

Historical charcoal-burning mounds in the Engure area, Latvia, and their significance for the history of forest exploitation

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Abstract

The application of airborne laser scanning (LiDAR) has led to the discovery of numerous man-made mounds encircled by pits in the forests near Engure, north-western Latvia. Field survey revealed these to be historical features remaining from charcoal-burning in mound kilns. Archaeological excavation was undertaken at one of the features, along with analysis of recovered wood charcoal, dendrochronological and radiocarbon (¹⁴C) dating and archival research into documents relating to historical charcoal production in the area. All of the analysed charcoal samples are from Scots pine (*Pinus sylvestris* L.), the dominant tree species in this area.

It is concluded that the large-scale charcoal production served the needs of the ironworks operating at Engure in the 17th–18th century. The study of the charcoal-burning mounds has permitted estimation of the source area and volume of the wood supplied for charcoal production, and the period during which it was undertaken. Wood harvesting on such a scale had a significant impact on the surrounding forests and also had some effect on subsequent forest growth in the area. These findings demonstrate that features of this kind deserve to be regarded as archaeological remains of considerable research potential.

Keywords: Duchy of Courland and Semigallia, forest history, Scots pine, charcoal-burning mounds, charcoal kilns, wood charcoal

Introduction

Since it was a prolific consumer of wood charcoal prior to the use of fossil fuels, the iron industry features prominently in earlier as well as current discourse on the human activities that have promoted global deforestation (Williams 2003). In a recent overview, Iles (2016) examines the wide range of socioeconomic and forest-growth factors that need to be taken into account for a realistic assessment of the impact of historical iron production on forests and considers the contribution of archaeological research in this field in conjunction with other lines of evidence.

This discourse is highly relevant to forest history in the East Baltic region because of the past exploitation of bog ore for iron production, most notably in the 17th and 18th century in the former Duchy of Courland and Semigallia, corresponding to present-day western and southern Latvia (Jakovļeva et al. 2019). Although iron production, along with shipbuilding and other early modern industrial activities, is recognized as having drawn heavily on the forest resources of this territory (Zunde 1999), the impact

on forests has not previously been investigated in detail and has been considered exclusively on the basis of written sources. The present study, proceeding from the analysis of newly-discovered archaeological evidence, in conjunction with archival research, offers for the first time a picture of charcoal production associated with one of the Duchy's ironworking centres, seeking to gauge its impact on the surrounding forest.

Charcoal-burning sites from prehistoric as well as historical times, occurring mainly in sparsely populated, forested as well as mountainous areas across Europe, are viewed as a very important source of information on forest history (Ludemann 2012, Deforce et al. 2013). From ca. 500 BC up to the Middle Ages charcoal was produced in pit kilns, initially rectangular in layout and later circular as well; but starting from the 14th century the pit kilns were replaced by earth-covered mound kilns up to ca. 4 m in height, permitting charcoal production on a much larger scale (Deforce et al. 2021). Remains of the latter kiln type are still visible at many sites, taking the form of mounds

encircled by several pits or by a ditch, referred to as charcoal-burning mounds.

During the last two decades in particular, many areas have seen large-scale, comprehensive research on charcoal-burning sites, involving systematic survey and excavation, as well as ^{14}C dating and palaeobotanical analysis of charcoal samples. These include studies in Germany (Nelle 2003, Ludemann 2012), Belgium and the Netherlands (Deforce et al. 2013, 2021, Deforce and Draily 2019), Italy (Carrari et al. 2017), France (Bonhote et al. 2002), Poland (Rutkiewicz et al. 2017, Rutkiewicz et al. 2019) and elsewhere. In the Baltic states, the most extensive research has so far taken place in the Ropaži area of central Latvia (Guščika 2016, Guščika and Urtāns 2018, Kalējs 2020), focussing on the typology and chronology of charcoal-burning sites and the process of charcoal production, with analysis of the wood used for this purpose, identification of the source areas of the wood, etc. The historical context of the distribution of charcoal-burning sites has also been considered, particularly in relation to the development of iron smelting.

It has been demonstrated that wood charcoal analysis, in addition to providing information significant for economic history and the history of technology, can also offer major insights into forest history in the respective areas and contribute to the understanding present-day ecological processes. Accordingly, a separate research direction has emerged, aimed at assessing the impact of charcoal production on the environment and forests in the short and long term, and on the vegetation of the areas affected during the period when charcoal-burning was practiced (e.g. Bonhote et al. 2002, Nelle 2003, Ludemann et al. 2004, Deforce et al. 2013, Carrari et al. 2016).

All of the charcoal-burning mounds investigated in Latvia in previous years are located east of Riga, but in 2016 an extensive concentration of similar remains was quite accidentally discovered in the area surrounding the village of Engure, at the west coast of the Gulf of Riga, potentially offering the first archaeological evidence of historical charcoal production in this part of the country. These features were discovered as a result of airborne laser scanning (LiDAR – Light Detection and Ranging) undertaken within the frame of a national scanning programme conducted by the Latvian Geospatial Information Agency (LGIA). In the terrain model they had created from LiDAR data, revealing for the first time the detailed relief of forested areas, researchers from the Faculty of Geography and Earth Sciences, University of Latvia (FGES UL), observed in the Engure area numerous features consisting of a circular mound encircled by several pits (Figure 1). This discovery was duly reported to archaeologists at the Institute of Latvian History, University of Latvia (ILH UL).

