup>14</sup>C dating, pollen analysis and statistical analyses of Lake Balaton

Sediment lithology was described in the laboratory following the system of Troels-Smith.<sup>85</sup> Sixteen radiocarbon dates were obtained from core Tó-34a (Tab. 1). Terrestrial plant macrofossils were mainly used for AMS <sup>14</sup>C dating, but zooplankton remains, charcoal and pollen extracts were also dated due to the lack of plant macrofossils in some layers. AMS <sup>14</sup>C dating was done in the Hertelen-di Laboratory of Environmental Studies at ATOMKI in Hungary.<sup>86</sup> <sup>14</sup>C dates were calibrated using CALIB Rev 6.1.0<sup>87</sup> and the IntCal20 calibration curve (Tab. 1).<sup>88</sup> The age-depth model was calculated in BACON, a Bayesian age modelling software package.<sup>89</sup> The core top was assigned to 2017 CE and this date was also used to constrain the age-depth model. The deposition time (DT) was calculated using the age-depth model and expressed as yr cm<sup>-1</sup>.<sup>90</sup>

82 The quantity of the samples is given in terms of mass. In the literature, both volume and mass are commonly used to express sampling quantities. There is, however, no precise protocol specifying whether only volume or mass should be applied (PETŐ – KENÉZ 2018, 32).

83 CAPPERS *et al.* 2012; SCHERMANN 1967.

84 GREGUSS 1959; SCHWEINGRUBER 1978; GENCSI – VANCSURA 1992; BABOS 1994.

85 TROELS-SMITH 1955.

86 MOLNÁR *et al.* 2013.

87 STUIVER *et al.* 2011.

88 REIMER *et al.* 2020.

89 BLAAUW – CHRISTENY 2011.

90 BENNETT 1993.

**Tab. 1.** Relative frequencies and absolute numbers of wood charcoal genera and species identified from the investigated Roman age sites in the Balaton region of Pannonia province.

| Genus/species Latin name/English name  | Balatonlelle-Rádpusztá<br>number of soil samples: 6 |     | Balatonfőkajár-Sólápa<br>number of soil samples: 75 |      | Tác-Gorsium/Herculia<br>number of samples: 55 |      | Szabadbattyán-Péterbán-<br>kút-dűlő<br>number of samples: 1 |   |
|--|---|-----|---|------|---|------|---|---|
|  | %   | n   | %   | n    | %   | n    | %   | n |
| <i>Abies alba</i> /silver fir          | 0   | 0   | 0   | 0    | 1.91  | 22   | 0   | 0 |
| <i>Acer</i> sp./maple                  | 0   | 0   | 0   | 0    | 0.96  | 11   | 0   | 0 |
| <i>Alnus</i> sp.- alder                | 1.70  | 3   | 0   | 0    | 2.26  | 26   | 0   | 0 |
| <i>Carpinus betulus</i> /hornbeam      | 0   | 0   | 0   | 0    | 0.87  | 10   | 0   | 0 |
| <i>Euonymus</i> sp./spindle tree       | 0   | 0   | 0   | 0    | 4.87  | 56   | 0   | 0 |
| <i>Fagus sylvatica</i> /beech          | 0   | 0   | 0.69  | 7    | 15.74   | 181  | 0   | 0 |
| <i>Frangula alnus</i> /alder buckthorn | 0   | 0   | 0.09  | 1    | 0   | 0    | 0   | 0 |
| <i>Fraxinus</i> sp./ash                | 0   | 0   | 0   | 0    | 4.09  | 47   | 0   | 0 |
| <i>Picea abies</i> /spruce             | 0   | 0   | 0   | 0    | 0.35  | 4    | 0   | 0 |
| <i>Pinus</i> sp./pine                  | 0   | 0   | 0   | 0    | 0.52  | 6    | 0   | 0 |
| <i>Pinus sylvestris</i> /Scots pine    | 0   | 0   | 0   | 0    | 1.30  | 15   | 0   | 0 |
| <i>Pomoideae</i>                       | 0   | 0   | 0   | 0    | 2.70  | 31   | 0   | 0 |
| <i>Prunoideae</i>                      | 0   | 0   | 0.78  | 8    | 0.17  | 2    | 0   | 0 |
| <i>Quercus</i> sp./oak                 | 98.30   | 173 | 98.15   | 1006 | 55.57   | 639  | 100   | 3 |
| <i>Sorbus</i> sp./rowan                | 0   | 0   |   |      | 1.39  | 16   | 0   | 0 |
| <i>Ulmus</i> sp./elm                   | 0   | 0   | 0.29  | 3    | 7.30  | 84   | 0   | 0 |
| Total number                           | 100   | 176 | 100   | 1025 | 100   | 1150 | 100   | 3 |

Samples for pollen analysis were taken at 4-cm intervals<sup>91</sup> from the Holocene sediment section of core Tó-34a (Szemes sub-basin, Lake Balaton) to examine vegetation changes. For pollen analysis 1 cm<sup>3</sup> subsamples were prepared in the laboratory using standard methods (HCl, NaOH, HF, acetylation and sieving between 10–125 µm.<sup>92</sup> Pollen, spores and non-pollen palynomorphs (NPP) in-

91 We applied a 4-centimetre sampling resolution for two main reasons. First, our pollen analysis covered not only the Roman period but also other phases of the Holocene. With 4-centimetre sampling intervals, we were able to trace vegetation changes over 100–200 years, based on our radiocarbon dates. Within the sections of the core corresponding to the Roman period, the 4 cm sampling resolution provided information on the composition and proportions of plant taxa across successive centuries. Statistical analyses of the pollen data further allowed us to reconstruct aspects of Roman-period agricultural land use and changes in vegetation cover.

92 BENNETT – WILLIS 2001.

cluding algae and microcharcoal particles were counted and identified under a Motic BA310 light microscope at 400× and 1000× magnification. At least 500 terrestrial pollen grains were counted on each slide. The pollen atlases of Reille<sup>93</sup> and the pollen identification key in Moore *et al.*<sup>94</sup> and in Beug<sup>95</sup> were used for pollen identification. Pollen percentages and pollen accumulation rates were plotted using Psimpoll 4.27.<sup>96</sup>

**Tab. 2.** Vegetation types and their indicator taxa based on Marinova and Ntinou (MARINOVA – NTINO 2017).

| Vegetation types                    | Taxa   |
|-------------------------------------|--|
| Alpine spruce forest                | <i>Picea abies</i> /spruce,  |
| Deciduous oak forest                | <i>Acer</i> sp./maple; <i>Carpinus betulus</i> /hornbeam; <i>Euonymus</i> sp./spindle tree; <i>Quercus</i> sp./oak |
| Illyrian and subalpine beech forest | <i>Abies alba</i> /silver fir; <i>Fagus sylvatica</i> /beech   |
| Open woodland/forest undergrowth    | <i>Pomoideae</i> ; <i>Prunoideae</i> ; <i>Sorbus</i> sp./rowan   |
| Pine woodland                       | <i>Pinus</i> sp./pine; <i>Pinus sylvestris</i> /Scots pine   |
| Riparian woodland                   | <i>Alnus</i> sp./alder; <i>Frangula alnus</i> /alder buckthorn; <i>Fraxinus</i> sp./ash; <i>Ulmus</i> sp./elm      |

Local pollen assemblage zones (LPAZ) were determined using optimal splitting by information content on the terrestrial pollen taxa exceeding 5% in at least one sample (16 taxa). The statistical significance of the pollen assemblage zone boundaries was tested by comparison with the broken stick model.<sup>97</sup> This way six significant pollen zones were identified in the Holocene section of core Tó-34.

Principal component analysis (PCA) is a well-known and the most applied numerical method, which extracts linear combination of variables.<sup>98</sup> PCA partitions the total variance among successive components with the maximalization of variance in low-numbered components.<sup>99</sup> We used the pollen percentage values of the terrestrial taxa to determine the principal components using covariance matrix and square-root transformation of those terrestrial pollen types that exceeded 1% in at least one sample. This way two significant principal components were found.

Palynological richness was estimated for the sum of 350 terrestrial pollen  $E(T_{350})$  using rarefaction analysis.<sup>100</sup> The rate of vegetation change was calculated on interpolated pollen spectra, where the recalculation interval was 100 years in our cases. The distance measure was chord distance.<sup>101</sup> Periods denoted by above-than average chord-distance values are interpreted as periods of higher-than-average rates-of-change in the vegetation composition.

The agricultural land use probability (LUP) index is a relatively new approach developed by Deza-Araujo *et al.*<sup>102</sup> to quantify human impacts on ecosystems using pollen types. Indicator taxa of the sub-Mediterranean vegetation belt were slightly modified in this study for the Pannonian biogeo-

93 REILLE 1992; REILLE 1995; REILLE 1998.

94 MOORE *et al.* 1991.

95 BEUG 2004.

96 BENNETT 2007.

97 BENNETT 1996.

98 PRENTICE 1980; LEGENDRE – BIRKS 2012.

99 PRENTICE 1980.

100 BIRKS – LINE 1992.

101 BENNETT – HUMPHRY 1995.

102 DEZA-ARAUJO *et al.* 2022.

graphical region.<sup>103</sup> The 17 taxa identified by Deza-Araujo *et al.*<sup>104</sup> were supplemented with 12 additional taxa related to agricultural land use (Tab. 4).

Due to differences in pollen production and dispersal mechanisms, percentage pollen records do not accurately reflect vegetation composition and vegetation openness.<sup>105</sup> The development of extended R-value models and mechanistic pollen dispersal-deposition models became widespread in the 1980s<sup>106</sup> and their development has led to the Landscape Reconstruction Algorithm (LRA),<sup>107</sup> which can be used for regional vegetation cover reconstruction in the large lakes. The model relies on estimates of the relative pollen productivity and fall speed of pollen (m/s) of key taxa to convert pollen percentages into estimates of plant cover. It has been successfully tested.<sup>108</sup> In this study, we use this model to track changes in vegetation cover over the past 3000 years. Regional plant cover was estimated using a set of 31 pollen types for which pollen productivity estimates have been published by Githumbi *et al.* (Tab. 7).<sup>109</sup>

The REVEALS (Regional Estimates of Vegetation Abundance from Large Sites) model requires raw pollen counts and parameters such as the site radius (R), which is 3850 m, pollen fall velocity (FSP, m.s<sup>-1</sup>), pollen productivity estimates (PPE) and their standard errors (SE) (Tab. 7). The study uses an R script to simulate the REVEALS model (REVEALS.v4.2.2. – Tallinn.wks.exe) binary.<sup>110</sup> In this study we use the GPM pollen dispersal model assuming neutral atmospheric conditions and a wind speed of 3 m/s.<sup>111</sup> Zmax, the maximum extent of regional vegetation from the site center, was determined to be 200 km based on comparison of the surface pollen sample and Corine Land Cover maps. REVEALS taxon estimates were grouped into eight classes: arable fields, open land, subalpine needle leaved forest, montane needle leaved forest, mesophilous broadleaved forest, termophilous deciduous forest, Sub-Mediterranean woodland, Eu-Mediterranean evergreen woodland (Tab. 7) and transformed into REVEALS estimates. The REVEALS model assumes that pollen records from large areas (>50–100 ha) reflect regional vegetation (>50–100 km).

