Turfs and Timbers – Resource use in the construction of the Viking Age Ring Fortress Borgring, Southeast Denmark

Morten Fischer Mortensen[1,8], Claudia Baittinger[1], Jonas Christensen[2], Anne Birgitte Nielsen[3], Søren Nielsen[4], Anders Pihl[5], Lisbeth Prøsch-Danielsen[6], Morten Ravn[4], Søren Michael Sindbæk[7] and Jens Ulriksen[2]

[1] Environmental Archaeology and Materials Science, The National Museum of Denmark, I. C. Modewegsvej, 2800 Kgs. Lyngby, Denmark
[2] Museum Southeast Denmark, Algade 97, 4760 Vordingborg, Denmark
[3] Department of Geology, Lund University, Sölvegatan 12, 223 62 Lund, Sweden
[4] Viking Ship Museum in Roskilde, Vindeboder 12, 4000 Roskilde, Denmark
[5] Ancient Cultures of Denmark and the Mediterranean, The National Museum of Denmark, Frederiksholms Kanal 12, 1220 København K, Denmark
[6] Museum of Archaeology/University of Stavanger, 4036 Stavanger, Norway
[7] Department of Archaeology and Cultural Heritage, School of Culture and Society, Aarhus University, Moesgaard Allé 20, 8270 Højbjerg, Denmark
[8] Corresponding author (morten.fischer.mortensen@natmus.dk) ORCID 0000-0002-4167-8227

ABSTRACT
Viking Age ring fortresses were some of the largest construction projects in Danish prehistory. In this article we reconstruct the amount of turf and timber used in the construction of the Borgring ring fortress and estimate the resource area needed to supply the building materials. Using REVEALS pollen data modelling we quantify the regional oak land cover and estimate the resource area. The results show that even though Borgring was built in an open cultural landscape, sufficient supply of oak for the construction would have been accessible within a few kilometres of the fortress.

ARTICLE HISTORY
Received
11 September 2020;
Accepted
17 June 2021

KEYWORDS
Borgring; Ring fortress; Viking Age; Resource use; REVEALS; Pollen analysis

Introduction

The Danish ring fortresses, with their unique and precise geometric form, are distinctive monuments of Viking Age architecture (Figure 1 and 2A) and testify to the establishment of a central power structure that expressed its supra-regional dominion through large-scale monuments (Roesdahl and Sindbæk 2014, 460; Ulriksen, Schultz and Mortensen 2020). The construction of five Danish ring fortresses, as well as the Jelling complex, marks out Harald Bluetooth's reign and dates to the time between the end of the AD 950s and the beginning of the AD 980s (Holst et al. 2012, 494).

The ring fortresses were unusually large constructions for the time in Scandinavia and involved a great concentration of resources of manpower and building materials. Accordingly, it has been argued that they must have made a severe impact on the natural landscape (Jessen 1948, 175-178). Large amounts of earth and turf were needed for the ramparts, and adequate resources of timber were especially necessary for the timber-clad circular rampart and the wooden streets and houses. It is therefore important to determine whether the relatively open cultural landscape of the time could supply the amount of timber required, or whether it was necessary to import timber from other regions.

Reconstructing the resource use involves many factors that cannot be fully resolved such as timber quality, the range of tree taxa available, the possible import of timber, proximity to woodlands, and the intensity of woodland management. Previous calculations for Trelleborg, Aggersborg, Fyrkat, the fort at Trelleborg in Skåne, Sweden, and the Jelling complex have attempted to estimate the amount of timber required and the hectares of woodland needed to supply it (Arén 1995, 99; Jessen 1948, 173-179; Jessen et al. 2014, 15-17; Schmidt 1985, 50; Sindbæk 2014, 181-183).

The partial reconstruction of ring fortresses can aid the calculation of how much timber was required. Around 215 m^3 of oak (*Quercus* sp.) was used in the reconstruction of one of the 16 longhouses originally built at Fyrkat, which equates to

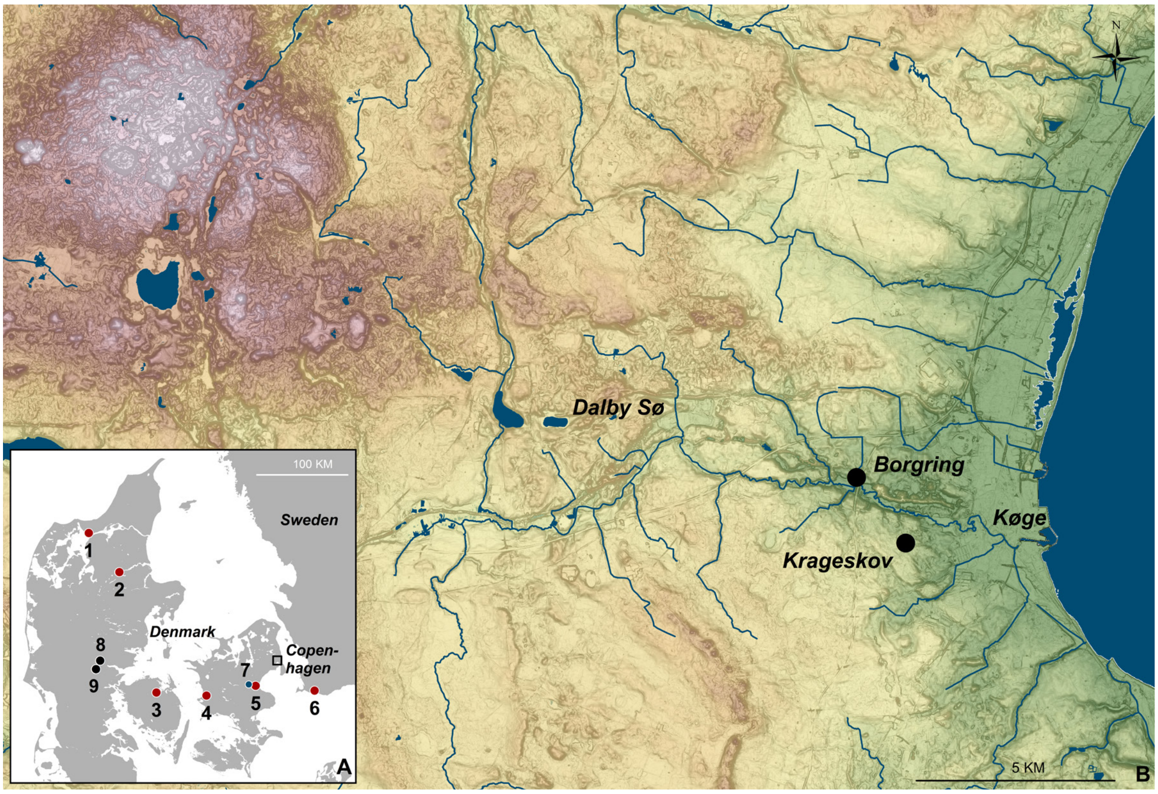

Figure 1. A) Denmark with the five known ring fortresses from the Viking Age, 1) Aggersborg, 2) Fyrkat, 3) Nonnebakken, 4) Trelleborg, 5) Borgring, as well as 6) Trelleborg in Sweden 7) Lake Dalby Sø, 8) Jelling and 9) Ravning Enge. B) Lake Dalby Sø is situated 7.5 km west of Borgring on the boundary between the forest-poor eastern Zealand and the hillier, forest-rich areas of central Zealand. Krageskov is situated 1.5 km south of Borgring (includes data from Agency for Data Supply and Efficiency, Terrain 10 m, December 2019 and Areal Information System lakes and watercourses).

around 135 fully grown (120-200 years) oak trees (Schmidt 1985, 50). A similar house reconstruction at Trelleborg, Zealand used 123 oak trees of differing sizes (Jessen 1948, 176). The amount of timber required for ramparts is more difficult to estimate. The ramparts at Trelleborg formed a massive construction, with timber cladding on both the internal and external faces, in addition to anchoring constructions in the earth fill. It is suggested that 3840 oaks were used for the rampart and internal roads while 8155 oak trees were used for the complete structure (Jessen 1948, 176). Other fortresses – for example, Aggersborg – had a more limited use of wood, and it is suggested that the construction here could have been built using perhaps only 340 large oak trees (Sindbæk 2014, 181). In the building of smaller ring fortresses, such as the earliest phase of ramparts at Trelleborg in Skåne, it is suggested that 437 trees were used (Arén 1995, 99).