In 2018–2021, a team from the ILH UL conducted an interdisciplinary study on the mounds of the Engure area. The initial aims were: to characterize this extensive spread of presumed charcoal-burning mounds, confirm their func-

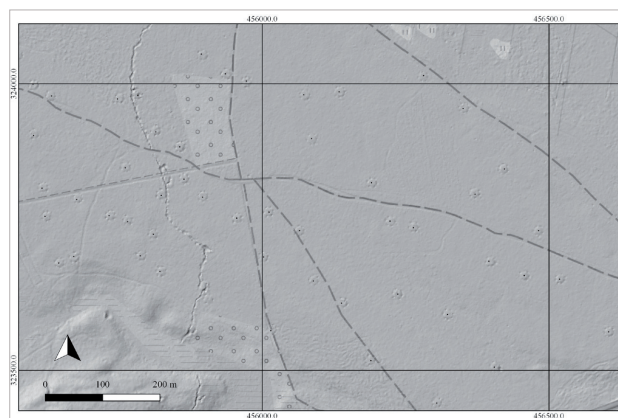


Figure 1. Charcoal-burning mounds by Apšuciems on LiDAR shaded relief image, corresponding to the Pipkaks forest area in the 18th century.

Prepared by E. Guščika; base map LIDAR HS. LIDAR DEM shaded relief mosaic, 1 m resolution, created from LGIA LiDAR data. LU ĢZZF WMS; TOPO 10 LV. LGIA scale 1 : 10,000 topographic map of the Republic of Latvia. LU ĢZZF WMS; available at: <http://www.geo.lu.lv/kartes> (accessed on 24.09.2021).

tion and establish their chronology. This work involved systematic identification of the features on the LiDAR terrain model, archaeological prospection, coring and excavation, analysis of recovered wood charcoal, dendrochronological and ^{14}C dating and study of written sources. The results of the investigation permitted the mounds to be linked to charcoal production for the Engure ironworks, operating in the years 1680–1777. Accordingly, in the further course of the study the data obtained was applied with the aim of determining the quantity of wood consumed in charcoal production for the ironworks and the impact on the area's forests.

The study area

The Engure area has been extensively researched from the perspective of settlement patterns, landscape change and human impacts (Strautnieks and Grīne 2011, Melecis et al. 2014, Kļaviņš et al. 2011), and the same area has seen studies on the structure and dynamics of Scots pine (*Pinus sylvestris* L.) forest (Laiviņš et al. 2014) and the influence of climate on pine growth (Dauškane and Elferts 2011). Pollen data indicate a high level of forest cover and a dominance of Scots pine in the Engure area already since at least the middle of the Holocene (Galenietse 1959, Kļaviņš et al. 2011, Pujāte 2015).

In the early modern period, Engure was selected as the site for one of the ironworks established in the Duchy of Courland and Semigallia (1562–1795). All in all, this ironworks was in use for about a century, from 1680 up to the early 1780s, although with interruptions and fluctuating output. The blast furnace producing cast iron as well as the hammer-works turning out bar iron and other processes demanded large quantities of fuel (Jakovļeva 2001, 2012, Jakovļeva et al. 2019). The written historical record indi-

cates that ironworking was not the only industry in Engure: there were other facilities as well, including a sawmill, a port with four warehouses and a cooper's workshop (Jakovļeva 2001). Accordingly, during the time of industrial activity at Engure, timber would also have been sourced in quite large quantities from the surrounding forests, along with fuelwood for heating buildings. It should be noted that the time of the Duchy of Courland and Semigallia coincided with a period of relatively cool climate, known as the Little Ice Age (ca. 1550–1850). In the Baltic Sea region, the longest cold period, with many harsh winters, lasted from the late 16th up to the mid-18th century (Niedźwiedź et al. 2015), affecting both tree growth and fuelwood consumption. Overall, it is clear that, starting from the late 17th century, the forests in the environs of Engure were subject to intensive human impact. Here we consider a specific portion of this impact, namely the provision of wood for charcoal production.

Material and methods

A digital terrain model with a resolution of 1 m, available on the University of Latvia VPN network (<http://kartes.geo.lu.lv/karte/>), created at the FGES UL from the LGIA LiDAR scanning data, with a point density of at least 1.5 points/m², was used to determine the distribution area of the mound features, their approximate number and key parameters, recording the coordinates of each mound.

The study of remote sensing data was followed by a survey on the ground, visually assessing the identified mound features and coring selected examples with a 3 cm diameter soil corer to reveal the internal stratigraphy. Archaeological excavation was undertaken at one of the mounds.

Recovered charcoal samples were determined taxonomically based on wood anatomical features (Schwein-gruber 1990). For this purpose, the charcoal fragments were split with a razorblade to obtain fresh fracture surfaces and examined at up to 200× magnification in reflected light using a Leica DM4500P microscope. Where the full cross-section of a charred trunk or branch was preserved in one piece, the fuelwood diameter was measured directly. In other cases only an approximate assessment of wood diameter could be obtained, based on the curvature of the outer (cambium) surface or the curvature of the growth rings, as observed in cross-section. Applying the method of Ludemann and Nelle (2002), the curvature was compared with a template, permitting five diameter classes to be distinguished: a) < 2 cm, b) 2–3 cm, c) 3–5 cm, d) 5–10 cm and e) > 10 cm.

Two of the charcoal samples extracted from the soil cores obtained from the mounds, one from Ķesterciems, and the other from Abragciems, were ¹⁴C-dated at Poznan Radiocarbon Laboratory.

Dendrochronological dating was undertaken at the ILH UL Dendrochronological Laboratory. The dating work was performed on sawn cross-sections of the charcoal samples in wet condition, bound with adhesive tape to prevent them from disintegrating. In each case, measuring paths were chosen on one of the faces of the cross-section, the paths essentially being radially oriented but deviating in places in order to avoid cracks and cavities in the charcoal surface. The charcoal surface along the measuring path, still damp and rather soft, was made very smooth using a sharp razorblade, whereby the latewood of each ring partially reflected light, while there was practically no light reflection from the earlywood, something that significantly improved the visibility of the growth ring boundary. Ring-width measurement of each charcoal sample was undertaken in two or three radial directions, in addition to which measurement was undertaken twice along each measuring path in order to reduce the influence of subjective errors on the results of comparison between the short ring-width series. Thus, three series of mean values of ring width data were used for dating, each of them compiled from ring-width data obtained in either four or six measurement cycles.

