Pine Timber from Trakai Castle as a Source of Information about Past Climate in Lithuania

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Abstract

Scots pine tree-ring chronology was compiled from the rostwerk constructions of the Trakai Castle fore-work. The chronology involves dated 18 tree-ring-width series and runs for 220 years between 1192 and 1411. Constructed chronology shows high similarity with chronologies developed for Lithuania, Latvia and Poland. The investigated samples contain on average 33 sapwood rings with waney edge missing among all samples. The estimation of missing sapwood rings indicates the tentative date of felling in 1426. Abrupt growth depressions with missing rings are typical for the first half of the 13th century; two growth depressions lasted from 1219–1221 and 1237–1239 with the smallest measured ring width in 1238 (on average 0.27 mm). The 14th century is characterized by smaller variations in tree-ring pattern with major depression from 1356–1358.

Key words: dating, Scots pine, tree-ring chronology, Trakai Castle, pointer years

Introduction

Dendrochronology determines the calendar years of tree-ring formation and felling date of tree, which allows to determine the age of wooden objects by one year precision (Haneca et al 2009). Development of dendrochronology is closely related to the construction of long-term chronologies (Hughes et al 1982). The chronologies have been used as a tool for dating timber from historical buildings (Crone and Mills 2012) and reconstructions of the past environmental conditions (Grudd et al 2002, Helama et al 2004, Koprowski et al. 2012). However, well-replicated datasets enable to explore more thematic issues, like provenancing (Bridge 2012, Eckstein and Wrobel 2007, Läänelaid and Nurkse 2006).

Because of the intense timber trade of oak from the Baltic region to Western countries (Wazny and Eckstein 1987, Zunde 1999), Scots pine timber was the commonly used species for building activity in Lithuania (Vitas 2008, Vitas and Zunde 2008). Due to devastating historical events (wars, fires, etc.) in the Baltic countries (Läänelaid 2002), the original timber from building time only seldom could be found, while wood from the later restoration works usually predominate (Vitas 2008). Therefore, in contrast to the Western Europe, construction of the long-term centennial chronologies in Lithuania is more challenging.

Several chronologies of Scots pine were developed in Latvia (Zunde 1998) and Estonia (Läänelaid and Eckstein 2003). The biggest number of chronologies compiled from historical timber in Lithuania usually represents single objects-buildings (Karpavičius et al 1998, Pukienė 2002b) and these chronologies are limited in time. Two long-term pine chronologies were compiled for Lithuania: Litpinus 1 spanning from 1487–2002 (Vitas 2008) and the Vilnius Lower Castle chronology from 1010–2009 (Pukienė 2002a, Pukienė 2009). In spite of new chronologies, only the Vilnius Lower Castle chronology covers the 11th–13th centuries thorough. The sapwood estimation in pines is not performed in Lithuania making the estimation of the date of felling complicate, when the outer sapwood rings are not present in the samples.

Dendroclimatological research using Scots pine tree-ring widths has shown that air temperature in February – March has the most important effect on the radial growth in Lithuania (Vitas 2004, Vitas 2006) as well as in Poland (Koprowski et al. 2012). The higher positive links with precipitation in summer were found only in Eastern Lithuania (Vitas 2006). The sharp decreases of the radial growth of pine are provoked by winter colds and summer droughts, and the marked increases in tree-ring widths were related with higher temperature in winter, spring and summer (Vitas 2008).

The exact dates of the building phases of the Trakai Island Castle and its fore-work are not established. According to historical chronicles, archaeological investigations and architectural analysis, the castle is dated to the second half of the 14th – beginning of the 15th centuries (Baliulis et al 1991, Filipavičienė 2003). The building phases of the fore-work have been dated to the end of the 14th–16th centuries (Baliulis et al 1991, Filipavičienė 2003, Navickaitė-Kuncienė 1961). The aim of the study was to assess the potential of pine timber from the constructions of the Trakai Island Castle for dating and climate reconstruction, and to develop a pine chronology by using tree-ring-width series of archaeological timber.

Material and Methods

Samples of archaeological pine timber were taken during the archaeological investigation of the western casemates (fore-work) of the Trakai Castle in 1978–1979 (Vaškelis 1983). The Castle was built on a peat layer (Baliulis et al 1991), which was found ca. 150-200 cm from the ground level. Pit holes of 60–70 cm depth were excavated in the peat, and the lower layer of pit hole was filled with boulder stones and coarse gravel. The constructions of rostwerks from pine timber were erected in places, where the ground water level was high (Figure 1) (Lisauskaitė 1990a). A layer of boulder stones was set above the rostwerks, otherwise constructions of rosters were erected on the gravel and boulder stones without removal of the peat. Then, the foundations of stones were built (Vaškelis 1983). Rostwerk (in German Rost— grid, and Werk— building, reinforcement) is a single or double deck of logs or timbers carrying out a role of foundation.