These earlier studies have been limited to estimates of timber used and of the required hectare of woodland. When these studies were carried out, it was not possible to estimate the proportion of oak that was available in the hinterland and the area needed to supply the required timber. With the development of quantitative models for the interpretation of pollen data, such as REVEALS (**Re**gional **V**egetation **E**stimates **a**t **L**arge **S**ites) (Sugita 2007), it is now possible to estimate the areal coverage of the most common plant taxa and the vegetation types from pollen data, by taking into account the differences between plant species in pollen productivity and pollen dispersal properties. By applying this model, we can get an estimate of the average regional vegetation composition in an area, such as that in the Borgring hinterland. By combining the vegetation cover estimates with the estimates of timber required, a more precise quantification of the woodland resource areas needed to build monumental construction works is possible. Here we apply the results from the archaeological investigations at Borgring, Zealand, concerning the component parts of the rampart and gateways and the pollen data from a nearby lake, Dalby Sø (Figure 1), to specific questions re-

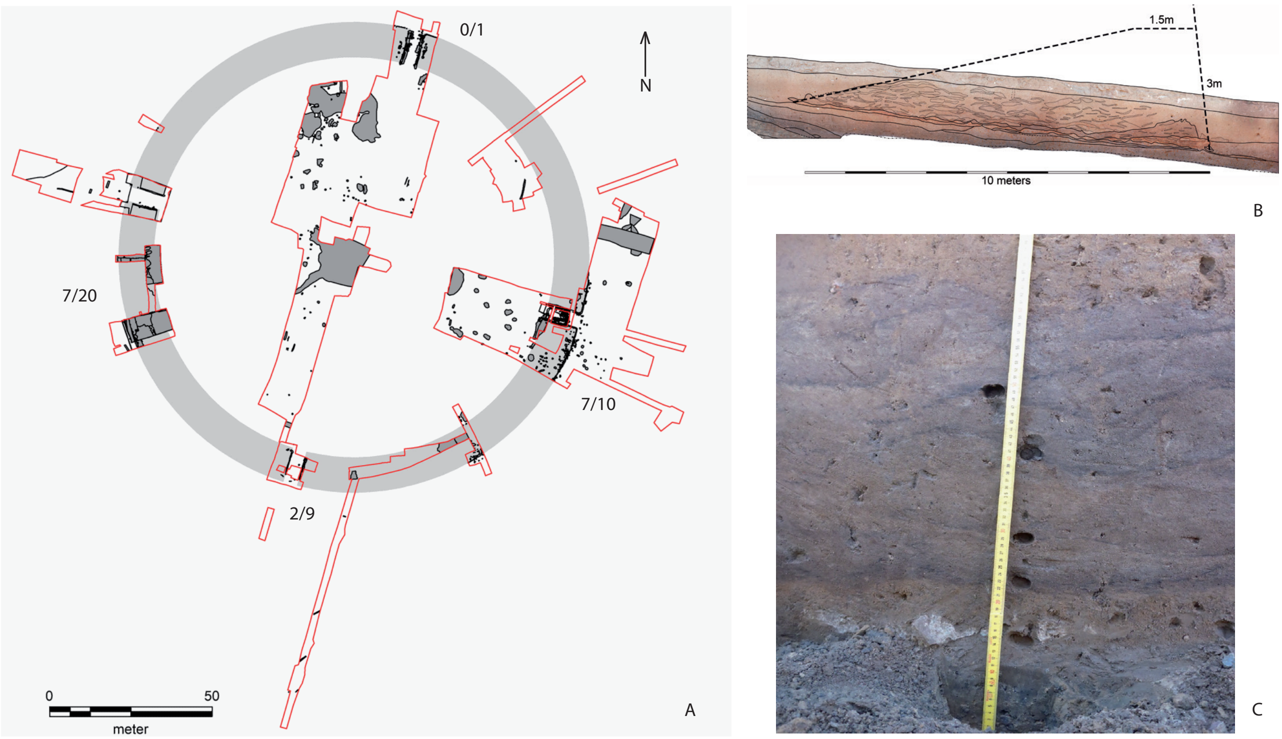

Figure 2. A) The excavation trenches (red line) and assumed shape and size of the circular ramparts at the Borgring fortress (light grey), dark grey represent structures within the excavated areas; B) Cross section showing the excavated height and angle of the rampart (Illustration: Jonas Christensen), assumed height and angle (dotted line), inside to the left, outside to the right; C) Cross section of the rampart showing the building turfs (Photo: Morten Fischer Mortensen).

garding resource use and the regional vegetation composition. Firstly, how much turf and timber were used in the construction of the ramparts, secondly, how large a resource area was needed to support this and thirdly, were there sufficient resources available for this in the local area, and if so, where were they located?

Any estimation of resource use is necessarily based on a number of assumptions, as no ring fortresses are sufficiently preserved to determine their precise manner of construction. These assumptions include the ramparts' original height, which tree taxa were used, construction details and whether the building was completed. Pollen based vegetation models such as REVEALS also include a number of assumptions, including constant and known relative pollen productivities for each plant species, predominantly wind dispersed pollen etc. (Sugita 2007). Our reconstruction attempts an approximate and balanced estimate of resource use and resource area, as well as a basis for the discussion of whether the import of timber was a prerequisite in the construction of ring fortresses.

The Site

Borgring is situated close to the town of Køge, around 30 km southwest of Copenhagen (Figure 1). The ramparts were first identified in 1971, but they were only definitively recognised as parts of the iconic Viking Age ring fortresses by the use of high resolution LiDAR, geophysical surveys, and a small-scale test excavation in 2013 and 2014 (Goodchild, Holm and Sindbæk 2017). Selected parts of the ring fortress were the subject of large-scale investigations between 2016 and 2018, along with areas of the hinterland (Christensen et al. 2018; see also contributions in this volume).

Borgring lies on the northern bank of the Køge River valley, around 4 km from the coast. The small stream was not navigable by vessels larger than a dinghy during the Viking Age (Jessen et al. 2021, 8) and the ring fortress is situated on a raised area adjacent to areas of wetland. As the ring fortress had an external diameter of 144.5 m, it was necessary to add more than 1900 m^3 of sediment, which was up to 1.5 m thick in some areas, to give the ramparts a solid foundation.

Trial trenching of more than 40 ha of arable land around the ring fortress did not find evidence of other Viking Age buildings. The closest Viking Age settlement evidence was seen on the southern bank of the stream at Lellinge, where Baltic Ware pottery dating to the end of the Viking Period was found in a rubbish pit. A sunken lane is associated with a ford crossing Køge stream close to the ring fortress (Ulriksen, Schultz and Mortensen 2020, figure 5 and 6).

Pollen data from a 13 ha lake, Dalby Sø, situated 7.5 km west of Borgring was used for the regional reconstruction of vegetation in this study (Odgaard 2010, 57; Mortensen et al. in prep.). The lake is located at the transition between the flat basal moraine landscape towards the coast and the more hummocky dead ice landscape of central Zealand (Figure 1A-B). The flat eastern Zealand landscape is some of the best agricultural land found in Denmark and at present it is almost entirely cultivated and with very limited woodland coverage (Smed 2016, 198).

Methods

The circular Rampart

Information concerning the size and construction details of the rampart is obtained by the use of high-resolution LiDAR, geophysical surveys together with observations gained during the excavation campaigns between 2016 and 2018. The methods are described in detail in Goodchild, Holm and Sindbæk (2017), Christensen et al. (2018) and contributions in the present volume.

Pollen analysis of the Rampart Turfs

Turfs, used in the building of the circular rampart, with well-defined growing surfaces (Figure 2B-C), were sampled for pollen analysis during the excavation. A total of 40 samples (20 from the west gate, 9 from the south gate, 10 from the east gate and 1 from the north gate) were examined and 16 of these contained sufficiently well-preserved pollen for analysis (raw data presented in supplementary A). Pollen preparation followed standard procedures, including KOH, HCl, HF, and acetolysis (Fægri and Iversen 1989, 77-81). No exotic marker was added. The residues were mounted in silicone oil. Whole slides were analysed to avoid effects of unequal distribution of pollen under the cover slip. Beug (2004) was consulted for general pollen identification, supplemented by the reference collection at the National Museum of Denmark. Due to low pollen concentrations and generally poor pollen preservation only between 148 and 277 pollen grains were identified in each sample, with a total pollen sum of over 3000.

All terrestrial pollen were included in the pollen sum.

Wood identification, Timbers and the reconstruction of the Ring Fortress

Charcoal was continuously sampled during the excavation with a special emphasis on that of timbers from the western, northern and eastern gates which were burnt during the Viking Age. A total of 64 charcoal samples were taken, representing 58 pieces of timber (11 from the western, 14 from the northern and 33 from the eastern gates). One sample of uncharred and highly degraded wood was taken from a post from the southern gate (Table 1) (Baittinger 2018; Daly 2017). Wood and charcoal fragments were analysed with the help of a simple stereo microscope, a light microscope and a high resolution fluorescence microscope. Schweingruber (1990) was consulted for general wood identification.