### Mapping potential vegetation and soils around the study sites

The natural vegetation in the Roman period in the vicinity of the sites likely differed from the modern potential vegetation, but all woody species were present by that time, and we assume only minor, higher than pre-industrial summer temperature related differences. In this study we use the potential natural vegetation map of Bálint Zólyomi<sup>112</sup> along with the soil database of Hungary called AGROTOPO (Figs 4–5) to infer potential vegetation before human impact and soil types. The potential vegetation cover map<sup>113</sup> was downloaded from the website of the MÉTA Program<sup>114</sup> and

103 BORHIDI 1993; BORHIDI 1996; BORHIDI 2003; FEKETE *et al.* 1997; KOVÁCSNÉ LÁNG – TÖRÖK 1997.

104 DEZA-ARAUJO *et al.* 2022.

105 FYFE *et al.* 2010.

106 PARSONS – PRENTICE 1981; PRENTICE 1985; PRENTICE – PARSONS 2010.

107 SUGITA 2007a; SUGITA 2007b.

108 SOEPBOER *et al.* 2010; FYFE *et al.* 2013.

109 GITHUMBI *et al.* 2022.

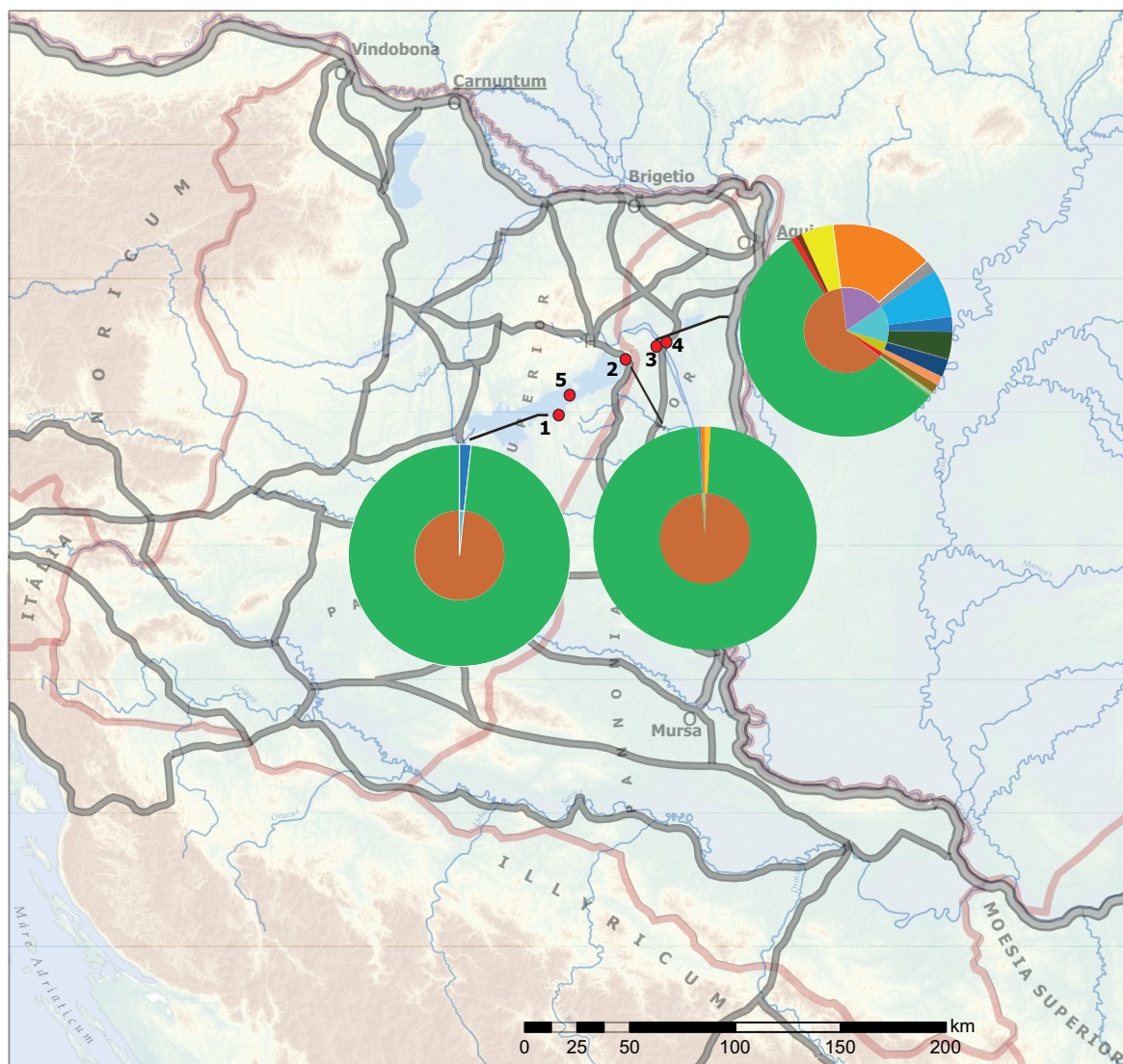
110 SUGITA unpublished.

111 The REVEALS model assumes neutral atmospheric conditions, as extreme local factors can distort both the transport distance and the dispersal pattern of pollen. Petr Kuneš provided professional guidance in determining the wind speed value, recommending 3 m/s for the Balaton region based on data from the relevant literature (PRENTICE 1985; SUGITA 1994; MAZIER *et al.* 2012; KUNEŠ *et al.* 2019).

112 ZÓLYOMI 1989.

113 ZÓLYOMI 1989.

114 Map Database of Hungarian Habitats.



**Large pie chart: taxa**

- *Abies alba*- silver fir
- *Acer* sp.- maple
- *Alnus* sp.- common alder
- *Carpinus betulus*- hornbeam
- *Euonymus* sp.- spindle tree
- *Fagus sylvatica*- beech
- *Frangula alnus*- alder buckthorn
- *Fraxinus* sp.- ash
- *Picea abies*- spruce
- *Pinus* sp.- pine
- *Pinus sylvestris*-scots pine
- Pomoideae
- *Populus* sp.- poplar
- Prunoideae
- *Quercus* sp.- oak
- *Sorbus* sp.- rowan
- *Ulmus* sp.- elm

**Small pie chart: vegetation types**

- Alpine spruce forest
- Deciduous oak forest
- Illyrian and subalpine beech forest
- Open woodland/forest undergrowth
- Pine woodland
- Riparian woodland

- Limes and main road
- Province border
- The investigated archaeological sites and location of sediments cores
- 1. Balatonlelle - Rádpusztá
- 2. Balatonfőkajár - Sólápa
- 3. Tác
- 4. Gorsium/Herculia
- 5. Sediments cores (Tó-34,Tó-35,Tó-36)

Fig. 6. Relative frequency distribution of Roman age wood charcoal remains and inferred forest types in the Balaton region of Pannonia province by sites.

then using the ArcGIS mapping software, we created the clipping (clip) with a radius of 15 km per site, after which the attribute table<sup>115</sup> was used to determine the surface coverage of the vegetation types as relative frequency data. The site catchment analysis (space use analysis) used in archaeology provided a clue in determining the size of the examined area. The basis of the method is to determine, based on the knowledge of geomorphological data, the area around archaeological sites from which the inhabitants of the given culture were able to obtain their natural resources (water, wood, pottery clay) with less effort and were able to create (arable land, pasture) the resources necessary for their subsistence material elements and food sources, so it is the area from which most of the resources could have come. Their most basic plant and mineral needs were usually gathered from within a 5 km radius, but animals and timber could also be sourced from further afield.<sup>116</sup> The AGROTOPO database was prepared at the HUN–REN Institute for Soil Science in 1991, from which the AGROTOPO GIS computer database was developed, which is standardised with EOTR,<sup>117</sup> scale: 1:100 000, and contains national data. The mapping of the soil data by site followed the same methodology as used for processing the potential natural vegetation maps.

## Results

### Anthracology and carpology

Charcoal samples from the Balatonlelle-Rádpusztza site were obtained from pits, oven and ash pit. A total of 176 remains were identified, of which more than 98% were oak (*Quercus* sp.), and one more taxon, alder (*Alnus* sp.), was observed (Fig. 6, Tab. 1).

The charred wood remains of Balatonfőkajár-Sólápa came from pits and ovens therefore they represent a mixture of long and short-term deposition.<sup>118</sup> The total number of identified woody taxa was 1025 (Fig. 6, Tab. 1). The results showed the predominance of oak (*Quercus* sp.) over 98%. The relative frequency of elm (*Ulmus* sp.), alder buckthorn (*Frangula alnus*), beech (*Fagus sylvatica*) and the genus Prunoideae was below 1%.

A total of 3 small charcoal pieces (Tab. 1) were found in the sample from the *horreum* of the Szabadbattyán-Péterbánkút-dűlő, which were identified as oak (*Quercus* sp.) based on their histological characteristics.

The Tác-Gorsium/Herculia site contained the largest number of charred wood remains. We analyzed 1150 coming from villa buildings, graves, well and pits. The composition of the wood was varied (Fig. 6, Tab. 1), with oak (*Quercus* sp.) dominating again, but reaching only 56%. Beech (*Fagus sylvatica*) was the second most abundant—15.74% followed by elm (*Ulmus* sp.) with 7.3% and spindle tree (*Euonymus* sp.) with almost 5%. In addition, we identified several other tree taxa < 5%. These include silver fir (*Abies alba*), maple (*Acer* sp.), alder (*Alnus* sp.) hornbeam (*Carpinus betulus*), ash (*Fraxinus* sp.), spruce (*Picea abies*), pine (*Pinus* sp.), Scots pine (*Pinus sylvestris*), Pomoideae, Prunoideae and rowan (*Sorbus* sp.) (Fig. 6, Tab. 1).

The wood taxon-based forest types (Tab. 2) were determined using the concept of Marionova and Ntinou.<sup>119</sup> It was modified and supplemented with the Carpathian Basin flora (Fig. 6, Tab. 3). At Balatonlelle-Rádpusztza, our data indicate that the dominant type is deciduous oak forest with more than 98%, and our macrobotanical results also indicate the presence of 1.73% riparian woodland.

115 Open Attribute Table.

116 ROPER 1979.

117 Unified National Map System.

118 ASOUTI – AUSTIN 2005, 4; KABUKCU 2018, 139.

119 MARINOVA – NTINO 2018, 7–10.

**Tab. 3.** Relative frequency of inferred vegetation types at the Roman Age archeological sites based on wood charcoal assemblages, Transdanubia, Hungary.

| Sites                               | Balatonlelle-Rádpuszta<br>number of soil samples: 6 |     | Balatonfőkajár-Sólápa<br>number of soil samples: 75 |      | Tác-Gorsium/Herculia<br>number of samples: 55 |      | Szabadbattyán-<br>Péterbánkút-dűlő<br>number of samples: 1 |   |
|-------------------------------------|---|-----|---|------|---|------|--|---|
|                                     | %   | n   | %   | n    | %   | n    | %  | n |
| Alpine spruce forest                | 0   | 0   | 0   | 0    | 0.35  | 4    | 0  | 0 |
| Deciduous oak forest                | 98.30   | 173 | 98.15   | 1006 | 62.27   | 716  | 100  | 3 |
| Illyrian and subalpine beech forest | 0   | 0   | 0.69  | 7    | 17.65   | 203  | 0  | 0 |
| Open woodland/forest undergrowth    | 0   | 0   | 0.78  | 8    | 4.26  | 49   | 0  | 0 |
| Pine woodland                       | 0   | 0   | 0   | 0    | 1.82  | 21   | 0  | 0 |
| Riparian woodland                   | 1.70  | 3   | 0.38  | 4    | 13.65   | 157  | 0  | 0 |
| Total number                        | 100   | 176 | 100   | 1025 | 100   | 1150 | 100  | 3 |

At the Balatonfőkajár-Sólápa site, deciduous oak forest was also dominant (Fig. 6, Tab. 3) with more than 98%, while riparian woodland, Illyrian and subalpine beech forest and open woodlands/forest undergrowth were also reconstructed under 1%. The few charcoal remains in the Szabadbattyán-Péterbánkút-dűlő (Fig. 6, Tab. 3) do not allow a detailed analysis of the forest type.

The most detailed analysis was carried out for TÁC-Gorsium/Herculia, where we identified 6 forest types (Fig. 6, Tab. 3) based on our wood charcoal findings. Again, the highest proportion of deciduous oak forest was found here (62.27%), followed by Illyrian and subalpine beech forests and riparian forests (17.65 and 13.65%). Illyrian and subalpine beech forests were unlikely to be present in the vicinity of the site. This is further supported by the potential vegetation map of the site (Fig. 5.3) and the ecological characteristics of the plant species.<sup>120</sup>