In total, 29 samples were taken to the Laboratory of Dendrochronology (Inventory Nos. 2645–2672). 23 samples are being kept in the repository of the Laboratory at present. Usually all four sides the logs are flattened – chopped. The cross-sections have rectangular shape; on average 15 cm on the shorter side and 31 cm on the longer side (Figure 2). The Waney edge, i.e. the last formed tree-ring before felling, is missing among all samples. Sapwood rings are fully or partially missing due to deterioration of the samples.

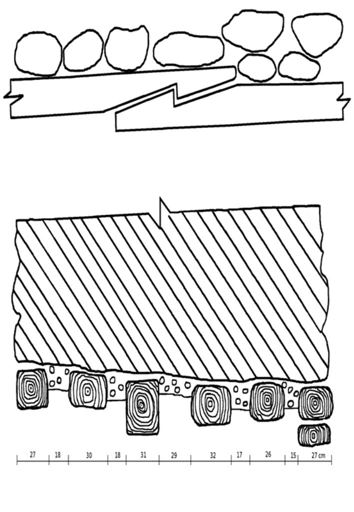

Figure 1. A typical construction of rostwerks from the foundation of western casemates of the Trakai Castle according to Vaškelis (1983): the upper image: the connection of pine timber in rostwerks, the lower image: the cross-section of the wall with the exposed ends of rostwerks

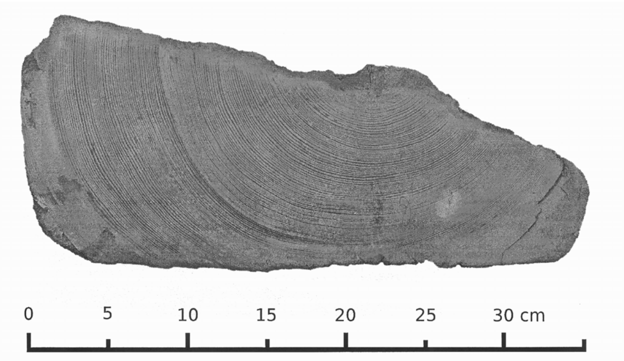

Figure 2. The photo of sample No. 2657 with visible deterioration of sapwood rings

Surface of the cross-sections was sanded with progressively finer grades of sand paper (80 to 320 grit) using eccentric grinder. Cross-sections were measured in two-four radii to the nearest 0.001 mm. For this purpose, LINTAB tree-ring measuring table and TSAPWin 4.67 computer program (F. Rinn Engineering Office and Distribution, Heidelberg) were used. Tree-ring series were synchronised against each other by visual comparison of ring-width graphs; and statistically by calculating the coefficients of similarity "Gleichläufigkeit" (*GLK*), correlation coefficients (r) and t -values according to Baillie and Pilcher (1973) (Eckstein 1987, Eckstein and Bauch 1969). The EPS (Expressed Population Signal) was calculated as an indicator of the common signal in the chronology. The sapwood rings were counted in the samples, and the reconstruction of felling dates of trees was done by estimating missing sapwood rings according to P. Gjerdrum (2013).

Compiled chronology was crossdated against other available pine chronologies from the Baltic region: Gotland (Sweden, Bartholin 1987), Kujawpom (Poland, Zielski and Krąpiec 2004), Polpinus and Polpinus 5 (Poland, Zielski 1992), Polskane (Poland, Zielski 1997), Vilnius Lower Castle (Lithuania, Pukienė 2009). The cluster analysis between chronologies was performed (Statistica 6, Statsoft Inc., Tulsa). The following statistical methods for the analysis of clustering were applied: joining (tree clustering) with linkage rule (Ward's method) and distance measure (1-Person r). The frequencies of cycles expressed in the tree-ring series were assessed by using a single series Fourier (spectral) analysis (Statistica 6.0, StatSoft Inc., Tulsa) was applied.

Standardisation of the series was carried out using Chronol 6.00P program (R.L. Holmes, Tucson). At first a negative exponential curve or linear regression was used and after the polynomial function – spline, preserving 50% of variance at wavelength 128 years was fitted. The index values were calculated as ratios between the actual values and the respective values of the fitted function and then combined using bi-weight robust estimation of the mean (Mosteller and Tukey 1977) into a tree-ring chronology.