REVEALS and local Resource Areas

Pollen data from Dalby Sø (Mortensen et al. in prep.; Odgaard 2010, 57) is used to calculate the area needed to supply the Borgring fortress with building materials. This study focuses on the period from AD 500 to AD 1500, where the pollen data has a sample time resolution of *c.*45 years between the samples. We especially consider the period around AD 985 and the estimated vegetation cover of oak (*Quercus* sp.). The terrestrial pollen sum ranges from 538-1363 grains per sample. The pollen was better preserved than in the rampart

Table 1. Wood identification of 59 wood and charcoal fragments from the gates at the Borgring fortress.

Northern gate		
Oak	*Quercus* sp.	8
Elm	*Ulmus* sp.	6
Eastern gate		
Oak	*Quercus* sp.	18
Elm	*Ulmus* sp.	12
Ash	*Fraxinus excelsior*	1
Alder	*Alnus* sp.	1
Fruit tree	Spiraeoideae	1
Southern gate		
Oak	*Quercus* sp.	1
Western gate		
Oak	*Quercus* sp.	8
Elm	*Ulmus* sp.	3

turfs, so the maximum proportion of unidentified grains was 1.4 % in one sample, and in most samples, there were no unidentified pollen. The REVEALS model corrects for the differences in pollen productivity and pollen dispersal between species in order to estimate regional vegetation composition from pollen assemblages from large lakes or mires (Sugita 2007). For a lake >50 ha, the spatial scale represented is approximately a 25-50 km radius (Hellman et al. 2008), but as Dalby Sø with its 13 ha is somewhat smaller, the reconstruction will reflect a smaller area, and local vegetation near the lake may be overrepresented to some degree relative to vegetation further away. However, as Dalby Sø is located only 7.5 km away from Borgring, the reconstruction should be representative for the relevant area. We applied a set of pollen productivity estimates from Southern Sweden and Denmark (Broström, Sugita and Gaillard 2004; Nielsen 2004; Sugita, Gaillard and Broström 1999; summarised by Fredh 2012). REVEALS calculations were carried out using the software REVEALS v4.5 (Sugita, unpublished) applying the lake model (Sugita, 1993) with default settings (average windspeed 3 m/s and neutral atmospheric conditions). The pollen types included in the REVEALS analysis made up 89-97 % of the terrestrial pollen sum.

Results

The circular Rampart

The grass turf and soil rampart of Borgring was 10.6 m wide, as calculated based on the geophysical survey and field observations (Figures 2 and 3, Table 2). In some areas a clear radial structure was observed in the geophysical survey which, when excavated in the southwest part of the rampart, was seen to be due to a regular pattern of shifting dark and light turfs and soil (Figure 3B). Traces of timber cladding with shallow foundations were seen along parts of the outer margin of the rampart but no traces of timber were observed on the inner margin. Although evidence for timber structures holding the turfs in place in the inner margin have been

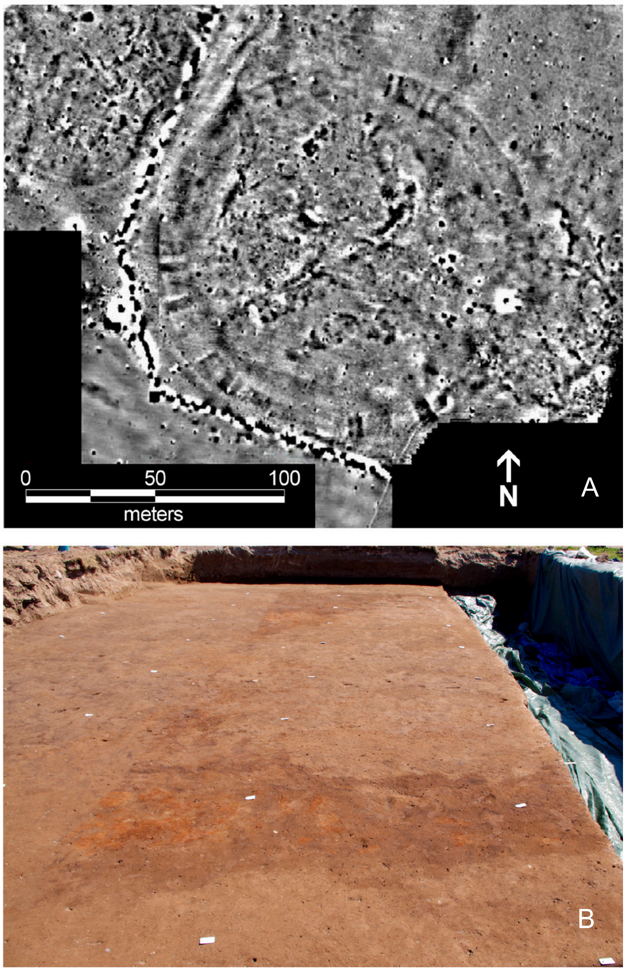

Figure 3. Sectioning of the rampart seen in A) A fluxgate geometry map (Helen Goodchild); B) Southeastern part of the rampart seen from the outside and in (Photo: Museum Southeast Denmark).

found at, for example, Aggersborg and Fyrkat, no trace of such structures was observed at Borgring.

The rampart of Borgring is partly preserved, but severely eroded, with the highest section only 1.1 m high. Here, it was possible to establish the surface of the rampart declining towards the inside of the fortress at an angle of *c.*20^0. In the same section, the outside front of the rampart inclined *c.*70^0 towards the eroded top (Figure 2B). We propose that the upper part of the rampart had a levelled surface along the covering palisade on top for ease of movement. Based on the preserved surfaces of the rampart and the assumed height of the gateways, it is estimated that here the rampart was *c.*3 m high with a 1.5 m wide plateau, giving a total volume of the ramparts of 6567 m^3 excluding the gates (Table 2). Although it cannot be ruled out that the plateau was wider or narrower, nor that the collapse of the rampart altered its original form. However, an increase of the plateau dimensions by 1.0 or 2.0 meters gives a volume increase of 1.6 % and 3.5 % respectively, and therefore would not affect the calculation of the total quantity of turfs used in the construction considerably.

The majority of the turfs used were between 70 and 130 mm thick when recorded during excavation (Figure 2C); for the calculation of the harvested area, an average turf thickness of 100 mm over an area of *c.*65,670 m^2 or 6.57 ha was used. Calculations using 70 mm and 130 mm thick turfs gives areas of 50,515 m^2 and 93,814 m^2 respectively. However, as parts of the rampart consisted of loose soil infilling among the turfs, this area is most likely an overestimation. A possible source area for harvesting turfs is shown in Figure 4 and is the nearest dryland area from Borgring where the turfs could be harvested.

Rampart	
Outer diameter (m)	144.4
Inner diameter (m)	123.2
Circumference (m)	453.65
Rampart width (m)	10.6
Gate width (m)	4.6
Northern gate (m)	4.3-4.7
Eastern gate (m)	4.35-4.8
Southern gate (m)	4.2-4.3
Western gate (m)	4.4-5.1
Palisade	
Palisade length (m)	435.25
Palisade observed (m)	49.2
Palisade ditch measured (m)	21.5
Palisade post recorded	77
Palisade post average size (m)	0.39 x 0.114
Turf	
Rampart area (m^2)	4261
Volume (m^3)	6567
Rampart height (m)	3
Turf height (cm)	10
Area turf (ha)	6.57

Table 2. Rampart dimensions and the resulting turf source area needed for building the rampart at the Borgring fortress.

Pollen analysis of the Rampart Turfs

The pollen analysis showed great uniformity between the samples, indicating that they were harvested from the same vegetation type (Figure 5 and Supplementary A). There was, however, a slight tendency for the turfs from the rampart to the west to have more pollen of trees and sedges (Cyperaceae) along with some ferns (*Dryopteris* sp.) than the turfs from the rampart to the south, which had slightly more herbs. This could be due to minor differences

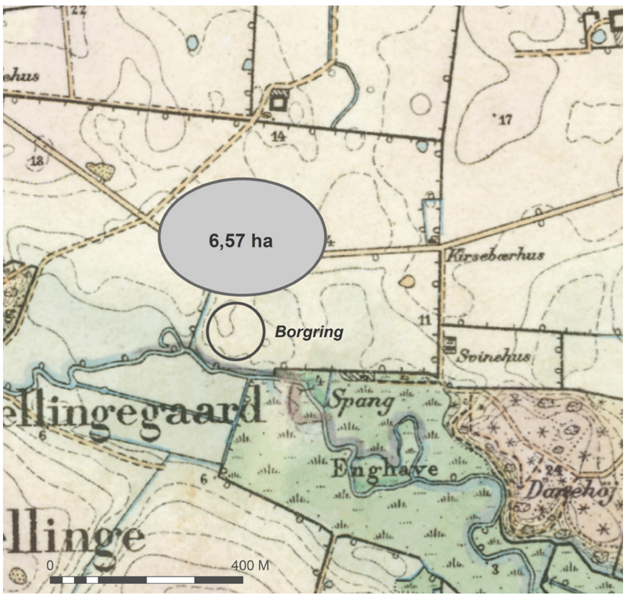

Figure 4. The total area and possible source area of grassland needed to collect turfs for the circular rampart to a height of 3 m at the Borgring fortress (includes data from Agency for Data Supply and Efficiency and Høje Maalebordsblade, December 2019).