Ring-width measurement was undertaken with a precision of 0.01 mm, using a TimeTable TT59-M-100/5 (VIAS Dendrolabor 2015) tree-ring width measurement system in conjunction with the PAST5 dendro-data processing software package (Cichocki and Knibbe 2009). The COFECHA (Holmes 1983, Grissino-Mayer 2001) and SAKORE V.3 (SAKORE version 3 was created by programmer J. Eglitis in 1995 in accordance with specifications from M. Zunde) programs were used for additional assessment of the similarity between the series by cross-dating. Tree-ring width indices and their mean values for each year were calculated using the program ARSTAN (Cook and Holmes 1996).

The overall scale of wood consumption for charcoal production in the Engure area was assessed, utilizing historical records on charcoal stack volumes and fuelwood quantities required by the ironworks (documents held at the State Historical Archive of Latvia and partially published in Jakovļeva 2001) as well as the data on charcoal-burning mounds identified in the terrain model. The total volume of fuelwood consumed was compared against the mean standing volume of forest growing in similar conditions at the present day, so as to estimate the size of the area that could have provided this volume of fuelwood by clear-felling. The intention was to gauge approximately the impact of the fuelwood consumption of a single ironworks on the forest resources of the Duchy as a whole. Additionally, the intensity of forest-cutting in the environs of Engure during the time of the ironworks is characterized on the basis of several historical documents discovered in the Latvian State Historical Archive.

Results

Analysis of the LiDAR terrain model revealed ca. 1000 such features, the majority concentrated in the southern part of the distribution area (Guščika 2020, Guščika et al. 2021). The distribution of the charcoal-burning mounds identified in the environs of Engure occupies an area of the coastal lowlands between the villages of Apšuciems and Bērciems: ca. 20 km by 1.5–4 km, with a surface area of ca. 5,000 ha (Figure 2). This is an area of mainly dry forest, corresponding to the *Cladinoso-callunosa*, *Vacciniosa*, *Myrtillosa* and *Hylocomiosa* forest site types according to the Latvian forest site type classification (Liepa et al. 2014). As is characteristic of these forest site types, the dominant tree species is Scots pine (Figure 3).

The majority of the mounds are 13–15 m in diameter, but smaller examples (starting from 10 m diameter) as well as larger ones (17–18 m in diameter) also occur. The mounds were most commonly encircled by six or seven

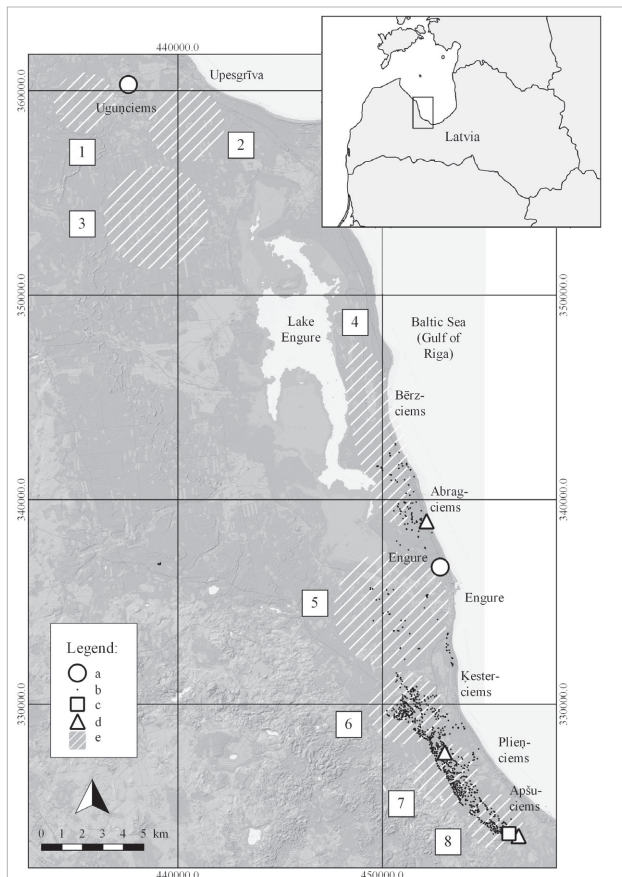


Figure 2. The research area in the environs of Engure: a – ironworks sites, b – charcoal-burning mound, c – excavation area, d – coring sites, e – forest areas mentioned in 18th-century text: 1 – Ugunčiemis, 2 – Upešgrīva, 3 – Mērsrags, 4 – Bērciems, 5 – Engure, 6 – Ķesteriems, 7 – Pliņciems, 8 – Pipkaktis.

Prepared by E. Guščika and M. Auns; base map: LIDAR HS. LIDAR DEM shaded relief mosaic, 1 m resolution, created from LGIA LiDAR data. LU ĢZZF WMS; TOPO 10 LV. LĢIA LR scale 1 : 10,000 topographic map. LU ĢZZF WMS; available at: <http://www.geo.lu.lv/kartes> (accessed on 24.09.2021).



Figure 3. Two charcoal-burning mounds in the forest landscape by Abragciems (corresponding to Bērciems forest area in the 18th century).

(Photo: E. Guščika).

pits with a width of 3–4 m, but in some cases the pits number only five or as many as 10 (Figure 1).