Pointer years (Schweingruber et al. 1990) were analysed by using Weiser 1.0 computer program (I.G. García-González, Lugo) (García-González 2001). The threshold value for negative event years is $Z_i \leq -0.75$ and for positive is $Z_i \geq +0.75$. Pointer years during 1210–1383 were detected using a 75% threshold level of event years.

Results

18 out of 23 available samples were synchronized and mean chronology spanning for 220 years was compiled (Figure 3). Five samples remain undated. The undated samples are characterized by much shorter time span – 64–100 years. The similarity between tree-ring series is high and statistically reliable (r = 0.57-0.73, on average r = +0.65). The living span of trees varied from 115 to 202 years (Figure 4), the average tree-ring width from 0.78 to 1.31 mm (on average – 1.03 mm) and mean sensitivity from 0.18 to 0.26 (on average – 0.21). Four missing rings were observed in 1228, 1229, 1230 and 1357.

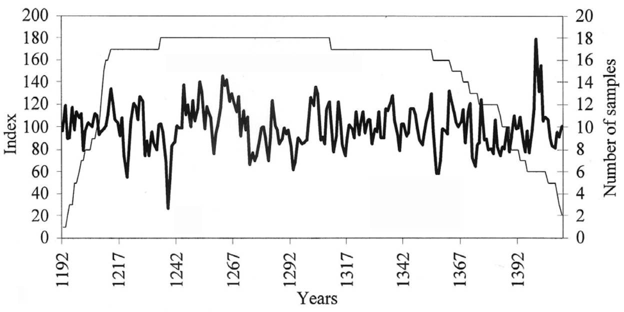

Figure 3. Tree-ring chronology of the Trakai Castle in indices and the number of samples (secondary axes)

Constructed chronology (Figure 3) was crossdated to 1192–1411 against other Scots pine (*Pinus sylvestris* L.) chronologies available for the Baltic region (Table 1). The chronology shows high similarity with the Vilnius Lower Castle pine chronology (t-value is 17.9) and weaker links with chronologies from Poland (t-values range from 6.4 to 7.5), and the Southern Sweden – Gotland chronology (t-value is 4.4). Moreover, the derived chronology shows good agreement with the pine chronologies from Rīga and Cēsis, Latvia (t up to 8.4) (M. Zunde, personal communication). The *EPS* from 1210–1383 was above the usually applied threshold of 0.85 indicating a high similarity between tree-ring series.

Table 1. t-values between chronology of the Trakai Castle against other pine chronologies for the Baltic region; *OVL* is the overlap (years), *GLK* is the coefficient of similarity, *R* is the coefficient of correlation, *TVBP* is a t-test according to Baillie and Pilcher

Name	*OVL*	*GLK*	*R*	*TVBP*
Gotland (Bartholin 1987)	220	60	0.18	4.4
Kujawpom (A. Zielski, Poland)	220	68	0.24	7.3
Polpinus (A. Zielski, Poland)	220	69	0.03	6.4
Polpinus-5 (A. Zielski, Poland)	220	68	0.27	7.5
Polskane (A. Zielski, Poland)	220	68	0.25	7.0
Vilnius Lower Castle (R. Pukienė, Lithuania)	220	82	0.53	17.9

The trees used for constructions of rostwerks were cut from an even-aged stand; the first ring of the samples is from 1192–1210 (Figure 4). 13 samples contain from 9 to 69 sapwood rings. Five samples with the last ring from 1404–1411 contain 29–57 sapwood rings (on average 30 sapwood rings). The outermost ring in the samples stands for 1411 pointing out that the trees were cut after 1411 (Figure 4). The sapwood was totally absent in five out of 18 samples. The series, in which ends before 1380, usually has a small number of sapwood rings. This indicates that sapwood rings were deteriorated or removed artificially, suggesting that all investigated trees were cut at the same time. The estimation of missing sapwood rings gave a val-

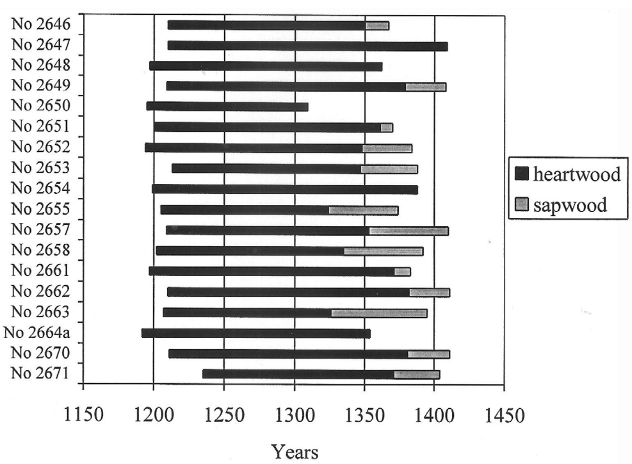

Figure 4. Bar diagram of cross-dated tree-ring series used to construct the Trakai Castle pine chronology; heartwood rings in the samples are shown in dark grey and sapwood rings in light grey

ue of 76–78, indicating that trees were likely felled around 1426.