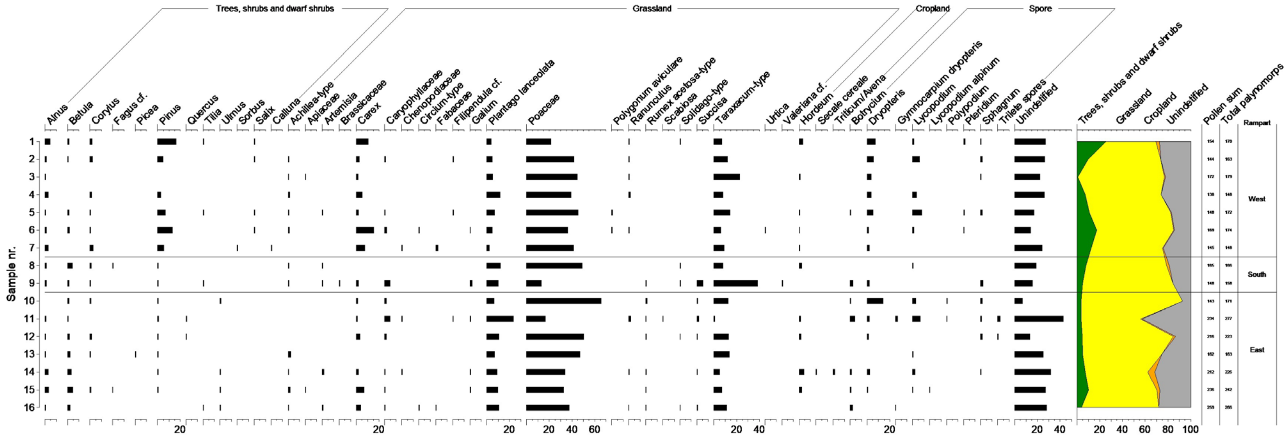

Figure 5. Pollen records from analysed turfs from the eastern, southern, and western ramparts at the Borgring fortress.

in the local vegetation caused by variations in soil type, moisture content and grazing pressure. Some of the samples contain a high amount of unidentified pollen (up to 20 %), which potentially could alter the general picture of the open land condition. However, many of the most common tree pollen types can be determined even in a relatively degraded state. The majority of the unknown pollen types are believed to belong to non-arboreal types.

On the whole, the pollen samples, with their high content of grasses and grazing indicators such as common sorrel (*Rumex acetosa*-type) and ribwort plantain (*Plantago lanceolata*), indicate that the turfs were harvested from a mostly treeless, dry agrarian landscape with persistent grazing (Figure 5).

Wood identification, Timbers and the reconstruction of the Ring Fortress

Five different tree taxa were found amongst the 59 analysed fragments of wood and charcoal sampled from the construction timbers of the gates that were burnt down during the Viking Age (Baittinger 2018). Oak (*Quercus* sp.) is dominant with 59 %, followed by elm (*Ulmus* sp.) with 34 %, along with some ash (*Fraxinus excelsior*), alder (*Alnus* sp.), and fruit trees (Spiraeoidea, including taxa like *Prunus* and *Sorbus*), each with 2.3 % (Figure 6A-B; Table1). No timber is preserved from the rampart cladding, but the faint traces on the outer margin show that

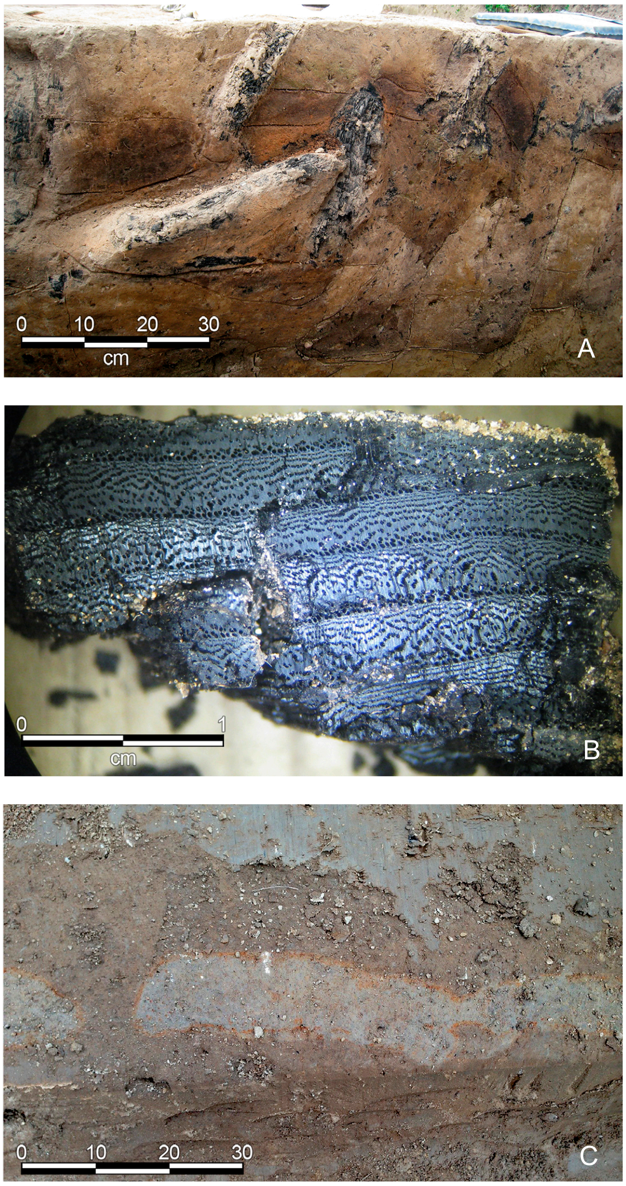

Figure 6. A) Burnt timbers and post of elm (*Ulmus* sp.) from the eastern gate at the Borgring fortress (Photo: Claudia Baittinger); B) Carbonised elm (*Ulmus* sp.) tree from the eastern gate (Photo: Claudia Baittinger); C) Palisade post traces (horizontal profile) (Photo: Museum Southeast Denmark).

both split planks and posts were used (Figure 6C). Most of the timbers were of relatively modest sizes i.e. 16-25 cm wide and 14-16 cm thick and even young trees were used. These thinner pieces, together with alder and fruit trees, were used where the builders could be less fastidious.

It was possible to estimate both the total amount of timber used and the size of timbers on the basis of these traces and the burnt construction timbers, along with the observed postholes. Due to the fragmented tree taxa data, the calculation of the total amount of timber used is based solely upon oak, as this was the preferred building material. The reconstruction may overestimate the required resource area if large numbers of other tree taxa have been used in the construction.

The observations of 26 plank and post traces associated with the timber cladding on the outer margin of the rampart suggest a plank size of *c*.0.29 m wide and 0.11 m thick, with an average gap of 0.13 m between the planks. The planks for the cladding were placed in a trench dug along the outer foot of the rampart. The trench was, however, seldom deeper than the topsoil, suggesting that some sort of horizontal plank structure fixed the vertical planks in place. Furthermore, since the planks may have been tapered before being placed in the trench, the spacing between the planks is likely to have been less than 0.13 m above the surface of the ground. Therefore, in our reconstruction of Borgring, we have set the spacing between the above-ground planks to 0.03 m. The vertical and the horizontal planks were approximately the same size, which would ensure stability in a structure with gaps of around 0.1 m between the timber posts. In order to secure the plank cladding of the rampart, at least four rows of these 'barrel hoop' type fixtures (stringers) would have been needed. These stringers were secured to the planks along the rampart frontage and must have been placed on the inner side of the cladding so that they could not be used by attackers as steps from the outside. The fixing of the vertical planks on the rampart frontage with the stringers was probably done by driving large wood pegs through both planks and into the rampart turfs (Figure 7). This technique was used to fix timber cladding at the Kanhave Canal on the island of Samsø dating to AD 726 (Christensen 1995, 99-117). The Borgring gates were built with heavy-duty corner posts with a post-built wall along openings in the rampart. It is assumed that this was fixed in place with a wall plate supported by transverse tie beams. The Borgring construction is, in principle, a tunnel gate, but it is not known whether the roof covered the whole gates or just the frontage.