In order to encompass the maximum diversity of areas with the features observed in the LiDAR terrain model, they were studied on the ground at four locations: in the environs of the villages Apšuciems (two locations), between Pliņciems and Ķesteriems (further Ķesteriems), and in the vicinity of Abragciems (Figure 2). One mound in every location was cored (Latvian coordinate system LKS-92: 456238x/323635y, 456653x/323632y, 453045x/327632y, 452157x/338946y), confirming that they are indeed charcoal-burning sites. The excavation of a mound near the village Apšuciems (LKS-92: 456324x/323595y) revealed the various layers and structural elements of the charcoal-burning site. The mound chosen for excavation was, in outward appearance, a charcoal-burning mound typical of the Engure area, located within the largest concentration of such features – in the southern part of their distribution. A mound with relatively little tree cover was selected, both for practical reasons and with the expectation that the stratigraphy would be relatively little disturbed. Since previous research had indicated that the structure of charcoal-burning mounds is rather homogenous (e.g. Guščika 2016, Kalējs 2020), one quarter of the mound was chosen for excavation, providing cross-sections from the centre to the edge of the mound and incorporating two pits at the foot of the mound. An area of 59 m² was excavated.

The mound was ca. 15 m in diameter and 0.6–0.7 m high. There were seven pits around it, each ca. 5 m in diameter, visible as ca. 0.5 m deep depressions in the relief. The excavation area revealed that the mound consisted of sand layers containing numerous charcoal fragments (Figure 4) (Guščika 2020, Guščika et al. 2021). Beneath the forest soil, it consisted mainly of dark yellow-brown sand saturated with wood charcoal fragments of various sizes, the largest measuring ca. 25 × 15 cm. The charcoal-rich layer was up to 0.5 m thick. At the base of the mound, a layer of light grey sand up to 0.2 m thick was uncovered,

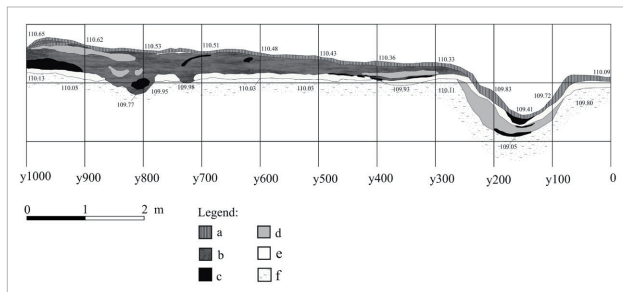


Figure 4. Archaeological excavation of a charcoal-burning mound near Apšuciems. Cross-section of half of the mound with a pit at its foot: a – forest topsoil layer, b – dark yellow-brown sand with intensive admixture of charcoal, c – very charcoal-rich areas, d – yellow sand with minor admixture of charcoal, e – light grey sand with minor admixture of charcoal fragments, f – natural subsoil. (Drawing: E. Guščika).

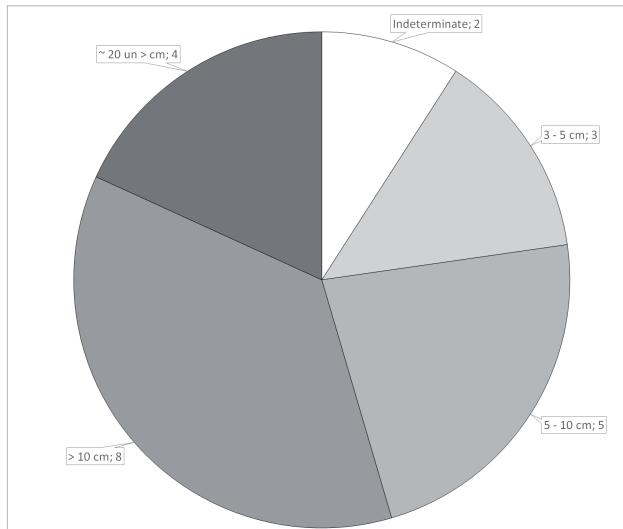


Figure 5. Classification of 22 charcoal fragments into wood diameter classes (diameter class; number of charcoal samples).

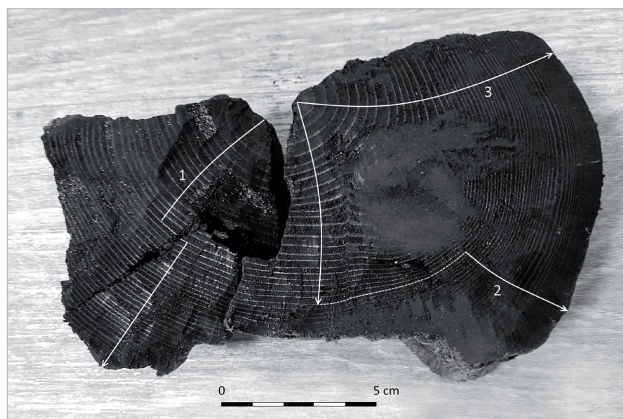


Figure 6. Wood charcoal sample 4-7.2 with three tree-ring width measurement paths on its cross-sectional surface.

with a minor admixture of wood charcoal fragments. The pits investigated around the mound reached a depth of 0.7–1 m. They were filled mainly with yellow sand, mixed with small wood charcoal fragments. In the lower parts of the pits, larger concentrations of charcoals occurred. The pits surrounding the mound probably relate to supporting structures for the stack of wood (see, e.g. Davis and Lundin 2021) and accordingly they encircle the mound almost symmetrically. Long poles could have served as the supports. Alternatively, the pits could have been dug when covering the mound with earth for controlled combustion.

All 17 of the charcoal samples from the excavated Apšuciems mound were identified as pine, indicating the dominant or exclusive use of Scots pine for charcoal production at this site. The single samples from Ķesterciems and Abragciems are likewise pine.