Abrupt growth depressions are typical for the constructed chronology, especially for the first half of the 13th century. Missing rings were observed among two samples (Nos. 2650 and 2658) in 1228, 1229 and 1230. Spectral analysis has confirmed the domination of longer cyclic components in the patterns of series ranging on average from 33 to 57 years (results not shown in the article).

13 negative and 8 positive pointer years were detected from 1210–1383 (Table 2). The number of pointer years is similar during the 13th and 14th centuries. The first half of the 13th century saw two growth depressions as negative pointers years in 1220 and 1238, which affected 100% of the trees. The depressions lasted from 1219–1221 and 1237–1239, respectively (Figure 3). During the aforementioned depression, the smallest ring width during the entire growth period formed in 1238 (on average 0.27 mm). The period was followed by radial growth release; two positive pointer years were found in 1245 and 1252. During the second half of the century, five negative pointer years were recorded in 1254, 1258, 1270, 1282 and 1293 (Table 2). Smaller variations in tree-ring pattern prevailed during the 14th century (Figure 3). The most pronounced is the growth depression in the 1350s, which lasted from 1356–1358. In 1357, a missing ring was found in sample No 2649.

Table 2. Signature years in the pine chronology derived from the Trakai Castle from 1210–1383; "-" indicates the percentage of trees with negative event years, and "+" the percentage of trees with positive event years

Pointer year	Percentage of trees	Pointer year	Percentage of trees
1213	+77	1307	-78
1220	-100	1309	+78
1238	-100	1311	-77
1245	+100	1313	+94
1252	+89	1316	-82
1254	-78	1340	-82
1258	-100	1354	+76
1270	-89	1357	-75
1282	-94	1373	-77
1284	+89	1376	+83
1293	-89		

Cluster analysis among Scots pine chronologies from the Baltic region (Figure 5) have revealed that the Trakai Castle chronology has the greatest similarity to the Vilnius Lower Castle chronology. The Gotland chronology, in spite of lower correlation with the Trakai Castle chronology, is closest to the Lithuanian chronologies. Four chronologies from Poland form the second sub-cluster.

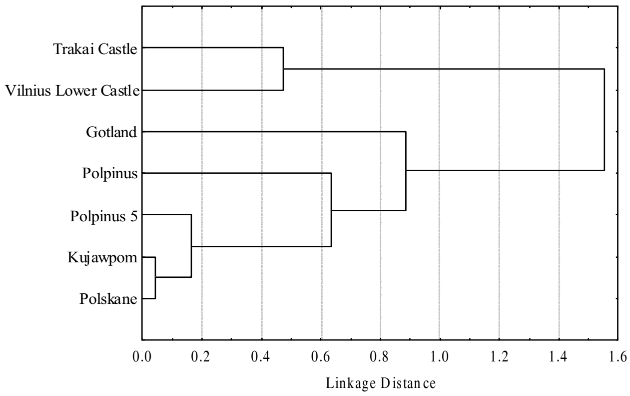

Figure 5. Cluster analysis among Scots pine chronologies for the Baltic region

Discussion and Conclusions

Tree-ring series of pine are characterized by high similarity (r = 0.65, on average). This indicates that trees used for the rostwerk constructions of the Trakai Castle were taken within the same stand. Longer cyclical components (on average from 33 to 57 years) predominate in tree-ring series and may indicate that trees grew under wet conditions as shown by Stasytė et al. (2005) and Vitas (2009, 2010). Constructed pine chronology from the Trakai Castle shows high similarity with chronology derived from the Vilnius Lower Castle (Table 1, Figure 5).