The reconstruction (Figure 7) is based on the results gained from the excavation campaigns

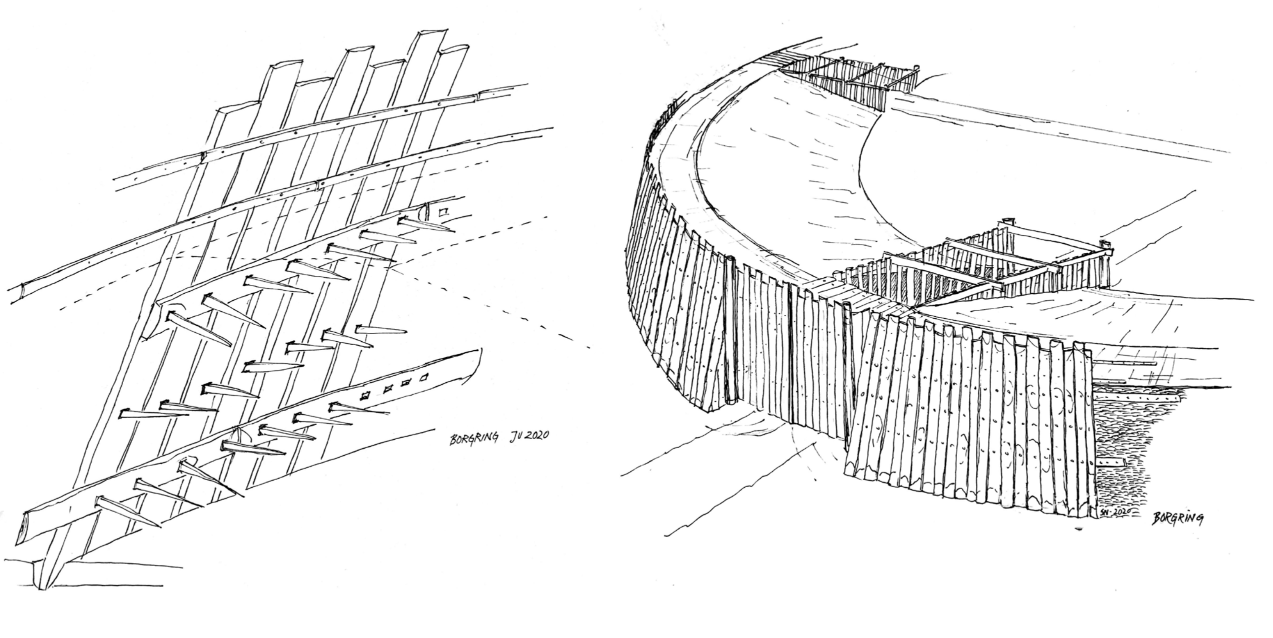

Figure 7. Left) Reconstruction drawing of the palisade construction components; The two different sizes of vertical cladding planks, the four runs of stringers and the large wood pegs used for fixing the vertical planks on the rampart frontage with the stringers and the rampart turfs; Right) Reconstruction drawing of the Borgring fortress palisade and rampart (Drawings: Søren Nielsen and Jens Ulriksen).

Timbers utilized (estimated)		
Components	Dimensions Length x breadth x thickness (m) *or* Length x diameter (m)	Quantities
Palisade		
Vertical cladding planks (long)	4.90 x 0.29 x 0.10	680
Vertical cladding planks (short)	4.70 x 0.29 x 0.10	680
Horizontal stringers (above the top surface of the rampart)	3.50 x 0.20 x 0.10	249
Horizontal stringers (below the top surface of the rampart)	3.50 x 0.15 x 0.10	259
Gateways		
Vertical timbers	4.30 x 0.30 x 0.10	60
Horizontal stringers	2.30 x 0.20	16
Diagonal braces	3.50 x 0.20	8
Corner uprights	5.60 x 0.36	16
Side posts	3.50 x 0.22 x 0.15	240
Roof-bearing stringers	5.50 x 0.20 x 0.10	16
Roof planking	2.65 x 0.30 x 0.10	64
Beams	5.00 x 0.20	20
Timbers in all		**2308**

Applied number of trees	
Tree-boles with an average breast-height diameter of 0.65 m (providing raw materials for an average of six timbers)	183
Tree-boles with an average breast-height diameter of 0.35 m (providing raw materials for an average of two timbers)	605
Trees in all	**788**

Table 3. Calculations of timbers and trees needed for the construction of the Borgring fortress.

conducted at the site, along with research results gained from investigating the other Danish Viking Age ring fortresses and conducting experimental archaeological projects exploring Viking Age craftsmanship (Nielsen 2011, 59-82; Ravn 2016, 17-54). Many assumptions have been made in the calculation of the amount and sizes of the different timber components and it is important to stress that the stated total amount of timbers utilised must be viewed with some caution. A minimum use of 2308 timber components is calculated for the construction of Borgring (Table 3). Tree boles with an average breast-height diameter of either 0.35 or 0.65 m from approximately 789 trees of two size classes were used to craft these timbers (Table 3 and Figure 8). The calculated amount of oak timber used for the Trelleborg ring fortress included different growth age/size classes (Jessen 1948, 173-178) and similarly estimated the area of oak woodland required to supply the construction. This was based on a series of woodland studies of the eastern Danish oak woodlands between the end of the 1800s and the beginning of the 1900s, which gives the density of oak per hectare in Danish woodlands at that time. In the calculations for the timber used at Borgring, we use corresponding size classes. We also estimate the area of oak-dominated woodlands required to collect the required amount of oak timber by applying the density data of Jessen (1948, 173-178) of oak in native Danish forests. The resulting estimated forest required to supply the Borgring construction is 7.4 ha (Table 4). As timber sizes are as small as 10 cm, we can expect that practically all usable oak was felled.

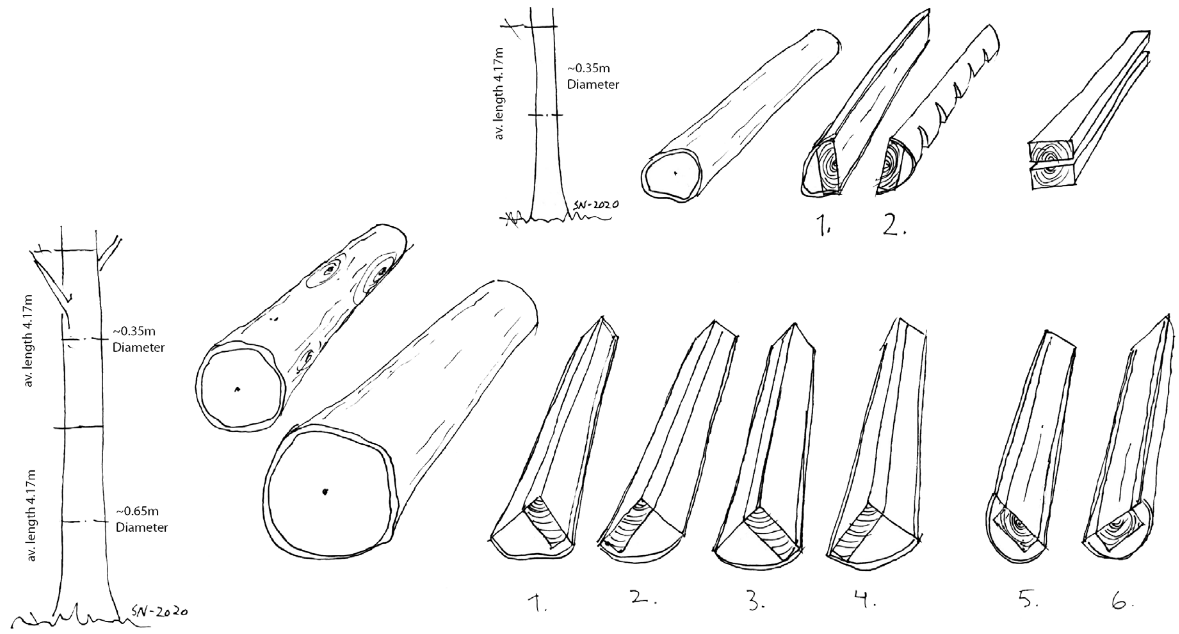

Figure 8. Procurement of wood resources for building the Borgring fortress. Top) A tree with a breast-height diameter of approximately 0.35 m and a minimum bole height of 4 m is felled. The log is cleft in two and subsequently dressed by axe providing raw materials for an average of two timbers; Bottom) A tree with a breast-height diameter of approximately 0.65 m and a minimum bole height of 8 m is felled. The log is divided into two parts: A bottom part with a diameter of approximately 0.65 m and a top part with a diameter of approximately 0.35 m. The bottom part is cleft in four and the top part is cleft in two. The cleft pieces are subsequently dressed by axe providing raw materials for an average of six timbers (Drawing: Søren Nielsen).