The estimates of wood diameter based on charcoal fragments indicate that, in the case of the excavated mound, the stack of wood for charcoal production included sections of tree trunks and branches with a diameter varying from 3–5 cm up to ca. 30 cm (Figure 5).

Three of the charcoal samples from the excavated Apšuciems mound that apparently derived from the outer part of the tree trunk had a sufficient number of tree-rings to warrant an attempt at dendrochronological dating in order to determine the absolute date. Dendrochronological dating was applied to charcoal samples 4-7.1, 4-7.2 and 4-17 (Figure 6), the first two recovered from the central part of the excavated charcoal-burning mound, and the third one from one of the pits. Sample 4-7.1 has 92 tree-rings, sample 4-7.2 has 64, and sample 4-17 has 35 rings from the outer part of the trunk. The presence of a remnant from a branch in sample 4-7.2 indicates that this sample probably comes from the trunk at crown height. Branch remains were not observed in the other two charcoal samples, suggesting that these most probably derive from the lower part of the trunk. This difference may partially explain the difference in the number of rings between samples 4-7.1 and 4-7.2.

Comparison of the repeated ring-width measurements along the same measuring path showed that in the two ring-width series thus obtained the positive/negative direction of change from one year to the next coincided in only 79–94% of all cases, with a mean of 87%. The non-coincidence in the direction of change from one year to the next is observed more commonly when measuring successive rings of closely similar width. Two factors may account for the cases of non-coincidence: a) the width of each ring always shows at least some variation around the circumference, and b) a minor deviation, i.e. error, inevitably arises when aligning the cross-hair viewed through the eyepiece of the microscope with the growth ring boundary.

The highest values of similarity between all three tree-ring width series in synchronous arrangement was returned by SAKORE V.3 programme, performing standardization

Table 1. Similarity values for the synchronised tree-ring width series from the charcoal samples, obtained using the dendrochronological data processing programme SAKORE V.3

Similarity statistic	Series compared		
	no. 4-7.1 / no. 4-7.2	no. 4-7.1 / no. 4-17	no. 4-7.2 / no. 4-17
w (%)	67	62	71
t	4.00	3.35	6.66

of ring-width data using an original method known as the constant sum or Špalte method (Table 1) (Špalte 1985).

Overall, the values of the similarity indices of the mean values of the tree-ring width indices, even as calculated using the SAKORE V.3 programme, are not very high. The relative date of the last, i.e. relatively youngest, tree-ring preserved in each of the three charcoal samples was confirmed and the absolute date ascertained when all three series of mean values of ring-widths of the charcoal samples were successfully cross-dated with several absolute pine tree-ring chronologies previously compiled in Latvia. The ranges of Baillie-Pilcher *t*-values (abbreviated as TVBP; Baillie and Pilcher 1973), characterizing the significance of the similarity between the series of mean tree-ring width indices for the three charcoal samples and various absolute chronologies for pine from Latvia, are shown in Table 2.

The results of cross-dating the series of mean values of ring-width indices confirm that the youngest annual ring in all three samples relates to the same calendar year, namely AD 1705. Although all three charcoal fragments were preserved without bark, it is reasonable to assume that the identical date obtained for the outermost tree ring observed on these three charcoal fragments from the same mound corresponds to the year when the last ring was formed on these three pines. The trees would have been cut together in that year or in the first four months of the following year – which falls within the period of operation of the Engure ironworks. According to information in written historical sources, the ironworks operated in the years 1680–1721 (except for 1696) and 1763–1777, i.e. for a total of 56 seasons (Jakovļeva 2001).

Two of the charcoal samples extracted from the soil cores obtained from the mounds, one from Ķesterciems, and the other from Abragciems, were ¹⁴C-dated, supple-

Table 2. Comparison of *t*-values characterizing the similarity of the series of mean values of tree-ring width indices for the charcoal samples and absolute chronologies for pine compiled in Latvia

No.	Series of mean values of ring-width indices	Range of <i>t</i> -values (TVBP)	Mean <i>t</i> -value (TVBP)
1	nr. 4-7.1	1.6–5.6	3.28
2	nr. 4-7.2	0.8–5.6	3.70
3	nr. 4-17	0.9–5.5	3.36
4	nr. 4-7.2 + nr. 4-17	0.5–6.8	4.03
5	nr. 4-7.1 + nr. 4-7.2 + nr. 4-17	1.5–8.5	4.56

Table 3. ¹⁴C-datings for samples from charcoal-burning mounds. Calibrated according to the IntCal20 curve (Reimer et al. 2020), using OxCal 4.4 software (Bronk Ramsey 2009, 2020)

Sample description	Material	Lab. no.	¹⁴ C age BP	Calibrated date, cal AD	
				1σ (68.3% probability)	2σ (95.4% probability)
Abragciems, core 1, 40–50 cm depth (dark grey sand with abundant charcoal fragments)	wood charcoal (<i>Pinus</i> sp.)	Poz-123930	215 ± 30	1648–1799	1641–
Ķesterciems, core 1, depth: 26–40 cm (dark grey sand with abundant charcoal fragments)	wood charcoal (<i>Pinus</i> sp.)	Poz-132864	175 ± 30	1667–	1658–

menting the dendrochronological date from Apšuciems despite the relatively low precision of this dating method. The dating results are consistent with the hypothesis that charcoal production in these areas likewise took place in the time of the ironworks, i.e. during the second half of the 17th or the 18th century. Thus, the Abragciems sample is dated to 1648–1799 with a probability of 68.3% (1641 or later with a probability of 95.4%), while the Ķesterciems sample is dated to 1667 or later with a probability of 68.3% (1658 or later with a probability of 95.4%) (Table 3).