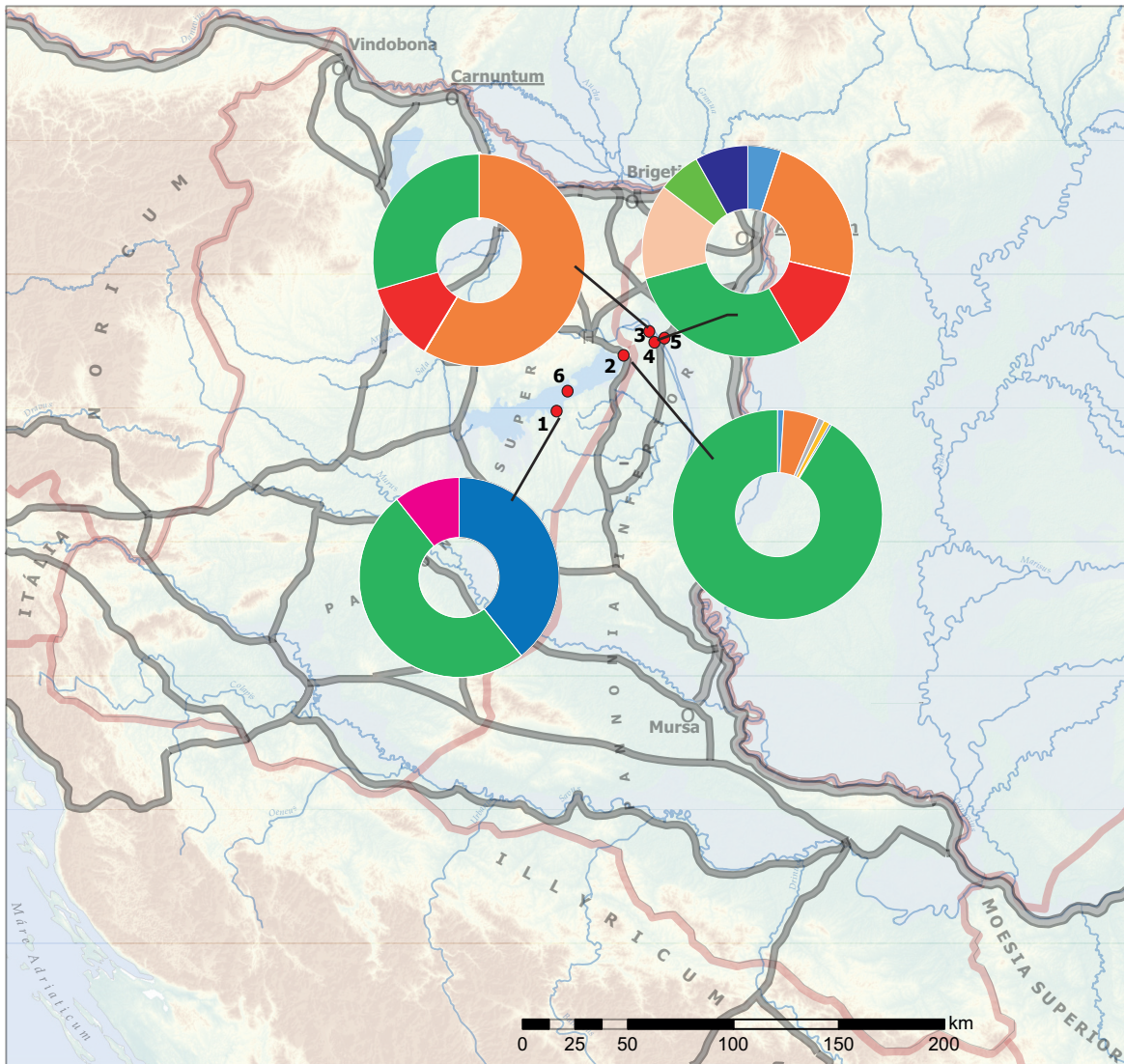
The tree species (*Abies alba* and *Fagus sylvatica*) were most likely introduced to Gorsium/Herculia from a more distant part of the range or from another province, similarly to the Alpine spruce forest vegetation type (*Picea abies*). This is considered well-founded based on the ecological characteristics of these plant species<sup>121</sup> and the potential vegetation maps (Fig. 5). Based on the natural conditions of the site and the ecological properties of *Pinus sylvestris*, it can be assumed that the species and thus the Pine woodland vegetation type could have existed in the vicinity of the site. The genera (*Pomoideae* and *Prunoideae*) show anthropogenic influence also indicate the existence of open woodland vegetation type in the immediate vicinity of the site during the Roman period.

From Balatonlelle-Rádpuszta (Fig. 7, Tab. 4), 11 pieces of millet (*Panicum miliaceum*) were identified, and 17 pieces of cereals (*Cerealia*) were unidentifiable at the species level due to their fragmentary character. The quantity of weeds was not significant; however the following species were identi-

120 GENCSI – VANCSURA 1992, 220–221.

121 GENCSI – VANCSURA 1992, 115, 122–125, 220–221.

fied blue woodruff (*Asperula arvensis*), white goosefoot (*Chenopodium album*), catchweed bedstraw (*Galium aperine*), stickwilly (*Galium spurium*), dane weed (*Sambucus ebulus*), medick (*Medicago* sp.) and *Polygonaceae*.



- *Cannabis sativa*-hemp
- Cerealia
- cf. Cerealia
- *Cucumis melo*-melon
- *Hordeum vulgare*- barley
- *Panicum miliaceum*- millet
- *Secale cerealea*-rye
- *Triticum aestivum*- common wheat
- *Triticum aestivum/spelta*
- *Triticum dicoccum*- emmer
- *Triticum monococcum*-einkorn
- *Triticum spelta*- spelt
- *Vicia ervilia*-bitter vetch

- Limes and main road
- Provincie border
- The investigated archaeological sites and location of sediments cores
- 1. Balatonlelle - Rádpuszta
- 2. Balatonfőkajár - Sólápa
- 3. Szabadbatyán - Péterbánkút-dűlő
- 4. Tác
- 5. Gorsium/Herculia
- 6. Sediments cores (Tó-34,Tó-35,Tó-36)

Fig. 7. Relative frequency distribution of cultivated plants at the studied Roman age archaeological sites in the Balaton region of Pannonia province.

**Tab. 4.** Relative frequencies and absolute numbers of species, genera and families identified from the car-pological material of the investigated Roman Age sites from Transdanubia, Hungary.

| Sites  | Balatonlelle-Rádpusztá<br>number of soil samples: 6 |    | Balatonfőkajár-Sólápa<br>number of soil samples: 75 |     | Tác-Gorsium/Herculia<br>number of samples: 55 |      | Szabadbattyán-Péterbán-<br>kút-dűlő<br>number of samples: 1 |      |
|--|---|----|---|-----|---|------|---|------|
|  | %   | n  | %   | n   | %   | n    | %   | n    |
| Genus/species Latin name/English name          |   |    |   |     |   |      |   |      |
| cf. Cerealia                                   | 7.14  | 3  | 0   | 0   | 0   | 0    | 0   | 0    |
| Cerealia                                       | 33.33   | 14 | 86.40   | 286 | 29.09   | 1498 | 29.14   | 945  |
| Hordeum sp./barley                             | 0   | 0  | 0   | 0   | 0   | 0    | 0.03  | 1    |
| Hordeum vulgare/barley                         | 0   | 0  | 0.91  | 3   | 5.09  | 262  | 0   | 0    |
| Panicum miliaceum/millet                       | 26.19   | 11 | 0.30  | 1   | 0   | 0    | 0   | 0    |
| Secale cerealea/rye                            | 0   | 0  | 0   | 0   | 12.89   | 664  | 11.73   | 380  |
| Triticum aestivum/ common wheat                | 0   | 0  | 5.14  | 17  | 23.63   | 1217 | 57.78   | 1873 |
| Triticum aestivum/spelta                       | 0   | 0  | 0   | 0   |   |      | 0.03  | 1    |
| Triticum dicoccum/emmer                        | 0   | 0  | 0.91  | 3   | 0.02  | 1    | 0   | 0    |
| Triticum monococcum/einkorn                    | 0   | 0  | 0   | 0   | 0.04  | 2    | 0   | 0    |
| Triticum spelta/spelt                          | 0   | 0  | 0.91  | 3   | 0   | 0    | 0.12  | 4    |
| Agrostemma githago/corn cockle                 | 0   | 0  | 1.51  | 5   | 0.08  | 4    | 1.02  | 33   |
| Asperula arvensis/blue woodruff                | 2.38  | 1  | 0   | 0   | 0   | 0    | 0   | 0    |
| Asteraceae                                     | 0   | 0  | 0.3   | 1   | 0   | 0    | 0   | 0    |
| Bromus secalinus/arvensis/brome-grass          | 0   | 0  | 0   | 0   | 0   | 0    | 0.03  | 1    |
| Bupleurum rotundifolium/hare's ear             | 0   | 0  | 0   | 0   | 0   | 0    | 0.03  | 1    |
| Cannabis sativa/hemp                           | 0   | 0  | 0   | 0   | 14.50   | 747  | 0   | 0    |
| Chenopodium album/white goosefoot              | 4.77  | 2  | 1.21  | 4   | 0   | 0    | 0   | 0    |
| Chenopodium hybridum/maple-leaved<br>goosefoot | 0   | 0  | 0.30  | 1   | 0   | 0    | 0   | 0    |
| Chenopodium sp./goosefoot                      | 0   | 0  | 0.91  | 3   | 0   | 0    | 0.03  | 1    |
| Cucumis melo/melon                             | 0   | 0  | 0   | 0   | 6.48  | 334  | 0   | 0    |
| Echinochloa crus-galli/barnyard grass          | 0   | 0  | 0.30  | 1   | 0   | 0    | 0   | 0    |
| Galium aperin/catchweed bedstraw               | 2.38  | 1  | 0   | 0   | 0   | 0    | 0   | 0    |
| Galium spurium/stickwilly                      | 11.90   | 5  | 0   | 0   | 0   | 0    | 0   | 0    |
| Galium sp./bedstraw                            | 0   | 0  | 0.30  | 1   | 0   | 0    | 0   | 0    |
| Galium spurium/stickwilly                      | 0   | 0  | 0   | 0   | 0   | 0    | 0   | 0    |

| Genus/species Latin name/English name                | Balatonlelle-Rádpusztá<br>number of soil samples: 6 |    | Balatonfőkajár-Sólápa<br>number of soil samples: 75 |     | Tác-Gorsium/Herculia<br>number of samples: 55 |      | Szabadbattyán-Péterbánkút-dűlő<br>number of samples: 1 |      |
|--|---|----|---|-----|---|------|--|------|
|  | %   | n  | %   | n   | %   | n    | %  | n    |
| Fabaceae   | 2.38  | 1  | 0   | 0   | 0   | 0    | 0  | 0    |
| Fallopia convolvulus/black-bindweed                  | 0   | 0  | 0   | 0   | 0.02  | 1    | 0  | 0    |
| Lamiaceae  | 0   | 0  | 0   | 0   | 0.02  | 1    | 0  | 0    |
| Medicago sp./medick                                  | 2.38  | 1  | 0   | 0   | 0   | 0    | 0  | 0    |
| Poaceae  | 0   | 0  | 0.60  | 2   | 0   | 0    | 0  | 0    |
| Polygonaceae   | 2.38  | 1  | 0   | 0   | 0   | 0    | 0  | 0    |
| Rumex crispus/obtusifolius/sorrel                    | 0   | 0  | 0   | 0   | 0   | 0    | 0.03   | 1    |
| Sambucus ebulus/dane weed                            | 4.77  | 2  | 0   | 0   | 0   | 0    | 0  | 0    |
| Trifolium sp./Trigonella procumbens/clover/fenugreek | 0   | 0  | 0   | 0   | 0   | 0    | 0.03   | 1    |
| Vicia ervilia/bitter vetch                           | 0   | 0  | 0   | 0   | 8.12  | 418  | 0  | 0    |
| Vicia tetrasperma/smooth vetch                       | 0   | 0  | 0   | 0   | 0.02  | 1    | 0  | 0    |
| Total number   | 100   | 42 | 100   | 331 | 100   | 5150 | 100  | 3242 |

At Balatonfőkajár-Sólápa (Fig. 7, Tab. 4), we identified the largest amount of cereals (*Cerealia*). Among the identifiable species, common wheat (*Triticum aestivum*) had the largest number (17 pieces, 5.14%). The quantity of spelt (*Triticum spelta*), barley (*Hordeum vulgare*) and emmer (*Triticum dicoccum*) was 3–3–3 (0.91%–0.91%–0.91%). We also found 1 millet grain (*Panicum miliaceum*). Weeds were negligible and included corn cockle (*Agrostemma githago*), white goosefoot (*Chenopodium album*), maple-leaved goosefoot (*Chenopodium hybridum*) and barnyardgrass (*Echinochloa crus-galli*). In addition, we found bedstraw (*Galium* sp.), Asteraceae, goosefoot (*Chenopodiaceae*) and grasses (*Poaceae* *indet.*).

The Szabadbattyán sample contained the largest amount of cereal grains (Fig. 7, Tab. 4), with 3224 residues identified. Of these, 29% were unidentified cereals (*Cerealia*), while 2259 were identified to genera or species (Tab. 4). Common wheat (*Triticum aestivum*) was the most abundant (83%), followed by rye (*Secale cereale*) (17%), barley (*Hordeum* sp.) and spelt (*Triticum spelta*) with less than 1%. The proportion of weeds at the site was not significant (Fig. 7, Tab. 4), but the remains of corn cockle (*Agrostemma githago*), sorrel (*Rumex crispus/obtusifolius*), brome-grass (*Bromus secalinus/arvensis*), hares ear (*Buplerum rotundifolium*), goosefoot (*Chenopodium* sp.) and clover/fenugreek (*Trifolium* sp./*Trigonella procumbens*) were identified.

The carpological material of Tác was significant in both quantity and species richness. The number of identified remains was 5157 (Fig. 7, Tab. 4). The relative frequency of unidentifiable cereals was 29%. Common wheat (*Triticum aestivum*) was also dominant (24%), followed by hemp (*Cannabis sativa*) (14%) rye (*Secale cereale*) (13%) and chicory lentil (*Vicia ervilia*) (8%). We also identified can-

taloupe (*Cucumis melo*) seeds (> 6%), barley (*Hordeum vulgare*) (5%), einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*), both < 1%. If we only examine the percentage distribution of identifiable grains, the share of common wheat (*Triticum aestivum*) is slightly higher than 56%, that of rye (*Secale cereale*) over 30%, that of barley (*Hordeum vulgare*) is slightly over 12% and that of emmer (*Triticum dicoccum*) and einkorn (*Triticum monococcum*) is less than 1%.

#### <sup>14</sup>C dating, pollen analysis and statistical analyses of Lake Balaton Radiocarbon dating *Radiocarbon dating*

The BACON age-depth modelling indicated 4 dates as outliers, while most of the plant remains and charcoal particles gave satisfactory <sup>14</sup>C ages (Tab. 5).