The smallest size of timber – for example, the pegs used as fasteners – are not included, as these size classes would probably have been available from the crowns of the felled oaks and from the forest floor.

REVEALS and local Resource Areas

The results of the REVEALS modelling covering the last 2000 years (Figure 9; Supplementary B) show an open landscape dominated by grasses (Poaceae) (29-56 % cover) with a quite high cover of ribwort plantain (*Plantago lanceolata*) (1-9 %). This likely reflects large grazing areas. Open wetlands (represented in the REVEALS estimate by sedges (Cyperaceae) covering 3-23 % of the region) may also have been used for grazing or mowed for hay. Cereal (Cerealia) cover is seen throughout the period but increases strongly from the 1350s and peaks in the 1500s (Figure 9). The cover of cereal and rye (*Secale cereale*) are of course an underestimation of the area of arable fields, as these also contained weeds, such as part of the cover of common sorrel (*Rumex acetosa*-type) and mugwort (*Artemisia*) as well as species not included in the REVEALS analysis, such as hemp (*Cannabis sativa*) and flax (*Linum* sp.). The regional tree cover around AD 985 was 37 % ± 2 % and dominated by beech (*Fagus sylvatica*) and hazel (*Corylus avellana*). Oak (*Quercus* sp.) had a coverage of 3.3 % ± 0.3 %, which means that there was approximately 1 ha of oak stands for every 30 ha in the landscape. To supply the construction site with 7.4 ha of oak woodland, 223 ha of agrarian Viking Age's landscape was needed.

Discussion

The uniform and stringent design of ring fortresses shows that they were built to a predefined plan by competent builders who probably knew in advance the raw material requirements and whether there were sufficient local resources (Ulriksen, Schultz and Mortensen 2020). At Borgring there are few indications of how the work was organised, but the geophysical survey of the rampart, together with

	Trees
Oak (average 0.35 m)	605
Oak (average 0.65 m)	183
Oak trees in total	788
REVEALS oak land cover (%)	3.3
Ha cultural landscape needed for 1 ha oak	30.3

Borgring			
Size classes (after Jessen 1948)	Oak (average 0.35 m)	Oak (average 0.65 m)	
Rampart and gates	605	183	788

	Trees pr. ha forest	Trees needed	Area forest needed (ha)
Oak (average 0.35 m)	150	605	4.0
Oak (average 0.65 m)	55	183	3.3
SUM		788	7.4

	Ha cultural landscape	Km² cultural landscape	Radius from Borgring (km)
REVEALS 100 % usable oak for timber	**223**	**2.2**	**0.84**
REVEALS 50 % usable oak for timber	446.1	4.5	1.19
REVEALS 25 % usable oak for timber	892.2	8.9	1.69

Table 4. Calculation of the resource area of oak woodland (*Quercus* sp.) needed for the construction of the Borgring fortress.

field observations, clearly shows that it was built in sections (Figure 3). The rampart in the southwest was laid out with dark coloured turfs in the lowest layer with a slightly elevated boundary across the rampart. The rampart above this lowest layer was built in sections of alternately dark and light turfs and soil. The sectioning possibly reflects different work gangs cutting turf from different areas around the fortress. This is supported by the different pollen spectra seen in the turfs from the eastern, southern and western parts of the rampart (Figure 5). The pollen analysis of the turfs also shows that the ring fortress was built in an open, grazed agrarian landscape and it is not surprising that turf was chosen from these dryland areas, as the lower organic content of these turfs would have reduced any later settling of the ramparts.

Whilst the turfs are likely to have been harvested from the immediate surroundings, it was not necessarily the case that the timbers for the rampart cladding and gates were also found locally. Eastern Zealand has some of Denmark's best agricultural land, a flat moraine landscape that is relatively easily cultivated, and much of it was already deforested by the Bronze Age (Mortensen et al. in prep). Access to suitable timber was therefore not guaranteed. This raises the obvious question of whether the raw materials were sourced locally or whether

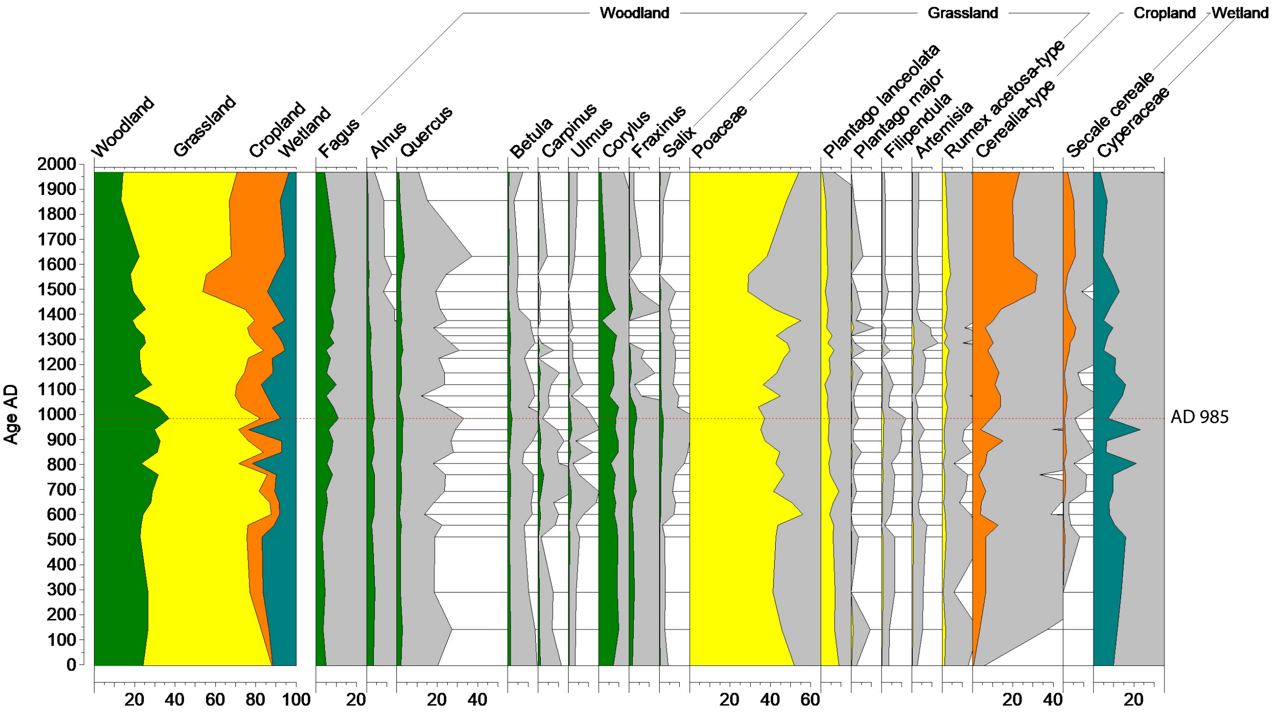

Figure 9. REVEALS-modelled diagram from lake Dalby Sø showing estimated regional vegetation land cover percentages over the last 2000 years. The grey curves represent 10x exaggeration.

they were imported from further afield. Studies of other large Viking Age construction projects, such as the Jelling complex or the monumental oak bridge found at Ravning Enge, indicate that timbers were sourced locally (Jessen et al. 2014, 17), however, we also know that large amounts of building timbers were exported from Norway to Iceland in the beginning of the eleventh century AD (Sigurđsson 2005, 181-196; Stefánsson 1997, 25-41). The import of timber over large distances was therefore a real possibility.

The pollen and REVEALS analysis indicate that beech was the most common tree species found in the region around Borgring (Figure 9) but there is no evidence of beech being used for construction components in the ring fortress, presumably because beech is of limited use as a building timber (Smith 1959).

As the pollen analysis of turfs indicates that Borgring was placed in an open grassland it is unlikely that natural or semi-managed oak-dominated forest could be found in the immediate vicinity of Borgring, as this would result in higher oak percentages in the pollen analysis of the turfs. The REVEALS model shows that the average regional coverage of oak within roughly 25 km of Borgring was approximately 3.3 % around AD 985, meaning that in principle there was enough timber for both the gates and the palisade within 223 ha (2.23 km^2). If we assume a uniform distribution of the vegetation in the surrounding landscape, this is equal to a radius of 840 m around Borgring.