Charcoal was required for many different ironworking processes: to fuel the blast furnace and reduce the ore to cast iron, as well as for foundry processes and in the forges (Anteins 1962), but charcoal consumption varied from year to year. For this and other reasons, there was considerable variation in the documented quantities of wood supplied for charcoal production from the Engure area. The written record attests that in 1690 an agreement was concluded, under which an annual quantity of 1,400 fathoms or 9,352 m³ of fuelwood was to be provided for iron production at the Engure works for at least four years (Jakovļeva 2001). There is evidence that in certain years double that quantity of fuelwood was supplied to the works, i.e. 2,800 fathoms or 18,704 m³ (Anteins 1976), but documentary records confirming this information have so far not been found in the archive.

The Engure Manor inventory records (SHAL 2, SHAL 3, SHAL 4) indicate the volume of wood prepared per charcoal stack in particular years. In the year 1694, it was 38 fathoms. Thus, for the conversion to charcoal of the planned annual volume of 1,400 fathoms of wood, ca. 37 stacks would have had to be burned each year (similar stack volumes are recorded in later years: 36 fathoms in 1718, 35 fathoms in 1731, but as much as 50 fathoms

in 1739). Hypothetically, had 37 stacks been burned each year, the 1,000 mounds identified from the LiDAR imagery would have accumulated in a period of 27 years.

What was the volume of wood consumed for charcoal production in terms of modern-day units of fuelwood measurement? If we take 1 cubic fathom as equalling 6.68 m³ (on the assumption that the cubic fathom referred to here is equivalent to 6×6×6 Rhineland feet; see Zemzaris 1981), then the recorded volume of wood per stack, namely 35–50 fathoms, is equivalent to 234–334 m³. Charcoal was still being burned in stacks in the first half of the 20th century, and at this time stacks of up to 400 steres (~ 280 m³) are described (Boķis 1937). Thus, in terms of the recorded volumes, the stacks at Engure are comparable with those of charcoal stacks of later centuries. The total volume for the 1,000 stacks comes to between 234,000 and 334,000 m³.

The true extent of the forest area in which wood was sourced to provide charcoal for the ironworks is most probably impossible to ascertain, but in the knowledge of standing volumes in Latvian forests at the present day, it is possible to obtain at least an approximate idea of the equivalent area of forest that would have had to be clear-felled to obtain the amount of charcoal consumed during the time the ironworks operated. According to data published by the Central Statistical Bureau of the Republic of Latvia, in 2021, the mean standing volume of well-drained forest in Tukums municipality, where Engure is located, was ca. 225 m³/ha (Stage II 2022). Assuming an approximately similar standing volume in the time of the Duchy, the total quantity of charcoal needed solely for the Engure ironworks is equivalent to the theoretically obtainable wood volume from clear-felling 1,040–1,485 ha of forest, which may be rounded to 1,000–1,500 ha. To give a clearer idea: this is equivalent to an unbroken rectangular area of forest 5 km in length and 2–3 km in width, which corresponds to about one quarter of the total area of distribution of the charcoal-burning mounds. For comparison, we may cite data from older publications, which have not been verified, according to which forest took up ca. 30% of the total 12,388.5 km² area of the Duchy of Courland and Semigallia, i.e. 3,716.55 km² or 371,655 ha (Šreinerts 1939, Strods 1999).

The information contained in several historical documents discovered in the State Historical Archive of Latvia obtains additional significance and may be more precisely assessed and interpreted when compared against the information from the archaeological investigation undertaken in the same area. For example, evidence concerning the state of forests in the vicinity of Lake Engure in February/March 1712 is contained in a record of an inventory of the Engure estate and ironworks (SHAL 6) (Figure 2). Among other information, it reports on the condition of the various forest tracts:

- 1) *Uggenzehm* (Uguņciems forest) – good mixed forest;
- 2) *Beckmünde* (Upesgrīva forest) – good forest, mainly oak;

- 3) *Marg Graffsche Busch* (Mērsrags forest) – good mixed forest;
- 4) *Bersezemsche Wald* (Bērzciems forest) – all cut, now left to re-grow, young stands or scrub growing in places;
- 5) *Angersche Waldt* (Engure forest) – rather depleted by cutting but still with good reserves, and the remainder is being left to re-grow;
- 6) *Dreyman oder Kösters-Busch* (Dreimaņi or Ķesterciems forest) – good forest of young pines, in good condition;
- 7) *Plönsche-Wald* (Pliņciems forest) – pure pine forest, partly cut;
- 8) *Pippeka[ck]tsche Busch* (Pipkakts forest) – all cut and now left to re-grow; young stand of spruce, birch and alder.

For a long period, up to the mid-18th century, the Engure forest is characterized as partly cut but still having good stocks, correlating with the number of charcoal-burning mounds found here at the present day. This could indicate selection cutting.

The intensity of wood harvesting and its impact on the surrounding forest during the time of blast furnace operation at Engure and Uguņciems is additionally characterized by evidence concerning the condition of the forests in the environs of Engure in later times. That the demand for charcoal from the Engure works and likewise from the ironworks established in 1763 at Uguņciems, 25 km further to the north, placed considerable pressure on the area's forest resources can be gauged from the Engure manor inventory of 1764, which records that only three out of the manor's eight forest tracts were in good condition, while the rest were severely depleted or had burned. It is stated specifically that 1,000 logs had been harvested in 1764 from the Uguņciems forest for the needs of the ironworks there (Barzdeviča 2013). Interestingly, charcoal-burning mounds have thus far not been identified in the Uguņciems area. This could at least partly be explained by the fact that the blast furnace at Uguņciems was operated only for short seasons, and its overall time of use was relatively brief – only ca. 15 years (Jakovļeva 2001).

It was ascertained that the State Historical Archive of Latvia does hold further documents providing quite significant information of this kind concerning specific forest tracts during other periods of the Duchy's existence, but these have not yet been identified and analysed in full.