According to our age-depth model, the sediment section between 553 and 495 cm (4310–2445 cal BP; 2360–495 BC) is characterized by a gradual increase in the sediment accumulation (30–34 year/cm). Towards to the top of the core, the sediment accumulation was the fastest during the Holocene (between 494–465 cm, 2445–1690 cal BP; 495 BC–AD 260), with the lowest deposition time (DT) around 24 year/cm, likely indicating accelerated biogenic carbonate precipitation in the Szemes sub-basin of Lake Balaton. The deposition time between 465–430 cm (1690 and 5 cal BP; AD 260–1945) increased to an av. 48 year/cm suggesting the slow down of sediment accumulation, while the top 10 cm fresh sediment was characterized by fast sedimentation again (av. 6 year/cm between 429–420 cm).

#### *The Lake Balaton pollen record and inferred terrestrial and wetland vegetation changes in the last 3000 years*

A total of 101 pollen samples were analyzed from core Tó-34a with an average pollen sum of 680. Optimal splitting by information content identified 6 significant pollen assemblage zones in the Holocene part of the core. The following description summarizes the changes in the pollen composition and microcharcoal accumulation rate changes for the Late Holocene.

Zone LB-2 (513–463 cm, 3000–1450 cal BP, 1050 BC–AD 500) is characterized by high relative frequencies of oak (*Quercus* sp.) (29%) and beech (*Fagus* sp.) (13%) (Fig. 8). Grasses (*Poaceae*) reached av. 9%, and hazel had low values (*Corylus* sp.), missing in some samples. Other important arboreal pollen types were common alder (*Alnus glutinosa*) (av. 7%), European birch (*Betula alba*) (av. 7%), pines (*Pinus* subgenus *Diploxylon*) (av. 7%), hornbeam (*Carpinus betulus*) (av. 5%), Norway spruce (*Picea abies*) (av. 2%) and hawthorn (*Crataegus*) (av. 2%). Among the herbaceous taxa, grasses (*Poaceae*) were accompanied by mugwort (*Artemisia* sp.), nettle (*Urtica* sp.) and chenopods (*Chenopodiaceae*). Average arboreal pollen frequencies (82%) and total terrestrial pollen concentrations were quite high in this zone but showed a decreasing trend suggesting a gradual decline in forest cover. Microcharcoal accumulation rates were low (av. 1710 particles cm<sup>-2</sup>yr<sup>-1</sup>) suggesting very low regional fire activity. Palynological richness increased and varied between 24 and 40 pollen types (Fig. 8).

Among the arboreal taxa, walnut (*Juglans* sp.) started to increase at 1900 cal BP (AD 50), while common ash (*Fraxinus excelsior*) temporarily disappeared in this sub-zone. Among the herbaceous taxa, the spread of *Secale*, *Triticum/Avena*, *Cannabis/Humulus* and *Urtica* were significant between 2450 and 2150 cal BP (500–200 BC, Late Iron Age), when the relative frequencies of oak (*Quercus* sp.) and beech (*Fagus* sp.) decreased, while hornbeam (*Carpinus betulus*) started to increase at the end of the zone, at 1450 cal BP (500 AD, Migration Period) (Fig. 8).

This pollen composition is a very good indicator of changes in anthropogenic influences. Figures 8 and 9 show that the proportion of woody species decreased and that of herbaceous species increased in Late Iron Age and Roman period. Natural reforestation is visible at the beginning of the Middle Iron Age and the end of the Late Iron Age (Figs 8–9).

Tab. 5. Results of the AMS  $^{14}\text{C}$  measurements from core Tó-34a, Lake Balaton, Szemes sub-basin, Hungary.

| Depth (cm) | Lab code  | Dated material   | Conv. age (cal yr BP) | ±   | Remarks |
|------------|-----------|--|-----------------------|-----|---------|
| 465–466    | DeA-18720 | zooplankton, plant remains (>125 $\mu\text{m}$ )               | 1777                  | 33  |         |
| 492–496    | DeA-16688 | pollen extract (10–41 $\mu\text{m}$ )                          | 2347                  | 23  |         |
| 492–496    | DeA-16699 | organic fraction dominated by zooplankton (125 $\mu\text{m}$ ) | 478                   | 27  |         |
| 523–526    | DeA-18721 | zooplankton, plant remains (>125 $\mu\text{m}$ )               | 6231                  | 44  | outlier |
| 554–557    | DeA-17085 | charcoal, terrestrial plant remains (>125 $\mu\text{m}$ )      | 3882                  | 72  |         |
| 554–557    | DeA-18722 | zooplankton, plant remains (>125 $\mu\text{m}$ )               | 4575                  | 44  | outlier |
| 587        | DeA-18723 | hand-picked plant remains                                      | 5022                  | 34  |         |
| 631        | DeA-18794 | charcoal and >125 $\mu\text{m}$ organic matter                 | >40,000               |     | outlier |
| 631        | DeA-18795 | charcoal and >125 $\mu\text{m}$ organic matter                 | 5830                  | 250 |         |
| 683        | DeA-18885 | hand-picked plant remains                                      | 9420                  | 110 |         |
| 753        | DeA-18796 | hand-picked plant remains                                      | 10,630                | 450 |         |
| 760–764    | DeA-18784 | hand-picked plant remains                                      | 12,220                | 120 |         |
| 760–764    | DeA-18724 | plant remains (>125 $\mu\text{m}$ )                            | 12,268                | 71  |         |
| 760–764    | DeA-18725 | plant remains (>125 $\mu\text{m}$ )                            | 12,378                | 69  |         |
| 776        | DeA-18886 | plant remains (>125 $\mu\text{m}$ )                            | 11,870                | 160 | outlier |
| 796        | DeA-18797 | plant remains (>125 $\mu\text{m}$ )                            | 13,470                | 410 |         |

Among the green algae, *Coelastrum* showed an upward increasing trend from 30 to 70% in the LIA, followed by a decline in the Roman Period. Notable is the low frequency of other green algae that produce sporopollenin walled cells: *Botryococcus* and *Pediastrum* species (including *P. simplex*, *P. boryanum* and *P. integrum*). These algae attained the lowest frequencies during the Roman occupation (Fig. 9). This, along with the *Coelastrum* decline suggest a change in the pelagic zone at the coring point that is difficult to interpret without information on the accompanying bluegreen algae flora. Overall, this change in itself reflect decreasing pelagic habitats, and a change in the lake's trophic level. Shallowing is the most likely scenario.

The next zone (LB-1 zone; 463–421 cm, 1450–60 cal BP; AD 500–1890) was divided into two sub-zones due to remarkable changes in the pollen composition. Average arboreal pollen frequency (66%) and total terrestrial pollen concentrations decreased. Microcharcoal accumulation rates increased significantly and reached the highest values in 2012 (CE) (more than 33,100 particles  $\text{cm}^{-2}\text{yr}^{-1}$ ). Palynological richness was high (varied between 34 and 39 pollen types).

The first subzone (LB-1b zone, 463–439 cm, 1450–380 cal BP; AD 500–1570) is characterized by the high relative frequency of oak (*Quercus* sp.) (29%) and *Pinus* subgenus Diploxylon (10%). Other important arboreal pollen types were beech (*Fagus* sp.) (av. 5%), common alder (*Alnus glutinosa*) (av. 5%), hazel (*Corylus* sp.) (av. 3%), birch (*Betula* sp.) (av. 3%), juniper (*Juniperus* sp.) (av. 2%), Norway spruce (*Picea abies*) (av. 2%), elm (*Ulmus* sp.) (av. 2%) and common ash (*Fraxinus excelsior*) (av. 2%). Among the herbaceous taxa, Poaceae dominated (av. 11%), accompanied by mugwort (*Artemisia*), Chenopodiaceae, rye (*Secale* sp.) and *Cannabis/Humulus*. The relative frequencies of Brassicaceae (at 1250 cal BP; AD 700) were high (Fig. 8).

The second subzone (LB-1a zone, 439–421 cm, 380–60 cal BP; AD 1570–1890) was characterized by the high relative frequencies of oak (*Quercus* sp.) (25%) and *Pinus* subgenus Diploxylon (9%) (Fig. 8).

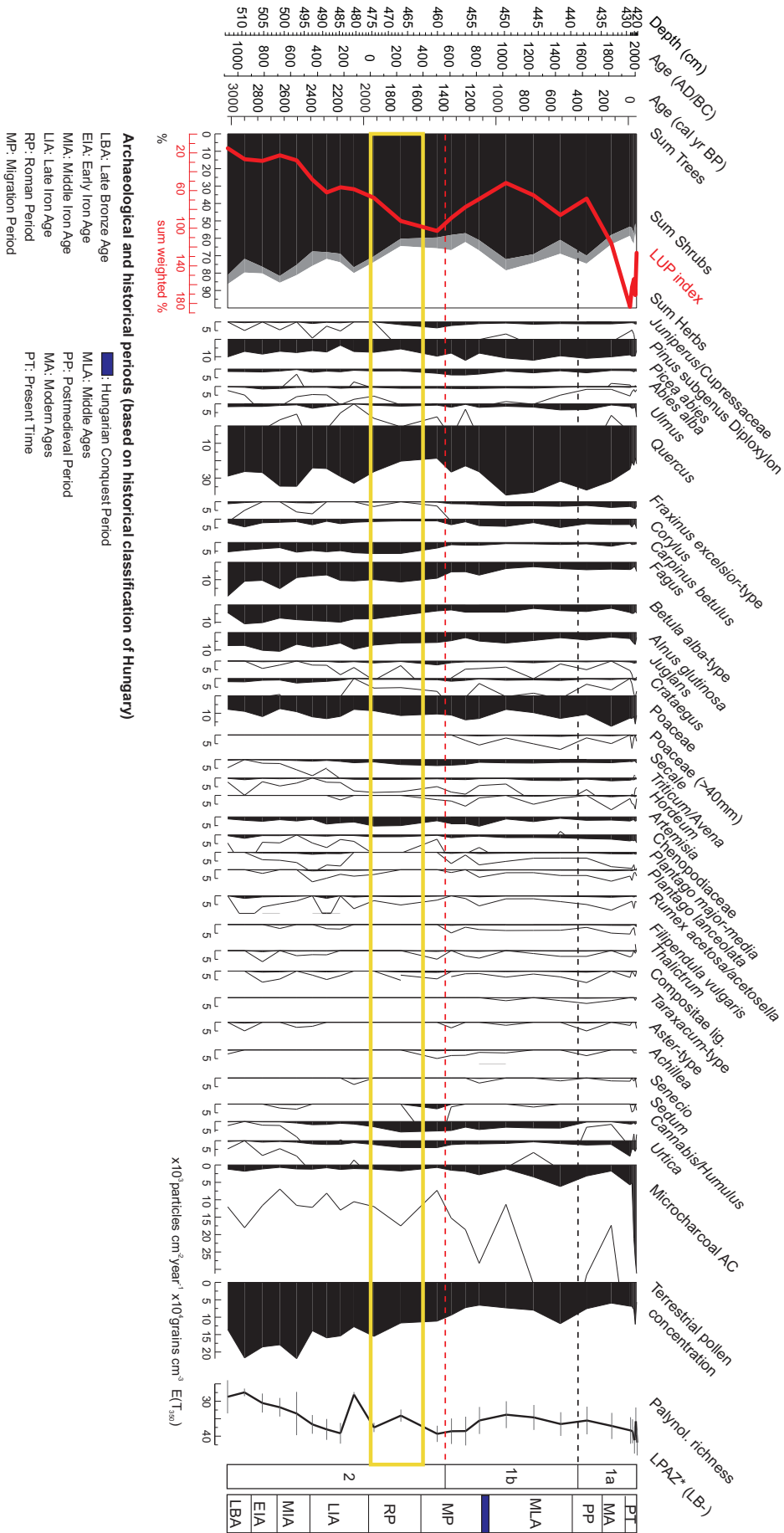


Fig. 8. Relative frequency diagram of selected pollen types and microcharcoal from Lake Balaton sediment core Tó-34a; data were plotted along depth, cal BP and AD/BC timescales; LPAZ: local pollen assemblage zones; the Roman period is highlighted in yellow.

Other important arboreal pollen types in this zone were common alder (*Alnus glutinosa*) (av. 4.5%), beech (*Fagus* sp.) (av. 4%), birch (*Betula* sp.) (av. 4%), hazel (*Corylus* sp.) (av. 3.5%), elm (*Ulmus* sp.) (av. 3%), common ash (*Fraxinus excelsior*) (av. 3%) and hornbeam (*Carpinus betulus*) (av. 1%). Among the herbaceous taxa, Poaceae (13%) dominated and accompanied by nettle (*Urtica* sp.), mugwort (*Artemisia* sp.) and Chenopodiaceae (Fig. 8). Other important herbaceous taxa were dropwort (*Filipendula vulgaris*), ribwort plantain (*Plantago lanceolata*, *Plantago major/media*) and sorrel (*Rumex* sp.). Cereals (*Secale*, *Hordeum* and *Triticum/Avena*) were important in this subzone. *Cannabis/Humulus* pollen declined from 500 cal BP (AD 1450). Oak (*Quercus* sp.) started to decrease from 320 cal BP (AD 1630), while *Cannabis/Humulus* and *Urtica* started to increase together with the microcharcoal accumulation rate values from 150 cal BP (AD 1800) (Fig. 8).