In reality, however, vegetation distribution is very unlikely to have been uniform. But the modelling gives us an opportunity to examine different scenarios and their impact on the required source area. For example, reducing the amount of usable oak in the area near Borgring by 50 % would increase the source area needed to a radius of 1190 m, while a reduction of 75 % necessitates a radius of 1690 m. In comparison, the constructions at Trelleborg – including 31 houses, oak cladding on both the inner and outer sides of the ramparts, and wooden circular and crossroads – would have consumed much more timber, and would have required a radial source area of 4040 m, assuming only oak was used. This expands to 5720 m if the amount of available oak is reduced by 50 %. Even though the model cannot give a complete and full representation of the source area, as it assumes an unrealistic uniformly distributed vegetation, it does give an indication of the scale of the hinterland necessary for such building projects. Though we cannot exclude the use of imported timber, the

Figure 10. Areas with preserved Celtic field systems in Krageskov (dotted line), south of the Borgring fortress, of around 500 ha. Present day forest is marked with green and the shaded areas show the preserved ridge and furrow system (includes data from GeoDanmark, Agency for Data Supply and Efficiency and Danske kommuner, june 2020 and Terrain 0.4 m, December 2019).

results show that sufficient timber resources for the construction of Borgring could be sourced in the local area and that the import of timber was not a precondition for the work. The size and type of wood used also indicates a local origin, as it is not likely that tree taxa with limited construction quality such as ash, alder, and fruit including *Prunus* sp. and *Sorbus* sp. were imported. The taxa used in the construction is, however, based on fragmentary material from the gates and it is not possible to say how common they were.

But where were the major forests close to Borgring? The pollen analysis of sediments from eastern Danish lakes shows that the overall landscape structure established during the Bronze Age was very similar to that seen on maps of the 1700s and updated maps of the early 1800s from Videnskabernes Selskab (the Royal Academy) (Nielsen and Odgaard 2010; Odgaard and Rasmussen 2000). Through these maps we can get a clue as to where the woodlands supplying the timber may have been located. The woodlands of the Viking Age were probably primarily found in the hilly central area of Zealand, where there are also many place names ending in 'tved' and 'rød', both of which indicate forest clearings from the Viking and Middle Ages (Dam 2015, 129-141). However, a more likely choice of woodland for the Borgring fortress lies 1.5 km south of Køge stream, in a forest now known as Krageskov (Figure 10). This forest has grown on a well-preserved Celtic field system, which is already known to have stretched over 124 ha (www.kulturarv.dk; accessed 2020) but has been recognised in a further 366 ha as a result of work within the present project. We know from other sites that these systems were abandoned in the first few centuries AD, and the fact that they are still preserved shows that the areas were not later ploughed (e.g. Arnberg 2007, 33; Rasmussen, Henriksen and Mortensen 2015, 137). These preserved field systems beneath present-day forests are fairly common in the eastern Danish region. One study shows that at Tårup Lund Forest, in eastern Fyn, the Celtic fields were abandoned around AD 300 and the forest took over immediately afterwards (Rasmussen, Henriksen and Mortensen 2015). As the younger 'ridge and furrow' fields are very rarely seen in Krageskov, this also indicates that the forests were established fairly soon after the abandonment of the Celtic field systems in most areas, and hence existed during the Viking Age. There are in total around 500 ha of forest growing on preserved Celtic field systems immediately south of Borgring, and it is therefore likely that these were the principal areas supplying timber for Borgring.

Quantification of the resource area needed for constructing a ring fortress has not been carried out for other ring fortresses. Trelleborg, Nonnebakken and Fyrkat all lie in open and cultivated landscape types, similar to Borgring (e.g. Christiansen 1989; Jessen 1948, 174; Odgaard and Nielsen 2009; Rasmussen 2005), and it is likely that local resources were similarly available. However, this was probably not the case for Aggersborg, a larger fortress with 48 houses within the ramparts, as Aggersborg lies in an area of northern Jutland that had far fewer woodlands than southern and eastern Denmark in the Viking Age (e.g. Kristiansen et al. 2020).

On a local scale, comparable to the resource area of a village, the impact of fortress building would thus have been considerable and may have led to a shortage of prime building timbers. However, it is also possible that the results were perceived as landscape improvement, since increased clearance of land for grazing and cultivation was ongoing. On a regional scale, the impact would have been hardly detectable. The Danish landscape had been transformed by intense cultural impact since the Neolithic period. The early medieval agrarian colonisation further contributed to large-scale clearance of former forest land. By comparison, the analysis of the materials used in the construction of the Borgring and Trelleborg fortresses show that the required resources could be sourced with a less severe impact on the natural landscape than previously suggested (Jessen 1948, 178). While the Viking Age ring fortresses were undoubtedly a powerful expression of organisation, the ecological impact on the local environment near Borgring and possibly its sister fortresses, was limited.

Conclusion

Prehistoric monumental building works are often believed to have caused severe impact on landscape. In the case of the Borgring ring fortress we can now model the impact with considerable precision.

The Borgring circular ramparts were built using turfs of dryland soils probably collected from the area immediately north of the fortress. Turfs from an estimated 6.57 ha of grasslands would have been needed to construct the ramparts to a height of 3 m.

By modelling the pollen data from the local lake, Dalby Sø, it is shown that if construction timber were entirely of oak (*Quercus* sp.), the timber for the rampart timber cladding and the gates was, in principle, available locally within a radius of 810 m. If the amount of usable timber in the forest is reduced by 50 % and 75 %, the radius required around Borgring increases to 1240 m and 1630 m respectively. If the larger ring fortress at Trelleborg, which had a much greater timber requirement, was in the same type of landscape, it would need a resource area with a radius of 4040 m.

The results indicate that the resources could be supplied from within a workable distance and that the import of timber was not necessary to build the fortress. The most likely timber source area for Borgring is within Krageskov 1.5 km south of Køge stream, where there are more than 500 ha of forest growing on preserved Celtic field systems.

Modelling of the required resource area indicates a much smaller area than previously assumed and the construction of the fortress would not have had such a significant impact on the environment in general, though local communities could have experienced a shortage of building timber over the following years.

Acknowledgements

The authors would like to thank the three anonymous reviewers for valuable comments on the manuscript. This work was part of the Borgring Project 2016-18 project funded by A.P. Møller og Hustru Chastine Mc-Kinney Møllers Fond til almene Formaal, with additional support from Køge Municipality. This article is one of more contributions discussing targeted aspects of the results of the Borgring Project 2016-18 published in Danish Journal of Archaeology. The authors declare that there is no conflict of interest.

References

Arén, E., 1995. Rekonstruktionen av Trelleborgen. *In*: B. Jacobsson, E. Arén and K.A. Blom, eds. *Trelleborgen – en av kung Harald Blåtands danska ringborgar.* Trelleborg: Trelleborgs kommun, 63-139.

Arnberg, A., 2007. *Där människor, handling och tid möts.* Stockholm Studies in Archaeology 42. Stockholm: Stockholm University.

Baittinger, C., 2018. *Vedanatomisk analyse af forkullede stolper og planker fra Øst- og Vestport i Lellinge Borgring KNV00047*. M&M rapport 40. Copenhagen: National Museum, 1-4.

Beug, H.-J., 2004. *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. München: Verlag Dr. Friedrich Pfeil.

Broström, A., Sugita, S. and Gaillard, M.J., 2004. Pollen productivity estimates for the reconstruction of past vegetation cover in the cultural landscape of southern Sweden. *The Holocene* 14(3), 368-381. https://doi.org/10.1191/0959683604hl713rp

Christensen, K., 1995. Kanhave-kanalen. *In*: H.H. Hansen and B. Aaby, eds. *Stavns Fjord – et natur- og kulturhistorisk forskningsområde på Samsø.* Copenhagen: National Museum, 99-117.

Christensen, J., Holm, N., Schultz, M.K., Sindbæk, S.M. and Ulriksen, J. 2018. The Borgring Project 2016–2018: Investigating the 5th geometrical Viking-age ring fortress in Denmark. *In*: J. Hansen and M. Bruus, eds. *The Fortified Viking Age. The 36th Interdisciplinary Viking Age Seminar, Odense 2017*. Odense: University Press of Southern Denmark, 60-68.

Christiansen, T.E., Foged, N., Jørgensen, S. and Petersen, K.S., 1989. Trelleborg og Pine Mølle. *Aarbøger for Nordisk Oldkyndighed og Historie* 1989, 9-98.