Discussion

Along with the local availability of bog iron ore and the potential of the River Engure as an energy source and ore supply route, the presence of large forest tracts, mainly consisting of pine, in an area that had seen virtually no agricultural activity on account of the poor soil conditions (Jakovļeva 1999) would have been one of the main factors why Engure was selected as the site for one of the ironworks set up during the time of the Duchy of Courland

and Semigallia. The use of pine for charcoal production in the environs of Engure reflects the availability of this species in the area. Studies in Latvia and elsewhere in Europe confirm that in all times charcoal production made use of wood species available in the vicinity of the charcoal-burning site (Deforce et al. 2013, Guščika 2020).

Naturally, considering the very small number of identified charcoal fragments, almost all from one mound, it cannot be asserted that pine was the only major tree species used for charcoal production; for the same reason, the wood diameter estimates cannot be assumed to provide an accurate picture of the size of material utilized in charcoal burning. The future study of samples from other mounds could clarify these aspects. On the other hand, considering that the charcoal-burning mounds in the Engure area are outwardly rather uniform, the excavated mound may be thought to constitute a representative example also in terms of internal stratigraphy. The observations from coring in other mounds provide some confirmation of this.

The information in historical records permits an assessment of the condition of the forests of this area and the impact of the charcoal-burning operations. Thus, the Pipkaks and Bērziems forests, and partly also the Plieņciems and Engure forests had already been cut before 1712, and this may largely be accounted for by wood utilization for the needs of Engure ironworks; on the other hand, Uguņciems, where an ironworks blast furnace went into operation only in 1763, and likewise nearby Mērsrags and Upesgrīva still had “good” forest (Figure 2). Considering the dense concentration of charcoal-burning mounds in the Dreimaņi or Ķesterciems forest (Figure 2), there is reason to believe that here, in the Bērziems forest, a young pine forest had grown by 1712, replacing the one that had been cut. In the area corresponding to the Bērziems forest, which had been cut, the number of charcoal-burning mounds is not so high, and in the northern part of this area they are absent altogether. However, two possible reasons can be given for why the intensity of forest cutting does not correlate with the number of charcoal-burning mounds in this particular area. In the first place, the Bērziems forest area was located close to the ironworks itself, and so it may be thought that trees were also cut in this area to provide a large proportion of the timber for the ironworks and associated buildings and wooden structures, as well as for heating. Secondly, it is highly probable that charcoal production was also practiced in the northern part of the Bērziems forest area, but that the charcoal-burning mounds are no longer visible here at the present day, having been covered by wind-borne sands, transported in this rather atypical case mainly in an easterly direction, i.e. from the interior towards the coast. Here it should be explained that part of this forest area was located between the shore of the Gulf of Riga of the Baltic Sea and Lake Engure, which was significantly lowered in 1842 in order to obtain additional agricultural land, achieved by connecting the lake and the sea with a canal. However, the exposed

lakebed was sandy, and the prevailing south-westerly and westerly winds began blowing the dry sand away from the lakebed towards the sea, blanketing not only the former lakeshore meadows but also the forest (Eberhards 2003).

In view of the large number of charcoal-burning mounds (ca. 1,000) in the Engure area, it appears that a great total quantity of wood was consumed during the long period when the ironworks was operational. In accordance with the stated aim of determining the quantity of wood consumed in producing the charcoal required for the ironworks, such calculations were performed based on the estimated number of charcoal-burning mounds and their volume as well as on relevant information discovered in written historical sources. It emerged in the course of the study that the previously known and newly uncovered evidence can only provide an approximate indication of the quantities of wood used in the area for charcoal production and for the Duchy’s other needs. Also, the limits of the area providing fuelwood for charcoal production have not yet been precisely determined. Several factors affect the precision of the results:

- a) Historical documents from the time of the ironworks as well as later publications do provide quite extensive information about quantities of fuelwood consumed, supplied or anticipated for the production of a set amount of charcoal and cast or bar iron. However, these figures generally cover only short periods of time (specific years or even shorter periods), and there is no accurate record of wood supplied during the whole time the ironworks operated.
- b) The quantities are given in historical units of measurement, which varied in this period, depending on the kind of material being quantified, and on the particular time and place, and sometimes other factors as well. Although historians have tried to relate these historical measurement units to SI units, not all of these issues have been satisfactorily resolved. For example, a number of historical sources give the quantity of fuelwood required to produce a barrel of charcoal. However, the volume of a barrel of charcoal in the Duchy of Courland has so far not been ascertained (Zemzaris 1981).
- c) It would not be appropriate to directly apply data on the mean charcoal yield from a given quantity of wood at ironworks elsewhere, given that in the period corresponding to the beginning of iron production at Engure, fuelwood was being used for charcoal production very inefficiently and wastefully in the Duchy of Courland. Thus, in 1687 Swedish engineer Bengt Ström found in his inspection of the Duchy’s ironworks that in Courland 40 cords of wood gave only 12–15 lasts of charcoal – compared with 2 lasts of charcoal obtained from each cord in Sweden (SHAL 1), i.e. by his calculation the charcoal yield in Courland was about six times lower. However, other information from written historical sources (Jakovļeva 2001) as well as the size and number of the charcoal-burning mounds that have

been discovered provide indirect evidence that during the time the ironworks was in operation fuelwood consumption could in reality have reached the above-mentioned amount of 1,400 cubic fathoms or 9,352 m³ only in certain years and would for the most part have been significantly lower.