Among the green algae, *Coelastrum* characterized this pollen zone (av. 84%) accompanied with the significant increase in the relative frequencies of *Botryococcus* and *P. simplex*. Other important algae were *Botryococcus* (av. 35%), *P. simplex* (av. 18%) and *P. boryanum* (av. 13%). *Scenedesmus*, *Tetraedron*, *P. integrum* and *P. duplex* were presented in this zone (Fig. 9). Among the aquatic herbs, Cyperaceae dominated this zone (av. 3%), while reed (*Phragmites* sp.) (av. 1%) and *Sparganium/Typha* (av. 0.5%) showed low relative frequencies (Fig. 9). Eurasian watermilfoil (*Myriophyllum spicatum*) and sphagnum moss (*Sphagnum* sp.) were present in some samples (Fig. 9). Altogether these changes in the algal and wetland pollen composition indicate increasing water depth, stable medium water levels and mesotrophic conditions in Lake Balaton.

We used the values of 29 anthropogenic indicator taxa to present the land use intensity around Lake Balaton over the last 3000 years. Table 6 contains the anthropogenic indicator taxa used and their anthropogenic indicator values (AIV).<sup>122</sup> Figure 8 and Figure 9 show the change in agricultural land use probability (LUP) over the last 3000 years.

According to the diagram, the highest probability of agricultural land use is experienced from 2400 years ago (450 BC, LIA Celtic period) which amplifies until the end of the Roman period (1400 cal BP, AD 550), after which pollen inferred agricultural land use decreases until 900 cal BP (AD 1050), Migration period until the Hungarian Conquest. This is followed by land use intensification in the Middle Ages, but it only attains exceptionally high values in the Postmedieval period, after World War I (Fig. 9).

The PCA (Principal Component Analysis) diagram (Figs 9–10) provides clear evidence of vegetation changes in the natural landscape over the past 3000 years. The section corresponding to the Roman period (approximately 465–475 cm depth) indicates a marked transformation in vegetation compared to earlier periods. During this interval, the first principal component (PC1) shifts in a positive direction, reflecting an increase in landscape openness and the expansion of disturbance-tolerant taxa. The more frequent occurrence of *Rumex* sp., *Betula alba*-type, and *Corylus* suggests the proliferation of forest edges, disturbed habitats, and secondary vegetation. Simultaneously, the relative abundance of dominant forest taxa—such as *Fagus sylvatica*, *Carpinus betulus*, and *Alnus glutinosa*—declines, likely as a consequence of intensified human activities such as forest clearance and grazing. The second principal component (PC2) also displays slightly positive values, which can be interpreted as indicators of anthropogenic disturbance (e.g., grazing, tillage, and slash-and-burn practices), consistent with the appearance of cultivated and other human-related taxa. Palynological diversity remains moderate, supporting the inference of a mosaic-like, partially open landscape during the Roman period, characterized by the coexistence of various habitat types (arable fields, grasslands, woodland patches, and disturbed areas). These results reflect the transformative land-use practices of the Roman era and the gradual retreat of natural forest vegetation, which however started in the pre-Roman Celtic occupation period and intensified in the Roman period.

**Tab. 6.** Anthropogenic Indicator Taxa and their Anthropogenic Indicator Values (AIV).

| Selected pollen indicators                     | Anthropogenic Indicator Values (AIV) |
|--|--------------------------------------|
| <i>Avena</i> -type*                            | 10                                   |
| Cerealia-type*                                 | 10                                   |
| <i>Fagopyrum</i> *                             | 10                                   |
| <i>Hordeum</i> -type*                          | 10                                   |
| <i>Linum usitatissimum</i> -type*              | 10                                   |
| <i>Pisum sativum</i> *                         | 10                                   |
| <i>Secale cereale</i> *                        | 10                                   |
| <i>Triticum</i> -type*                         | 10                                   |
| <i>Vicia faba</i> -type*                       | 10                                   |
| <i>Zea mays</i> *                              | 10                                   |
| <i>Ambrosia</i> **                             | 10                                   |
| <i>Artemisia</i> **                            | 0.5                                  |
| Asteraceae subfam. Lig.**                      | 0.5                                  |
| <i>Cannabis sativa</i> -type*                  | 0.25                                 |
| <i>Castanea sativa</i> *                       | 0.25                                 |
| <i>Centaurea cyanus</i> **                     | 10                                   |
| Chenopodiaceae**                               | 0.5                                  |
| <i>Geranium</i> **                             | 10                                   |
| <i>Juglans regia</i> *                         | 2.5                                  |
| <i>Mercurialis annua</i> *                     | 10                                   |
| <i>Olea europaea</i> *                         | 10                                   |
| Papaver**                                      | 10                                   |
| <i>Plantago lanceolate</i> -type*              | 10                                   |
| <i>Plantago major</i> / <i>P. media</i> **     | 10                                   |
| <i>Polygonum aviculare</i> -type**             | 10                                   |
| <i>Rumex acetosa</i> / <i>R. acetosella</i> ** | 10                                   |
| <i>Spergula</i> / <i>Spergularia</i> **        | 10                                   |
| <i>Verbascum</i> **                            | 10                                   |
| <i>Urtica dioica</i> -type*                    | 10                                   |

\* selected by DEZA-ARAUJO *et al.* 2022.

\*\* selected by Enikő Magyari and Ilona Pál

The regional vegetation was estimated using a set of 31 pollen types. The REVEALS taxon estimates were grouped into 8 classes (Tab. 7), and the model's regional vegetation estimate for 3000 years is shown in Figure 9.

At the end of the Late Bronze Age and the beginning of the Iron Age (3000 cal BP; 1050 BC), the proportion of forests was around 73%, the percentage of open land marked by herbaceous plants was



24%, and the portion of agricultural areas (arable fields) reached a minimum total value of around 4% (Fig. 9). By the beginning of the Roman period (2000 BP; 50 BC), forest cover had decreased to 64% according to the model estimate, the proportion of open land had increased by 3%, and the size of croplands had increased by 6% (Fig. 9).

Tab. 7. Vegetation groups and associated taxa used in the REVEALS model.

| Vegetation type                    | Taxa  |
|------------------------------------|---|
| arable fields                      | <i>Cerealia</i> , <i>Secale cereale</i>   |
| eumediterranean evergreen woodland | <i>Carpinus orientalis</i> , <i>Phillyrea</i> , <i>Pistacia</i>   |
| mesophilous broadleaved forest     | <i>Alnus glutinosa</i> , <i>Fagus sylvatica</i> , <i>Fraxinus</i> , <i>Salix</i>  |
| montane needle leaved forest       | <i>Abies alba</i> , <i>Betula</i> , <i>Juniperus communis</i> , <i>Pinus sylvestris</i>                                       |
| open land                          | Amaranthaceae, <i>Artemesia</i> , Cyperaceae, <i>Filipendula</i> , <i>Plantago lanceolata</i> , Poaceae, <i>Rumex acetosa</i> |
| subalpine needle leaved forest     | <i>Calluna vulgaris</i> , <i>Picea abies</i>  |
| submediterranean woodland          | <i>Buxus sempervirens</i> , <i>Castanea sativa</i> , <i>Quercus</i> evergreen   |
| termophilous deciduous forest      | <i>Carpinus betulus</i> , <i>Corylus avellana</i> , Ericaceae, <i>Quercus</i> deciduous, <i>Tilia</i> , <i>Ulmus</i>          |

After the Roman occupation, the REVEALS model suggest continued land use without natural reforestation, but montane needle leaved forests expand in the region (Fig. 9). Land abandonment and small-scale afforestation is suggested in the Late Migration period, after the Avar occupation (~1100 cal BP; 850 AD). At this time mainly oak (*Quercus* sp.) spread.

From the 1200s AD to the 1700s AD (Ottoman period), the proportion of forest areas decreased by nearly 20%, while the percentage of open land increased, and the size of arable field was roughly constant. By the 1810s, a further 7% decrease in forest cover was observed, while the area under crop cultivation increased by more than 4% as a result of increasing grain production. In the last 100 years reforestation was observed, with the area under forest increasing by nearly 20%, while the ratio of open land to agricultural land decreased (Fig. 9).

## Discussion

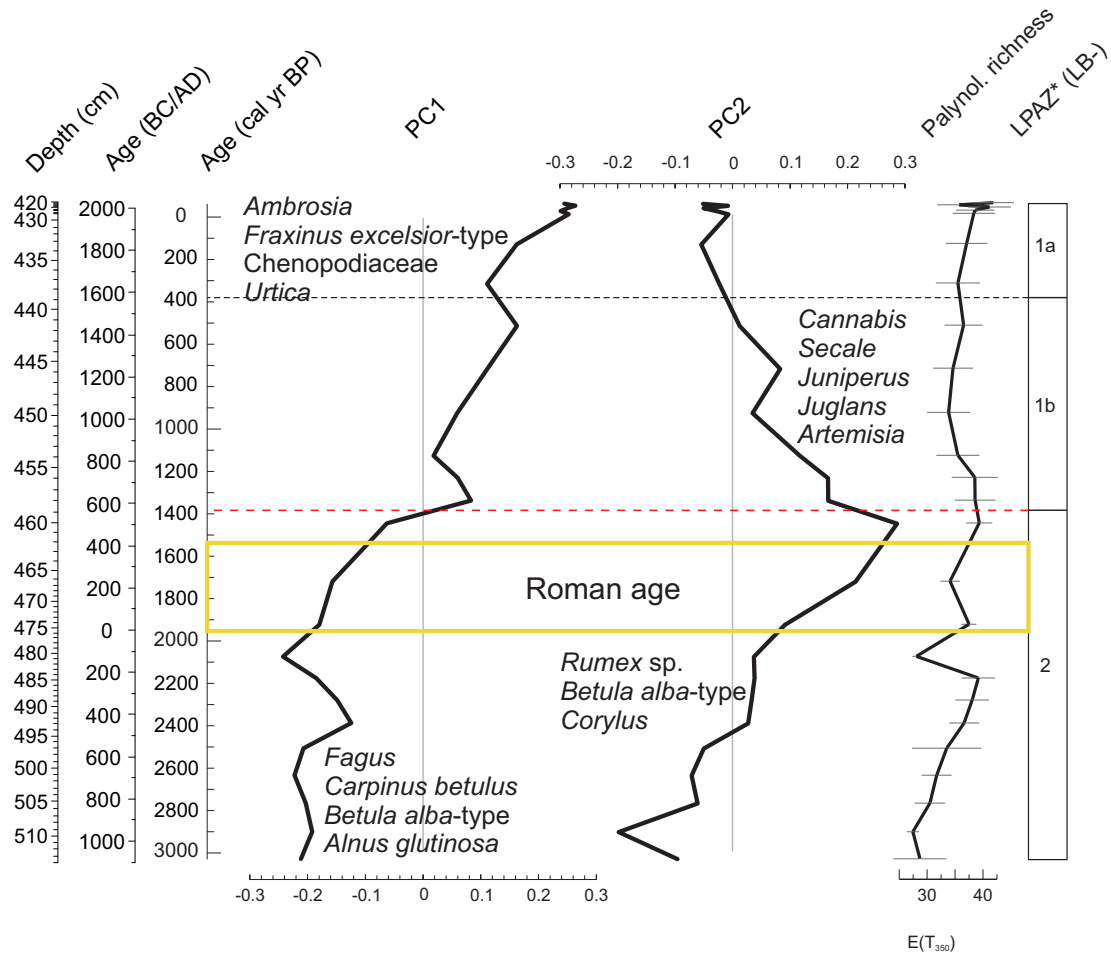
### Transformations in Roman Period land use in Pannonia inferred from the pollen record and macrobotanical remains

Limited data regarding the impact of the Romans on their environment, the correlations among pollen data,<sup>123</sup> carpological records, and charcoal analysis are available. In the present study, we aimed to show these interconnections and reveal the environmental effects of Roman activity, which influenced the natural vegetation of Pannonia—and consequently the landscape character—for several centuries.

Based on our pollen diagram from Lake Balaton (Tó-34a core) summarizing 3000 years of environmental change (Fig. 8), two significant phases of anthropogenic impact can be identified during the Iron Age, preceding the Roman period—approximately around 2900 cal BP and 2400 cal BP (950–450 BC).

123 The pollen catchment area of Lake Balaton can be interpreted as a circle with a radius of 200 km (SZÁDOVSZKY 2018, 47; MAGYARI *et al.* 2019, 2602). This area largely falls within present-day Transdanubia, meaning that our pollen data and the derived model results reflect the regional vegetation and land-cover changes of the Roman-period province.

These episodes are characterized by a decline in forest cover, accompanied by an increase in the percentage of herbaceous taxa. In both cases, the proportions of oak (*Quercus* sp.) and beech (*Fagus sylvatica*) decreased, while the relative abundance of grasses (Poaceae), mugwort (*Artemisia* sp.)—an indicator of arable farming—and *Plantago lanceolata*—a species linked to grazing and pasture expansion—showed a moderate increase. Both periods were followed by phases of natural reforestation.