Daly. A., 2017. *Undersøgelse af tømmer fra Borgring, Køge, KNV00047.* Dendro.dk rapport 71: 2017.

Dam, P., 2015. *Bebyggelser og stednavnetyper.* Navnestudier 44. København: Museum Tusculanums Forlag.

Fredh, E.D., 2012. *The impact of past land-use change on floristic diversity in southern Sweden – A quantitative approach based on high-resolution pollen data*. LUNDQUA Thesis 66, Department of Geology, Quaternary Sciences, Lund University.

Fægri, K. and Iversen, J., 1989. *Textbook of pollen analysis.* London: John Wiley.

Goodchild, H., Holm, N. and Sindbæk, S.M., 2017. Borgring: the discovery of a Viking Age ring fortress. *Antiquity* 91(358), 1027-1104. https://doi.org/10.15184/aqy.2017.118

Hellman, S.E.V., Gaillard, M.-J., Broström, A. and Sugita, S., 2008. Effects of the sampling design and selection of parameter values on pollen-based quantitative reconstructions of regional vegetation: a case study in southern Sweden using the REVEALS model. *Vegetation History Archaeobotany* 17, 445-459 (2008). https://doi.org/10.1007/s00334-008-0149-7

Holst, M.K., Jensen, M.D., Andersen, S.W. and Pedersen, A., 2012. The Late Viking-Age Royal Constructions at Jelling, central Jutland, Denmark. Recent investigations and a suggestion for an interpretative revision. *Prähistorische Zeitschrift* 87(2), 474-504. https://doi.org/10.1515/pz-2012-0022

Jessen, C., Henriksen, P.S., Hald, M.M. and Ulriksen, J., 2021. The lost Landscape of Borgring: Geoarchaeological Investigations into the navigation to, and location of, the Danish Viking Age Ring Fortress. *Danish Journal of Archaeology 10,* 1-14. https://doi.org/10.7146/dja.v10i0.121917

Jessen, K., 1948. Om naturforholdene ved Trelleborg og forbrug af træ ved borgens opførelse. *In*: P. Nørlund, ed. *Trelleborg.* København: Nationalmuseet, 163-179.

Jessen, M.D., Holst, M.K., Lindblom, C., Bonde, N. and Pedersen, A., 2014. A Palisade Fit for King: Ideal Architecture in King Harald Bluetooth's Jelling. *Norwegian Archaeological Review* 47(1), 42-64. https://doi.org/10.1080/00293652.2014.921239

Kristiansen, K., Melheim, L., Bech, J.-H., Mortensen, M.F. and Frei, K.M., 2020. Thy at the Crossroads: A Local Bronze Age Community's Role in a Macro-Economic System. *In*: K.I. Austvoll, M.H. Eriksen, P.D. Fredriksen, L. Melheim, L. Prøsch-Danielsen and L. Skogstrand, eds. *Contrasts of the Nordic Bronze Age. Essays in Honour of Christopher Prescott.* (The Archaeology of Northern Europe 1). Turnhout: Brepols, 269-282.

Mortensen, M.F., Prøsch-Danielsen, L., Stockholm, J.R., Nielsen, A.B. and Olsen, J., in prep. *11.000 years of vegetation dynamic and environmental changes based on pollen and macrofossil data from Lake Dalby, Southeast Denmark.*

Nielsen, A.B., 2004. Modelling pollen sedimentation in Danish lakes at c. AD 1800: An attempt to validate the POLLSCAPE model. *Journal of Biogeography* 31, 1693-1709. https://doi.org/10.1111/j.1365-2699.2004.01080.x

Nielsen, A.B. and Odgaard, B.V., 2010. Quantitative landscape dynamics in Denmark through the last three millennia based on the Landscape Reconstruction Algorithm approach. *Vegetation History and Archaeobotany* 19(4), 375-387. https://doi.org/10.1007/s00334-010-0249-z

Nielsen, S., 2011. The Sea Stallion from Glendalough: Reconstructing a Viking-Age longship. *In*: K. Staubermann, ed. *Reconstructions: Recreating Science and Technology of the Past.* Edinburgh: National Museum of Scotland, 59-82.

Odgaard, B.V., 2010. Skovens historie. *In*: K. Sand-Jensen and P.F. Møller, eds. *Naturen i Danmark - Skovene.* København: Gyldendal.

Odgaard, B.V. and Nielsen, A.B. 2009. Udviklingen i arealdækningen i perioden 0-1850. Pollen og landskabshistorie. *In*: Odgaard, B.V. and Rømer, J.R., eds. *Danske landbrugs-landskaber gennem 2000 år – fra digevoldinger til støtteordninger*. Aarhus Universitetsforlag. https://doi.org/10.7146/gn.v0i6.3535

Odgaard, B.V. and Rasmussen, P., 2000. Origin and temporal development of macro-scale vegetation patterns in the cultural landscape of Denmark. *Journal of Ecology* 88, 733-748. https://doi.org/10.1046/j.1365-2745.2000.00490.x

Rasmussen, P. 2005. Mid- to late-Holocene land-use change and lake development at Dallund Sø, Denmark; vegetation and land-use history inferred from pollen data. The Holocene 15,8. 1116-1129 https://doi.org/10.1191/0959683605hl884rp

Rasmussen, P., Henriksen, P.S. and Mortensen, M.F., 2015. Tårup Lund – Vegetationshistorie. Oldtidsagernes datering og vegetationshistoriske sammenhæng belyst gennem geobotaniske undersøgelser af et lille mosehul. *In*: V. Nielsen and N.C. Clemmesen, eds. *Oldtidsagre i Danmark. Fyn og Langeland*. Højbjerg: Jysk Arkæologisk Selskab, 137-149.

Ravn, M., 2016. *Viking-Age War Fleets. Shipbuilding, resource management and maritime warfare in 11th-century Denmark.* Roskilde: Viking Ship Museum. https://doi.org/10.1111/1095-9270.12231

Roesdahl, E. and Sindbæk, S.M., 2014. The purpose of the fortress. *In*: E. Roesdahl, S.M. Sindbæk, A. Pedersen and D.M. Wilson, eds. *Aggersborg: The Viking-Age Settlement and Fortress*. Højbjerg: Jutland Archaeological Society, 383-414.

Schmidt, H., 1985. Om bygningen af et vikingetidshus på Fyrkat. *Nationalmuseets Arbejdsmark* 1985, 48–59.

Schweingruber, F., 1990. *Anatomy of European wood: an atlas for the identification of European trees, shrubs and dwarf shrubs.* Bern: Haupt.

Sigurðsson, J.V., 2005. Høvdingene, storkirkene og den litterære aktiviten på Island fram til ca. 1300. *In*: S. Imsen, ed. *Den kirkehistoriske Utfordring.*Trondheim: Tapir Akademisk, 181-196.

Sindbæk, S.M., 2014. The fortress. *In*: E. Roesdahl, S.M. Sindbæk, A. Pedersen and D.M. Wilson, eds. *Aggersborg: The Viking-Age Settlement and Fortress.* Højbjerg: Jutland Archaeological Society, 139-208.

Smed, P., 2016. *Sten i det danske landskab*, 4 udgave. Aalborg: Højers Forlag.

Smith, D.N., 1959. *The natural durability of timber*. Forest Products Research Records, No. 30. Wood preservation Series No. 4. 1-17.

Stefánsson, H., 1997. Medieval Icelandic Churches. *In*: L. Árnadóttir and K. Kiran, eds. *Church and Art. The medieval church in Norway and Iceland.* Reykjavik: National Museum of Iceland, 25-41.

Sugita, S., 1993. A model of pollen source area for an entire lake surface. *Quaternary Research* 39(2), 239–244. https://doi.org/10.1006/qres.1993.1027

Sugita, S., 2007. Theory of quantitative reconstruction of vegetation I: pollen from large sites REVEALS regional vegetation composition. *The Holocene* 17(2), 229–241. https://doi.org/10.1177/0959683607075837

Sugita, S., Gaillard, M.J. and Broström, A., 1999. Landscape openness and pollen records: A simulation approach. *The Holocene* 9(4), 409–421. https://doi.org/10.1191/095968399666429937

Ulriksen, J., Schultz, M.K. and Mortensen, M.F., 2020. Dominating the Landscape – the emblematic Setting of Borgring and the Viking Age Ring Fortresses of Denmark. *Danish Journal of Archaeology* 9, 1–22. https://doi.org/10.7146/dja.v9i0.116110

Supplementary A.

Raw pollen data from analysed turfs from the eastern, southern, and western ramparts of the Borgring fortress.

see excel-attachment.

Supplementary B.

Raw pollen data from lake Dalby Sø covering the last 2000 years.

see excel-attachment.