- d) Not all of the formerly existing charcoal-burning mounds will have survived as surface features, and the original number may have been significantly greater than 1,000. It should be noted that several villages have subsequently developed in the area around the former Engure ironworks and elsewhere within the distribution area of the mounds, and certain parts of the area have been covered by dune sands. Such features are also very vulnerable to destruction from contemporary logging activities (although forest-cutting in Latvia's protected coastal belt is subject to special legal restrictions, and this may have helped to reduce the damage). It should also be borne in mind that a particular charcoal-burning location could have been used twice or even several times, as confirmed by investigations in Germany, for example (Raab et al. 2015). The stratigraphy of the excavated and cored mounds in the Engure area did not provide indications of repeated use, but the possibility cannot be excluded that other mounds were indeed re-used.
- e) The volume of charcoal production reflected in the large number of charcoal-burning mounds around Engure is comparable with the charcoal demand of the ironworks during the ca. 56 years of its intensive operational life. However, such a comparison cannot be regarded as accurate: in reality, this number of mounds would have taken a considerably longer time to accumulate, because the ironworks was operating intermittently and at reduced capacity (Jakovļeva 2001), requiring much lower charcoal production.
- f) In assessing the limits and total extent of the source area of the wood for charcoal production, it should be considered that this area was probably at least slightly larger than the known distribution area of the charcoal-burning mounds, especially around the southern part of the distribution area, where the concentration is densest. This conclusion is based on written historical evidence that it was not the practice to supply wood for charcoal production from any forest area deemed suitable and to fell all the trees, i.e. undertake clear-felling; instead, specific areas were assigned, and selection cutting was undertaken, good quality standing timber being retained for other purposes (Šreinerts 1939, Strods 1999, Jakovļeva 2001). In 1726, for example, Friedrich Zieffer, who had leased the Engure works, stated that the site where wood for charcoal was to be cut had been assigned by the forester (*Wildnis-Bereuter*), and that the site also yielded good timber for beams and boards, which had been taken to the estate and the works (SHAL 5).

In relation to the calculated total area of the Duchy's forests (371,655 ha), the calculated theoretical 1,000–1,500 ha of forest cut to provide charcoal for the Engure ironworks may initially seem relatively small. However, it needs to be considered that a forest area of approximately this extent would have met the charcoal demand of just one ironworks. Written historical sources indicate that during the time of the Duchy ironworks were set up at various locations (Jakovļeva et al. 2019). Moreover, it should be borne in mind that in the time of the Duchy wood was also being exported in large quantities, and was being used by copper foundries, brickyards, glassworks, tar kilns and distilleries, in the production of ash, potash and saltpetre, as well as for construction of buildings and other wooden structures, ships and boats, roads, bridges, dams and harbours, for making masts and boards, as fuel wood, etc. (Juškevičs 1932, Šreinerts 1939). Apart from this, swidden cultivation was still being practiced, and forest fires were frequent. Overall, wood was being consumed as well as intentionally or accidentally burned in the Duchy on a very large scale, although this has never been investigated and quantified.

Conclusions

Although the long-term development of the Engure area has been a subject of research interest, none of the previous studies reach back far enough in time to consider the impacts of large-scale forest resource extraction in the early modern period, a lacuna that we have now begun to fill, utilizing archive records and, most importantly, the newly-discovered archaeological remains of charcoal-burning sites.

In spite of the factors affecting the precision of our calculations, by combining the study of written sources with archaeological research, we have obtained a clearer picture of the wood consumption relating specifically to the Engure ironworks and its impact on the surrounding forests. Charcoal production had the effect of reducing the density and altering the composition of forest stands in the surrounding area, and also reduced the forest cover, particularly in the southern part of the area of distribution of the charcoal-burning mounds. The study shows that the material remains and information recovered in archaeological excavation, along with LiDAR data, permit the source areas of wood charcoal to be located or more precisely delimited, revealing the main areas of charcoal production and enabling calculation of the volume of wood consumed.

As discussed above, there is reason to believe that the true number of charcoal-burning mounds providing fuel for the Engure ironworks exceeded the ca. 1,000 mounds that have been identified, and accordingly the total wood consumption would have exceeded the calculated 234,000–334,000 m³. Apart from this, the possibility of repeated charcoal burning on the same mound cannot be excluded. Further field research, with coring or excavation

of additional mounds, might provide stratigraphic evidence of such re-use and thereby alter the basis for calculations of wood consumption.

Dendrochronological dating was successfully applied in the study to determine the year in which wood was supplied for charcoal burning. The use of this method for dating charcoal more recent than AD 1650 is particularly important, given that the ^{14}C calibration curve shows marked deviations after this time, on account of which the calibrated age probability distributions for ^{14}C datings of charcoal kilns from this period are overly wide (Deforce et al. 2021).

Further excavation of charcoal-burning mounds holds the possibility of recovering additional samples for dendrochronological dating, which in the Engure case could help trace the successive exploitation of different forests in the area for charcoal production. With regard to other ironworks in the Duchy of Courland and elsewhere, for which historical records are inadequate, dendrochronological dating of charcoal-burning mounds in their environs could indicate the periods of operation and variations in the intensity of use of the blast furnace and other facilities.

Further data on the operations of the Engure ironworks could be sought in historical documents, in addition to which there is a need for additional information about the area, volume and weight measures used in the Duchy of Courland and Semigallia and their correspondence to present-day measures.

By further developing and broadening this kind of research, more general questions could be addressed in future: a clearer picture of forest resource utilization for industry could emerge and how it changed over time in present-day Latvia and the Baltic region as a whole during the Middle Ages and Early Modern period, which would also provide a context for more objectively assessing the characteristics of present-day forest in the respective areas (species composition, age structure, etc.). Considering that archaeological features still discoverable and identifiable in forested areas (former charcoal- and tar-burning sites, etc.) can play a very significant role in reconstructing forest history, such remains deserve to be surveyed, properly recorded, protected from destruction and investigated jointly by archaeologists, historians, forestry researchers and life science professionals.

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