**Fig. 10.** Stratigraphical plots of principal components 1 and 2 and palynological richness of core Tó-34a; data were plotted along cal BP and AD/BC timescales; the Roman period in Pannonia is highlighted in yellow.

The Roman period in Pannonia is dated approximately between 2000 and 1500 cal BP (50 BC–AD 450). During this phase, the diagram (Fig. 8) indicates regional (i.e., roughly the territory of present-day Transdanubia, the Austrian Pre-Alpine zone and northern Croatia and Slovenia) changes in land cover. From the onset of Roman rule, a gradual decline in forest cover can be observed, from 70% to around 60%, persisting until the 8th century (Migration Period), after which a natural reforestation trend emerges, lasting until the establishment of the Hungarian state. The intensity of Roman-era agricultural land use in Pannonia is also supported by the results of our pollen-based LUP (Land Use Probability) indices (Figs 8–9), which indicates that within the last 3000 years of the Holocene, the Roman period shows the second highest level of land use intensity, surpassed only by the modern era (from AD 1800). According to the diagram, land use intensity increased continuously from the beginning of the Roman period until the early 5th century, followed by a marked decline that lasted until the foundation of the Hungarian state. Interestingly, the LUP index suggests that the extent of arable fields during the Roman period exceeded or equalled that of the Hungarian Middle Ages.

The REVEALS model and PCA values also point to a strong anthropogenic influence beginning in the Celtic and Roman period in Pannonia (Figs 8, 9 and 10). At the beginning of the Roman era, agricultural land accounted for approximately 10% and open areas for about 28% of the landscape. From the 310s AD onward, a 1–3% increase in agricultural land is observable compared to the decline in the 3rd century. By the 6th century, arable fields had reached 11%, while the proportion of open areas stabilized around 26%. The REVEALS model data indicate a lower intensity of agricultural production than the results of the LUP index. This discrepancy can be attributed to the low pollen productivity estimates (PPE) of cereals, which influence the outcome of the REVEALS model, resulting in a smaller proportion of agricultural land cover represented in the model. Among woody taxa, the decline in oak (*Quercus* sp.) is the most pronounced (Fig. 8), with its proportion decreasing by approximately 10% from the beginning of the Roman period until the 5th century. This reduction in oak is corroborated by our anthracological results (Fig. 6, Tab. 1), as well as by data from charcoal remains and pollen analyses from other Hungarian sites.<sup>124</sup> Based on potential vegetation maps (Fig. 5) and the vegetation types identified by Marinova and Ntinou (Tab. 3), the area surrounding our study sites was originally dominated by oak (*Quercus* sp.) as the primary community-forming species, a finding that is also supported by our anthracological data, which indicate the intensive local use of this taxon and the clearance of the once likely much more extensive lowland oak woodlands (Fig. 6, Tab. 1).

A correlation can be observed between the anthracological data referring to oak from the sites (Fig. 6) and our pollen-based results for the same taxon (Fig. 8). One possible explanation is that oak possesses a wide ecological tolerance, allowing it to form part of various plant communities; another is that, due to their excellent wood structural properties, oak species are perfectly suitable for use as both construction material and fuel.<sup>125</sup>

The decrease in oak (*Quercus* sp.) during the Roman period is not unique to Pannonia; similar patterns have been documented in other Roman provinces based on pollen records and anthracological data.<sup>126</sup>

According to our pollen diagram (Fig. 8), no significant change in the proportion of beech (*Fagus sylvatica*) or hornbeam (*Carpinus betulus*) was observed during the Roman period. Among the charcoal remains (Fig. 6, Tab. 1), hornbeam (*Carpinus betulus*) appears only in very low quantities (0.87%), while beech (*Fagus sylvatica*) was present in higher proportions exclusively at the Gorsium site (15.74%). In the Roman-period pollen record from Zalavár<sup>127</sup> both beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*) are scarcely represented, and in the Roman layer at Pölöske (Zala County), their proportions remained unchanged compared to the Celtic period.<sup>128</sup> These two hardwood taxa likely also played a role in local wood use, as indicated by the pollen and anthracological data.

Our pollen data (Fig. 8) show a slight decrease in the percentage of alder (*Alnus* sp.) during the Roman period. This decline may be linked to the drainage of marshlands around Lake Balaton and the subsequent conversion of these areas into arable land.<sup>129</sup> Supporting this interpretation is the observation that the lowest proportion of alder (*Alnus glutinosa*) coincides with the highest percentages of grasses (*Poaceae*) and rye (*Secale cereale*) (Fig. 8). Alder (*Alnus* sp.) was identified in two anthracological samples—from Balatonlelle and Gorsium—at proportions of 1.7–2.26%.

124 GRYNAEUS 2001, 199–201; GRYNAEUS 2002, 208–211; JUHÁSZ 2007b, 42; JUHÁSZ 2007d, 184; NÁFRÁDI 2011, 127.

125 GENCSI – VANCSURA 1992, 226–267.

126 KALIGARIČ *et al.* 2006, 247; MENSING *et al.* 2018, 3; CASTIGLIONI – ROTTOLI 2017, 104.

127 JUHÁSZ 2007b, 42.

128 JUHÁSZ 2007d, 184.

129 SERLEGI 2009, 167.

Ash (*Fraxinus* sp.) and elm (*Ulmus* sp.) were present in low proportions in the Roman-period layer. Ash (*Fraxinus* sp.) was identified in the charcoal samples from Gorsium (4.09%), while elm (*Ulmus* sp.) appeared in the samples from Balatonfőkajár (0.29%) and Gorsium (7.30%). No significant proportional changes were observed in fir (*Abies alba*) and spruce (*Picea abies*) based on our pollen record (Fig. 8), consistent with the findings from Zalavár.<sup>130</sup> A minor decrease in *Pinus diploxylon* was observed in the Late Roman period (Fig. 8). Scots pine (*Pinus sylvestris*) was only present in the anthracological material from Gorsium, though its quantity was negligible (Fig. 6, Tab. 1).

Several additional taxa were identified in the charcoal assemblages from our study sites, each contributing less than 5%, including maple (*Acer* sp.), spindle (*Euonymus* sp.), alder buckthorn (*Frangula alnus*), Pomoideae, Prunoideae, and rowan (*Sorbus* sp.) (Fig. 6, Tab. 1). These reflect local wood use practices and the type of archaeological contexts,<sup>131</sup> and thereby offer insights into the composition of the surrounding Roman-period vegetation.<sup>132</sup>

When examining the distribution of wood taxa from previously studied Pannonian sites,<sup>133</sup> including those analyzed in this study, a high degree of concordance is found with the conclusions of Visser:<sup>134</sup> that is, the Romans primarily exploited locally available natural wood resources. Timber imports from other parts of the province or other provinces appear only in limited quantities, mostly in connection with larger urban centers—such as Gorsium/Herculia (Fig. 6, Tab. 1).<sup>135</sup>

In the 5th century AD, at the end of the Roman period, a proportional decline in most woody taxa can be observed in our results (Fig. 8). This trend is likely attributable to the historical events that brought significant changes to the province of Pannonia. This turbulent and transformative era marks the beginning of the Migration Period, which is also indicated by the presence of burnt and charred archaeological layers at sites around Lake Balaton<sup>136</sup> and by the increased concentration of microcharcoal particles in the lake sediments (Fig. 8). However, despite the considerable societal changes, land use was sustained until the Late Migration Period (including the Avar occupation), when our data suggest a considerable decline in land use that imply a population decline in Transdanubia.

In parallel with the decline in forest cover during the Roman period, our pollen record (Fig. 8) shows a continuous increase in the proportions of grasses (*Poaceae*) and rye (*Secale cereale*). Based on current carpological data, rye (*Secale cereale*) was the second most widely used cereal in Late Roman Pannonia after wheat (*Triticum aestivum*),<sup>137</sup> a pattern confirmed by our findings from the *horreum* in Szabadbattyán and from Gorsium (Fig. 7, Tab. 4).

Current data from Pannonia indicate that higher proportions of these two cereals (*Triticum aestivum* and *Secale cereale*) are primarily associated with larger urban centres.<sup>138</sup> In contrast, cereal consumption patterns at rural settlements and Roman military forts differed significantly,<sup>139</sup>

130 JUHÁSZ 2007b, 42.

131 E.g., long-term deposits (ASOUTI – AUSTIN 2005, 4).

132 See subchapter: *The environmental context of the studied sites in the Roman Period based on topography, soil characteristics, potential vegetation, and macrobotanical data.*

133 GRYNÆUS 2001, 199–201; GRYNÆUS 2002, 208–211; ŠOŠTARIĆ *et al.* 2006, 316; NÁFRÁDI 2011, 127; TOLAR 2022, 102.

134 VISSER 2021, 248.

135 VISSER 2021, 247–248.

136 MÜLLER 1996b, 93.

137 GYULAI 2010, 153.

138 GYULAI 2010, 153–155; REED *et al.* 2019, 631; REED – ROGULJIĆ 2020, 50.

139 GRÓH 2006, 55–58; ŠOŠTARIĆ *et al.* 2006, 318; ŠOŠTARIĆ *et al.* 2015, 832; GYULAI 2010, 155; KENÉZ 2014, 60; REED – ROGULJIĆ 2020, 47; TOLAR 2020, 244–247; TOŠKAN *et al.* 2022, 299.

although the specific reasons behind these intra-provincial differences remain unclear. Further complex archaeological and scientific analyses will be required to understand them.

This proportional difference is also evident in the comparison between cereals from two rural settlements and those from an urban site and *horreum* (Fig. 7, Tab. 4). At Balatonlelle, only millet (*Panicum miliaceum*) was present, while at Balatonfőkajár, in addition to common wheat (*Triticum aestivum*), remains of millet (*Panicum miliaceum*), barley (*Hordeum vulgare*), spelt (*Triticum spelta*), and emmer (*Triticum dicoccum*) were found in similar proportions. Rye (*Secale cereale*) was not found at either site. Current research explains the use of ancient cereals as a food source through the traditions of the indigenous (Celtic and Pannonian) populations.<sup>140</sup> However, a comprehensive interpretation must also consider the population's social status, the geomorphological characteristics of the cultivated area, applied agricultural technologies, intended uses of the products, and the settlement's role and function within trade and military provisioning networks.<sup>141</sup>

The approximately 5% proportion of barley (*Hordeum vulgare*) found in the samples from TÁC-Gorsium/Herculia may indicate its use as animal fodder, in addition to its role as a food and beverage source for humans.<sup>142</sup>

Although no grapevine (*Vitis vinifera*) seeds were found at the investigated sites, pollen of *Vitis* sp. was identified in the section of core Tó-34a<sup>143</sup> corresponding to the Early Roman period.<sup>144</sup> However, this taxon was no longer observed in the layers dated to the Late Roman period. The Early Roman values obtained are approximately similar to those from the 19th century, suggesting that the Romans may have already cultivated grapevines in Pannonia as early as the 1st century AD.

In addition to cereals, the macro-botanical assemblage from the TÁC-Gorsium/Herculia site contained notable amounts of melon (*Cucumis melo* – 6.48%), bitter vetch (*Vicia ervilia* – 8.10%), and hemp (*Cannabis sativa* – 14.49%) (Fig. 7, Tab. 4). According to the literature, melon (*Cucumis melo*) has only been reported from a few Roman sites in Pannonia to date melon. The presence of melon (*Cucumis melo*) during the Roman period has also been demonstrated through archaeobotanical remains from other provinces, including Lusitania,<sup>145</sup> Gaul,<sup>146</sup> Italy,<sup>147</sup> and parts of Germania.<sup>148</sup> Bitter vetch (*Vicia ervilia*) appears in the Carpathian Basin from the Middle to Late Bronze Age<sup>149</sup> and was used during the Imperial period as a high-protein food source. Its presence may indicate the existence of Roman-era household garden cultivation.<sup>150</sup>

In the pollen sequence from core Tó-34a attributed to the Roman period (Fig. 8), the percentage of *Cannabis/Humulus* is higher compared to other periods, which is in agreement with an increase in settlement density<sup>151</sup> and the intensive cultivation of hemp (*Cannabis sativa*) in Pannonia, as also evidenced by our carpological finds from Gorsium/Herculia/TÁC (Fig. 7, Tab. 4) and a current

140 GYULAI 2010, 155; REED – ROGULJIĆ 2020, 39.

141 SIMON 2019, 119–123; REED – ROGULJIĆ 2020, 50–52.

142 GYULAI 2010, 154; KENÉZ 2014, 60, 62.

143 *Vitis* sp. is not shown in Fig. 8

144 The pollen of *Vitis vinifera* and *Vitis sylvestris* is difficult to distinguish from one another.

145 Present-day Portugal (TERESO *et al.* 2025, 6–9).

146 Present-day France (WIETHOLD – SCHAAL 2019, 83).

147 BOSI *et al.* 2023, 9.

148 A part of present-day Germany (KREUZ 2005, 179, 229).

149 GYULAI 2010, 434.

150 KENÉZ *et al.* 2015, 205.

151 UJVÁROSI 1973, 659.

pollen-based review of several pollen records from East-Central Europe.<sup>152</sup> Pannonian hemp cultivation is further supported by the fact that the widespread diffusion of this plant species across Europe occurred during the Roman Empire and the Early Middle Ages.<sup>153</sup>

The rise in the percentage of mugwort (*Artemisia* sp.) in our pollen sequence from the onset of the Roman period reflects the intensification of anthropogenic impact on the Pannonian landscape, with this elevated proportion persisting throughout the entire period (Fig. 8). Similarly significant is the proportion of nettle (*Urtica* sp.) (Fig. 8), which is typically associated with the expansion of human settlements and increased manuring.<sup>154</sup> The proportion of goosefoots (*Chenopodiaceae*) is also higher in the Roman Imperial period than in the preceding or subsequent phases, indicating—as with *Artemisia*—the enlargement of cultivated and grazed areas. Remains of goosefoots (*Chenopodium album*, *Chenopodium hybridum*) were identified at all examined sites except Gorsium (Tab. 4).