The Medieval Warm Period has ended and climate in Europe has started to deteriorate at the beginning of the 13th century (Koprowski et al. 2012, Lamb 1995), and contrasts have increased (Bukantis 1998). The abrupt growth changes of pines were recorded in 1219–1221 and 1237–1239. In 1219 and 1221, winters were cold, and summer in 1219 was unusually wet (Bukantis 1998). Plague epidemics arose in 1221–1224. In 1237, a plague epidemic repeated, and the cold winter was documented in 1238 (Bukantis 1998). In 1219, the negative pointer year in the radial growth of pine was also observed in Poland (Koprowski et al. 2012). The number of extreme climatic conditions has reduced in the second half of the 13th century (Bukantis 1998). This coincides with planting of new vineyards in England in the 1280s and 1290s (Lamb 1995).

The coldest climate in Iceland reached the culmination around the 1300s (Lamb 1995) because of the beginning of the Little Ice Age (Bukantis 1998). In 1207–1346 and 1383–1425, the coldest periods were reconstructed in Poland (Koprowski et al. 2012). Low winter-spring temperatures prevailed in Poland in 1290–1310 (Zielski and Kamiński 2003). Wet summers altogether with cold winters prevailed in the 1310s. 1320s, 1330s and 1380s were warm and dry with serious droughts, but 1360s predominantly wet (Lamb 1995). The second half of the century is characterized by winter extremes (Bukantis 1998). Smaller variations in tree-ring pattern prevailed during the 14th century. The growth decrease in 1340 is attributed to the exceptionally wet summer in the central Europe (Lamb 1995). The most pronounced growth depression during the 14th century is from 1356–1358. The pointer year in 1357 cannot be related with any known climatic extreme. The pointer year in 1357 was also recorded in Poland (Koprowski et al. 2012). The growth decrease in 1373 (Table 2) coincides with the second recurrence of the plague epidemics in Europe (Hays 2005).

Dating of oak was widely practiced in the Western Europe from the 1960s (Bauch and Eckstein 1981). Dating of wood other than oak has been not so common. Partly, this is explained by predomination of oak in painting panels and building constructions (Baillie 1982). However, wood of conifers predominated as a timber material in Lithuania (Pukienė 2002a, Vitas 2008). Oak wood in bigger amounts was only discovered in the Klaipėda Castle and the old town as well as the Vilnius Lower Castle (Pukienė 2002b). Cross-dating of pine tree-ring series is usually more complicated than of oak because of individual character of the radial growth of pine (Bartholin and Zielski 1992) and missing rings in pine (Vitas and Erlickytė 2007), which only seldom occur in oak (Baillie 1982, Haneca et al 2009).

The exact building time of the fore-work of Trakai Island Castle is unknown (Baliulis et al 1991), and the suggested dating of the phases of building are still controversial. It is also not clear whether the casemates were built together (Lisauskaitė 1990b) with defensive wall or after the defensive wall (Filipavičienė 2003, Navickaitė-Kuncienė 1961). Baliulis et al (1991) affirm that the fore-work was built until 1409. In contrary, Filipavičienė (2003) states that defensive walls were built during the preparations of the coronation of Grand Duke Vytautas, and casemates in the fore-work were likely erected after the death of Grand Duke Vytautas in 1430. This is in agreement with Navickaitė-Kuncienė (1961), who established that casemates were built in the first half and middle of the 15th century.

The investigated pines germinated in 1190s–1200s; the first ring of the samples containing pith stands for 1192–1210. The even-aged stand may be formed because of artificial (logging activities, expansion of the arable land) as well as natural (wind throws, forest fires, etc.) factors.

The missing waney edge in the samples does not allow establishing a precise date of felling. When sapwood is partially missing, the year of felling could be estimated by adding an appropriate number of sapwood rings according to heartwood age rule (Gjerdrum 2013). When all sapwood rings are missing due to deterioration of wood or artificially removed because of weaker sapwood, the reconstruction of the date of felling is not possible. According to Gjerdrum (2013) Scots pine is distinguished by high and variable number of sapwood rings. The average number of sapwood rings in Europe is 51±15 and depends on the cambial age of a tree (Gjerdrum 2013). However, it is not clear does this estimation is also valid for the Baltic countries. The sapwood estimates of pedunculate oak have shown that the number of sapwood rings depends on geographical latitude and longitude (Sohar et al 2012).

An equation for sapwood estimation in pine proposed by Gjerdrum (2013) provided a date of felling in 1426. Hence, a tentative date of felling around 1426 should be treated as very preliminary. However, this date gives suggestion that the building of the western casemates has started before the coronation of the Grand Duke Vytautas, which was planned in 1430. The established felling date in 1426 may change, when the data on sapwood estimation in Lithuania becomes available. Such data will improve an accuracy of sapwood estimation and will lead to a more precise dating, when outermost rings are not present in the samples. Therefore, sapwood estimation in Scots pine in the Baltic States still requires a dedicated study.

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