In the case of both woody and herbaceous plants, our pollen data show a strong correlation with the anthracological and carpological results. Thus, when supplemented in the future with geomorphological, soil, and potential vegetation data of the investigated sites, as well as macro-botanical remains interpreted in an appropriate archaeological context, our pollen data may provide a solid foundation for the analysis of the local environment of archaeological excavations.

At the investigated sites, several weed taxa were also identified (Tab. 4), including corncockle (*Agrostemma githago*), blue woodruff (*Asperula arvensis*), catchweed bedstraw (*Galium aparine*), stickwilly (*Galium spurium*), smooth vetch (*Vicia tetrasperma*), hare's ear (*Bupleurum rotundifolium*), barnyard grass (*Echinochloa crus-galli*), black-bindweed (*Fallopia convolvulus*), brome (*Bromus arvensis/Bromus secalinus*), sorrel (*Rumex crispus/R. obtusifolius*), and dane weed (*Sambucus ebulus*).

The presence of *Agrostemma githago*, Rubiaceae, *Vicia tetrasperma*, and *Bromus arvensis/Bromus secalinus* indicates autumn-sown cereals,<sup>155</sup> while *Echinochloa crus-galli*, *Fallopia convolvulus*, and *Bupleurum rotundifolium* are associated with spring-sown cereals.<sup>156</sup> Among perennial weeds, *Rumex crispus/R. obtusifolius* and *Sambucus ebulus* were identified; these taxa typically grow along roadsides, in fallow areas, and on embankments—generally in well-watered environments.<sup>157</sup>

The small number of weed taxa recovered from the sites does not allow us to determine whether Roman agricultural techniques were intensive or extensive. However, the ecological characteristics and growth dynamics of these weed species<sup>158</sup> offer insight into Roman-era agricultural practices in Pannonia and contribute to the understanding of the local environment. Based on these data and the literature,<sup>159</sup> it is likely that in Pannonia, cereals were harvested high up, directly under the ears. The low weed frequency may point to an advanced level of Imperial-period agricultural technology.<sup>160</sup>

152 OFOSU *et al.* 2025; PÁL *et al.* 2025, 15. Pollen of hemp (*Cannabis sativa*) cannot be distinguished from that of hop (*Humulus lupulus*). However, an increase in the relative frequency of *Cannabis sativa* pollen in pollen diagrams corresponds with the rising proportions of cultivated crops (*Avena*, *Hordeum*, *Secale*, *Triticum*) and certain weeds (*Centaurea cyanus*, *Scleranthus annuus*, *Plantago lanceolata*), which indicate the cultivation of this plant species (OFOSU *et al.* 2025, 762).

153 MERCURI *et al.* 2002, 272; MCPARTLAND *et al.* 2018, 646; LECHTERBECK – RÖSCH 2021, 126; RULL 2022, 8–10.

154 UJVÁROSI 1973, 661–662.

155 UJVÁROSI 1973.

156 UJVÁROSI 1973.

157 UJVÁROSI 1973.

158 PINKE – PÁL 2005, 159.

159 PINKE – PÁL 2005, 46–48.

160 PINKE – PÁL 2005, 44, 46; UJVÁROSI 1973.

Considering the ecological traits and occurrence patterns of the weed taxa we identified, and in light of macro-botanical data from Germany,<sup>161</sup> it is plausible that the Romans in Pannonia also applied crop rotation, fallowing, and meadow management in their agricultural systems.

The increase in *Coelastrum* algae species in Roman times and the stagnation of *Pediatrum* and *Botryococcus* species may indicate a change in the Roman climate, an increase in anthropogenic influences (increase in agricultural land, deforestation) and changes in environmental conditions such as a decrease in water depth and a deterioration in oxygen levels.<sup>162</sup> This requires further research, which does not exclude the possibility that the Romans may have controlled the waters of Lake Balaton from the 4th century AD.<sup>163</sup>

The environmental context of the studied sites in the Roman Period based on topography, soil characteristics, potential vegetation, and macrobotanical data

The site of Balatonlelle-Rádpusztá, which was continuously inhabited for several centuries during the Roman period, is located at the foot of a gently sloping hillside within the north–south oriented Somogytúr–Orci meridional valley, approximately 1.5 km from the modern shoreline of Lake Balaton and in the immediate vicinity of the Tetves Stream to the west. Among the 176 identified anthracological remains, two woody taxa were identified (*Alnus* sp., *Quercus* sp.), with oak (*Quercus* sp.) accounting over 98% of the assemblage, while alder (*Alnus* sp.) represented less than 2%. Based on the genetic soil types of the site (Fig. 4.1), Zólyomi's vegetation map (Fig. 5.1), topographic conditions, and the ecological characteristics of oak (*Quercus* sp.), this taxon may have originated from the first alluvial, marshy environments near Lake Balaton and the Tetves Stream (RWM), or it may have been collected from turkey oak and sessile oak woodlands (TO), hornbeam–oak forests in hill regions (MHO), or even from Illyrian karst forests (IDO) at elevations above 150–200 metres (Fig. 5.1). The presence of alder (*Alnus* sp.) in the assemblage strongly suggests that carr woodlands (SWF) may also have been present near the site during the Roman period (Fig. 5). It is highly likely that the forest cover around Balatonlelle was not entirely closed during the Roman period, despite the fact that the topographic conditions would have offered limited areas suitable for cultivation, primarily Chernozem-brown forest soils (CHBF) and Ramann-type brown forest soils (RFS) (Fig. 4.1).

Among the identifiable cereals, only a small quantity of millet (*Panicum miliaceum*) was found (Fig. 7, Tab. 4), a species sown in modern agricultural practice after the soil warms up, typically around May.<sup>164</sup> Based on the ecological requirements of millet and the environmental conditions of the site, the species was likely cultivated locally. However, the composition of weed taxa identified from the site (*Asperula arvensis*, *Galium aparine*, *G. spurium*) suggests that autumn-sown cereals were likely grown near the settlement during the Roman period.

The Balatonfőkajár-Sólápa site is situated on a small elevation approximately 1 km from the present-day Bürkös-rét Stream and approximately 2.5–3 km from Lake Balaton. The soils in the immediate vicinity are predominantly meadow chernozem (MCH), pseudomyceliar chernozem (PCH), and lowland chernozem (LCH), all of which are highly suitable for agricultural use (Fig. 4.2). Over 98% of the more than 1000 identified anthracological remains belong to the oak genus (*Quercus* sp.). Four other taxa were also identified: one specimen of alder buckthorn (*Frangula alnus*), three elms (*Ulmus* sp.), seven beeches (*Fagus sylvatica*), and eight individuals belonging to the *Prunoideae*. Their proportions were considerably lower than that of oak (*Quercus* sp.). According to the poten-

161 KREUZ 2005, 241.

162 JANKOVSKÁ – KOMÁREK 2000.

163 SERLEGI 2009, 167; VAJDA 2014, 53–55.

164 ANTAL 1996, 356.

tial vegetation map, the dominant vegetation around the site in the Roman period was likely loess oak forest with Tatar maple (Fig. 5.2). Based on the ecological characteristics of oak (*Quercus* sp.), the wood may have originated from the floodplain of the stream or Lake Balaton, or from higher elevation hillsides. The alder buckthorn (*Frangula alnus*) indicates open, early successional alluvial environments.<sup>165</sup> Elm (*Ulmus* sp.), like oak (*Quercus* sp.), may have been derived from floodplain forests (*Ulmus laevis* and *U. minor*) or from upland woodlands (*Ulmus minor*).<sup>166</sup> The presence of beech (*Fagus sylvatica*) in the assemblage suggests that it may have originated from the nearby mid-mountain region, such as the modern Bakony Mountains or was an admixture in the local oak woodland. The occurrence of Prunoideae, like oak (*Quercus* sp.) and elm (*Ulmus* sp.), may indicate both wetter and drier habitats.<sup>167</sup>

It is highly probable that the forested areas surrounding the Roman-period site at Balatonfőkajár were not completely closed, because the surrounding soils were particularly well-suited for cereal cultivation. Few carpological remains were recovered from the site, with most belonging to cereals such as *Cerealia*, *Hordeum vulgare*, *Panicum miliaceum*, *Triticum aestivum*, and *T. dicoccum* (Tab. 4). The composition of the small number of weed taxa (*Agrostemma githago*, *Chenopodium album*, *Chenopodium hybridum*, *Echinochloa crus-galli*) (Fig. 7, Tab. 4) indicates both autumn- and spring-sown cereals, high-cut harvesting practices, and the presence of fallow land or human-disturbed areas around the site.

In terms of wood composition, the greatest diversity was observed at the Roman-period sites of Gorsium/Herculia/Tác, where oak (*Quercus* sp.) was the dominant taxon, accounting for 55.56% of the assemblage. A total of 15 woody taxa were identified at the study site. The following oak in frequency were beech (*Fagus sylvatica* – 15.73%) and elm (*Ulmus* sp. – 7.3%). Taxa occurring at proportions below 5% included ash (*Fraxinus* sp.), Scots pine (*Pinus sylvestris*), spindle (*Euonymus* sp.), rowan (*Sorbus* sp.), members of the *Maloideae*, silver fir (*Abies alba*), and alder (*Alnus* sp.).

Based on the ecological characteristics of the identified taxa,<sup>168</sup> the proximity of the site to today's Sárvíz stream, local microtopography, current soil maps (Fig. 4.3), and Zólyomi's reconstructed vegetation cover (Fig. 5.3), the following vegetation types likely existed in the immediate vicinity of the site during the Roman period.

Along the watercourses, on peaty meadow soils (PMS), alder (*Alnus* sp.), Hungarian ash (*Fraxinus angustifolia* ssp. *pannonica*), and willow species (*Salix* sp.) may have dominated. On the slightly elevated meadow alluvial meadow soils (MAMS), meadow solonchets (MSO), and peats (PE), the characteristic vegetation likely consisted of oak–ash–elm gallery forests. The key species in this association were pedunculate oak (*Quercus robur*), Hungarian ash (*Fraxinus angustifolia* ssp. *pannonica*), and two elm species: *Ulmus laevis* and, in higher-lying areas, *Ulmus minor*. Other species that may have appeared as companions in this assemblage include field maple (*Acer campestre*), white poplar (*Populus alba*), European aspen (*Populus tremula*), and both white and crack willow (*Salix alba*, *S. fragilis*). Among the lower-growing tree species, in more open or edge habitats, members of the *Pomoideae* subfamily such as crab apple (*Malus sylvestris*) and wild pear (*Pyrus pyraeaster*), as well as bird cherry (*Padus avium*), were likely present. The shrub layer may have included European spindle (*Euonymus europaeus*), blackthorn (*Prunus spinosa*), and both single-seeded and midland hawthorn (*Crataegus monogyna*, *Crataegus laevigata*).<sup>169</sup>

165 MAJER 1968, 390; GENCSI – VANCSURA 1992, 636.

166 MAJER 1968; GENCSI – VANCSURA 1992.

167 MAJER 1968; GENCSI – VANCSURA 1992.

168 MAJER 1968; GENCSI – VANCSURA 1992.

169 BÖLÖNI *et al.* 2007.

The hardwood gallery forest likely also contained the low-growing Tatar maple (*Acer tataricum*), which became more dominant at higher elevations on calcareous chernozem soils (PCH, LCH) and meadow chernozems (MCH), forming part of the loess oak forest with Tatar maple (SOT) association. Other typical tree species in this vegetation type included sessile oak (*Quercus petraea*), Turkey oak (*Quercus cerris*), pedunculate oak (*Quercus robur*), and downy oak (*Quercus pubescens*), along with field maple (*Acer campestre*), field elm (*Ulmus minor*), and wild pear (*Pyrus pyraster*). The shrub layer likely consisted of single-seeded hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), and, along the edges of the forest type, dwarf cherry (*Cerasus fruticosa*).<sup>170</sup>

In the higher, drier parts of the meadow alluvial and peat soils (MAMS, PE) north of the stream, the presence of sandy oak forests and sand steppe vegetation (SOS) during the Roman period is also plausible. The key species of this type was pedunculate oak (*Quercus robur*), while along moister transitional zones, white and European aspen (*Populus alba*, *P. tremula*), field elm (*Ulmus minor*), and rosemary willow (*Salix rosmarinifolia*) may have occurred. Light-demanding species like wild pear (*Pyrus pyraster*) and European spindle (*Euonymus europaeus*) also likely thrived. It is also conceivable that hornbeam–oak forests (LHO) existed within the alluvial belt, which may be supported by charred remains of hornbeam (*Carpinus betulus*) among the macro-botanical finds.<sup>171</sup>

At higher elevations, more drought-tolerant species may have dominated, forming a transitional zone toward the Tatar maple–loess oak forest (SOT). In this band, species such as Turkey oak (*Quercus cerris*), downy oak (*Quercus pubescens*), blackthorn (*Prunus spinosa*), and single-seeded hawthorn (*Crataegus monogyna*) could be expected.<sup>172</sup>

The small number of hornbeam (*Carpinus betulus*) remains among the macro-botanical finds may have originated from the hornbeam–oak forests (LHO) near the site, while the relatively large quantities of beech (*Fagus sylvatica*) suggest a provenance from the hilly regions of the Pannonian domain, such as the present–day Bakony or Vértes Mountains. Given its ecological plasticity across various topographies, Scots pine (*Pinus sylvestris*), might have also grown near the site in the Roman period.<sup>173</sup> In contrast, silver fir (*Abies alba*) and spruce (*Picea abies*) were likely imported from the higher western regions of the Pannonia province or even from more distant areas, based on literary and ecological evidence.<sup>174</sup> Rowan trees (*Sorbus aria*, *Sorbus domestica*), which prefer light and warmth, typically grow in loosely closed oak forests or along forest edges. Such forest types likely existed near the site in the Roman period, particularly in the area of present-day Kőszárhegy, which may also have been the source of the limestone building materials used in Gorsium/Herculia and Szabadbattyán.

The forests surrounding the cities of TÁC–Gorsium/Herculia were likely not entirely closed during the Roman period, given the presence of soils highly suitable for agriculture. Forest density and openness likely fluctuated over the nearly five centuries of Roman occupation, influenced by historical developments. Based on the composition of plant taxa and the presence of 11 metal tools (axes, hatchets, and brush-clearing knives) associated with woodworking found during excavations,<sup>175</sup> it is reasonable to assume that most of the wood was sourced from the nearby forests, which supports the observations made by Visser.<sup>176</sup>

170 BÖLÖNI *et al.* 2007.

171 BÖLÖNI *et al.* 2007.

172 BÖLÖNI *et al.* 2007.

173 GENCSI – VANCSURA 1992, 149–151.

174 MAJER 1968, 133–137, 171–174; GENCSI – VANCSURA 1992, 114–116, 120–126.

175 RUPNIK 2014, 246.

176 VISSER 2021, 247–248.

At the Szabadbattyán-Péterbánkút-dűlő site, three oak (*Quercus* sp.) wood remains were identified. Due to geomorphological characteristics, the scale of the villa economy, and the site's proximity to the TÁC-Gorsium/Herculia Roman towns, the surrounding environment was likely very similar to that of the Roman city.

The two latter sites are located approximately 5–6 km apart, with similar topographical features, both situated in close proximity to the present-day SÁRVÍZ River. According to the genetic soil map (Fig. 4.3), both sites are surrounded by large areas of arable land that is highly suitable for agriculture. The significant number of recovered cereal and other cultivated plant remains, the presumed extensive area of the Szabadbattyán villa estate, and the Roman-era size of the TÁC-Gorsium/Herculia city<sup>177</sup> all support the assumption that intensive agricultural production occurred around both the Szabadbattyán villa estate and the TÁC-Gorsium/Herculia military camp and towns in the Roman period.

This is further supported by the remains of various cereals (*Cerealia*, *Hordeum vulgare*, *Secale cereale*, *Triticum aestivum*, *T. spelta*, *T. dicoccum*, *T. monococcum*), melon (*Cucumis melo*), and bitter vetch (*Vicia ervilia*), as well as the high number of agricultural tools found at the TÁC-Gorsium/Herculia excavations.<sup>178</sup> These include socketed, blade-shaped ploughshares, plough chains, goads, spades, shovels, open-socket sickles, and sickles,<sup>179</sup> as well as weaving beaters used in textile production for making sacks to store and transport grain.<sup>180</sup> The presence of hemp (*Cannabis sativa*) in our sample may also indicate sack-making and the potential for waterborne transport.

The scale of agricultural production and the full spectrum of cultivated plant species at both sites are not yet fully understood. However, previous research in Pannonia suggests that the Romans most likely cultivated the required cereals locally.<sup>181</sup> It is presumed that cereal exportation only began in the third century CE, coinciding with the draining of wetlands, land clearance, and the emergence of large estate systems.<sup>182</sup> According to Simon,<sup>183</sup> grain imports were probably only necessary during wartime within the Pannonian province. Based on Western European data,<sup>184</sup> and in the absence of comprehensive data from Pannonia, it cannot be ruled out that villa estates, vici, and city districts in Pannonia may have specialized in the cultivation of particular crops.

It is also certain that there was vibrant commercial exchange between the Szabadbattyán and TÁC-Gorsium/Herculia sites during the Roman period, as both were located alongside major Roman road networks<sup>185</sup> and the present-day SÁRVÍZ River. The SÁRVÍZ connected with the Danube and the southern Transdanubian water system (Kapos, Koppány, Kis-Koppány, Jaba Stream, Cinca-Csíkgát Stream), and possibly even with Lake Balaton, providing a potential route for transporting goods via waterways.<sup>186</sup> No definitively imported seeds or fruit remains were found in the analyzed samples from either site, thus further macrobotanical evidence and ceramic data are required to determine possible trade routes.<sup>187</sup>

At the TÁC-Gorsium/Herculia site, few weed species were identified (Tab. 4), which may reflect the thorough winnowing of Roman seed stock and the effectiveness of mechanical weeding.<sup>188</sup>

177 45 hectares; FITZ 1996, 20.

178 RUPNIK 2014.

179 RUPNIK 2014.

180 RUPNIK 2014, 246.

181 SIMON 2019, 119; REED *et al.* 2022, 371.

182 PALÁGYI 2003, 238–239; SERLEGI 2009, 167.

183 SIMON 2019, 208.

184 REED *et al.* 2019, 624.

185 FITZ 1996, 15; NÁDORFI 2007, 172.

186 PÁSZTÓKAI-SZEŐKE – SERLEGI 2013, 71.

187 REED – ROGULJIĆ 2020, 56.

188 PINKE – PÁL 2005, 46.

We identified remains of three species (*Agrostemma githago*, *Fallopia convolvulus*, *Vicia tetrasperma*) and one taxon at family level (*Lamiaceae*). These taxa suggest both autumn and spring sowing of cereals and indicate a high cutting height during harvest.<sup>189</sup>

At the Szabadbattyán-Péterbánkút-dűlő site, six weed taxa were identified (*Agrostemma githago*, *Bromus arvensis*/*Bromus secalinus*, *Bupleurum rotundifolium*, *Chenopodium* sp., *Rumex crispus*/*Rumex obtusifolius*, *Trifolium* sp./*Trigonella procumbens*), with a total of 38 weed remains recorded (Tab. 4). These indicate the presence of both autumn- and spring-sown cereals, fallow and wetter areas, and leguminous species that may have been used for fodder in the surrounding environment. Similar to other sites, the growth habit of these weed species suggests harvesting took place at a relatively high cutting height.

## Conclusion

As in other parts of Europe, the Roman occupation of Pannonia brought about significant political, social, and economic changes in the lives of the region's fragmented Celtic and Pannonian indigenous communities. Our scientific findings, in addition to other palynological,<sup>190</sup> carpological<sup>191</sup> and anthracological<sup>192</sup> data, as well as archaeological artefacts,<sup>193</sup> suggest that intensive land use and agricultural activity had already begun in the Celtic period continued and intensified throughout the Roman era in the province of Pannonia.<sup>194</sup>

This intensive land use is clearly reflected in our pollen-based analyses. The results indicate a significant decline in forest cover during this period, particularly in the abundance of oak (*Quercus* sp.), and a parallel increase in agricultural land use. This trend is supported by PCA and high LUP index values, the REVEALS model, and the increasing proportions of cultivated crops and weed taxa associated with arable farming (*Secale*, *Artemisia*, *Chenopodiaceae*).

Our anthracological data from several sites corroborate the pollen analysis findings, showing extensive use of oak wood (*Quercus* sp.). The reasons for this can be traced to the fact that species of the genus oak (*Quercus* sp.) possess a wide ecological tolerance, allowing them to occur in various plant communities. Furthermore, due to their excellent wood structural properties, oak species (*Quercus* sp.) are perfectly suitable for use as both construction material and fuel.<sup>195</sup>

Moreover, our charcoal analysis revealed differences in wood usage practices between rural settlements and urban centers. In the two Roman vicus, oak accounted for more than 98% of the identified wood taxa, whereas in the urban site it was significantly lower, around 56%. Additionally, the urban wood assemblage was richer and more diverse compared to that of the vicus. These results indicate that in Pannonia, the Romans primarily exploited locally available wood resources.

While this was consistently the case in the vicus, urban centers show evidence of limited timber importation from more distant areas of the province or even other provinces (e.g., *Picea* sp., *Abies* sp.).<sup>196</sup> The identified taxa (*Frangula alnus*, *Pomoideae*, *Sorbus* sp.) and the agriculturally favorable

189 UJVÁROSI 1973; PINKE – PÁL 2005.

190 JUHÁSZ 2007b.

191 DÁLNOKI – JACOMET 2002; GYULAI 2010.

192 RUDNER 2007.

193 RUPNIK 2014.

194 JUHÁSZ 2007b; RUPNIK 2014.

195 GENCSI – VANCSURA 1992, 226–267.

196 In the case of the mentioned tree species, importation is assumed based on their ecological characteristics (GENCSI – VANCSURA 1992, 115, 122–125) and the potential vegetation maps (Fig. 5).

soils surrounding the sites, combined with our palynological record, suggest the presence of human-managed open woodland landscapes in the vicinity of the settlements.

The large quantities of cereal remains reflect, consistent with our pollen-based results, large-scale agricultural production during the Roman period. All studied sites were located in agriculturally optimal areas, with fertile soils and proximity to water sources. The macro-botanical evidence from the granary at Szabadbattyán and the city of TÁC-Gorsium/Herculia indicates a shift in cereal composition compared to the Celtic period,<sup>197</sup> with common wheat (*Triticum aestivum*) and rye (*Secale cereale*) becoming dominant in the Late Roman period. This shift was observed in both the granary and urban contexts. In contrast, cereal remains from the two rural settlements<sup>198</sup> were not abundant, and when compared to the grain composition of the granary and urban sites, notable differences were observed. In the vicus assemblages, alongside common wheat (*Triticum aestivum*), hulled wheats and millet (*Panicum miliaceum*)—likely linked to indigenous agricultural traditions—were identified.

At the site of TÁC, the large quantity of hemp (*Cannabis sativa*) remains, supported by our pollen analysis and literature,<sup>199</sup> suggests that hemp cultivation intensified during the Roman occupation.

The low number of weed remains points to the thorough cleaning of Roman seed stocks, effective mechanical weed control, and the use of advanced agricultural techniques. Based on the life forms and growth strategies of the identified weeds, both autumn and spring sowing practices, as well as a reaping technique targeting the base of the cereal heads, can be inferred in the areas surrounding the Roman sites.

To determine the degree of anthropogenic landscape transformation and the regional cultivation structures within the Pannonian province, further micro- and macrobotanical analyses, integrated interdisciplinary approaches (natural sciences and archaeology), and comparative studies will be required.<sup>200</sup>

Likewise, further investigations are needed to understand the causes behind the observed differences in cereal composition between rural areas, urban settlements, and military forts (including watchtowers), and to reconstruct the cultivation systems shaped by geomorphology and local agricultural practices.

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197 GYULAI 2010.

198 Balatonfőkajár and Balatonlelle.

199 MERCURI *et al.* 2002; JUHÁSZ 2007c; MCPARTLAND *et al.* 2018; LECHTERBECK – RÖSCH 2021; RULL 2022; OFOSU *et al.* 2025.

200 PESCARIN 2009; ROYMANS – DERKS 2011; FIRNIGL 2012; VAN DINTER 2013; REED 2019; SIMON 2019; REED – ROGULJIĆ 2020.

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## Archaeological database used

We managed to collect the data using the archeodatabase of the Hungarian National Museum: <https://archeodatabase.hnm.hu/hu/node/42113>

The database of the IVO system, which manages the registry of monuments and archaeological protections of the Ministry of Construction and Transport: <https://www.oeny.hu/oeny/ivo/ingatlan>

### Databases employed in the study

AGROTOPO GIS Magyarország természetes növénytakarója, ZB\_POTVEG (ESRI shape), ZÓLYOMI 1989 alapján digitalizálta Révész András a MÉTA Program keretében, <https://novenyzetiterkep.hu/node/308> (Retrieved 24 June 2024).

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