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RADIOCARBON DATING OF THE WOODEN CAUSEWAY IN HAUKIVAHONSUO BOG NEAR LIETSA IN RENKO

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Masonen (this volume) has described the background for the road investigations at Haukivahonsuo bog and the results of the excavations. This appendix accounts for the radiocarbon dating of the wooden causeway foundation for the road in the bog and the interpretation of the dating results.

Five samples of wood and one of charcoal were dated at the Geological Survey of Finland ^{14}C laboratory (Table 1). A decayed stump of a tree (Su-1502) found from below the causeway and charcoal (Su-1503) also from below the causeway and above a stone predate the structure. Two decomposed hewn boards (Su-1504, Su-1505) beneath the uppermost timbers at both ends of the causeway were assumed to be older than the uppermost timbers (Tiemuseo/ Masonen, 1985). They were dated to find the possible older constructions. Due to the total decomposition of these boards, it is however not known whether the samples dated represent the oldest or youngest annual rings of them. Two samples are from the causeway timbers from the most watery part of the bog: a log (Su-1542) and a pile (Su-1543). For dating these, twenty youngest annual rings were used. These timbers were dated also dendrochronologically (Zetterberg, this volume).

The chemical treatment of the samples for ^{14}C dating was as follows. All the samples were leached with acetone to remove possible contamination by power-saw oil. The wood samples were then reduced to cellulose, because it yields the most reliable dates on wood. The charcoal sample was subjected to acid-alkali-acid treatment, to remove the carbonate or humic contaminants.

The measuring technique employed was the

proportional counting of CO_2 . The conventional ^{14}C ages of the timber from the bridge are corrected for isotopic fractionation using $\delta^{13}\text{C}$ values, measured at the Geological Survey of Finland petrology department by Juha Karhu, ranging from -23.1 to -23.9 ‰ PDB. All the ^{14}C ages are calibrated using the dendrochronological time-scale calibration of radiocarbon.

When comparing ^{14}C ages with ages obtained by other methods, e.g. dendrochronology, they should first be converted to calendar years, because conventional ^{14}C ages may differ considerably from calendar years, due to variations in the atmospheric ^{14}C content (see Eronen & Kankainen, 1986, and cited references). How near the true historical age the calibration leads to, greatly depends on the age and type of sample, the precision of the ^{14}C analysis, and the calibration curve used (Mook, 1983).

The results of the calibration of the ^{14}C ages determined for this study (Table 1) are not necessarily unambiguous. These results are interpreted in more detail below. Many ^{14}C analyses on one aged tree from the causeway and application of a "curve fitting" technique (Pearson, 1986) would perhaps have given a precise calendrical date for this tree. For the results of the present study this was regarded unnecessary, because dendrochronology helped in solving the age problem.

Why is it then so difficult, using ^{14}C method, to date samples from the last centuries? There have been periods when the "wiggles" in the absolute high-precision calibration curve (Pearson & Stuiver, 1986; Stuiver & Pearson, 1986) cause an ambiguous calendrical conversion. One of these periods extends from about AD 1650 to the present time (see Fig. 1).

Table 1. Radiocarbon determinations of samples from Haukivahonsuo bog, Renko, Finland (60°49'N 24°03'E). Calibration drawn from curve by Stuiver and Pearson (1986, Figs 1 and 2).

Lab. No	Object dated	¹⁴ C age yr BP	Most probable date cal AD	68 % probability range cal AD
Su-1502	a stump of a tree found from below the causeway	550 ± 60	1400	1340–1430
Su-1503	charcoal from below the causeway above a stone	1000 ± 70	1020	970–1070
Su-1504	decomposed hewn board, SE end of the causeway	100 ± 40	1880, 1920	1680–1740, later than 1800
Su-1505	decomposed hewn board, NW end of the causeway	220 ± 50	1660	1640–1680, 1740–1800
Su-1542	a log of the causeway	160 ± 45	1680, 1740, 1800, 1940	1660–1700, 1720–1820, 1840–1880, 1920–
Su-1543	a pile of the causeway	175 ± 55	1670, 1750, 1800, 1940	1660–1700, 1720–1820, 1840–1880, 1920–

In this study, the calibration of the ¹⁴C ages of bridge timber (Su-1504, Su-1505, Su-1542, Su-1543) was drawn directly from the internationally accepted calibration curve based on ¹⁴C dated bi-decadal wood samples (Stuiver & Pearson, 1986, Fig. 1). Of these, the samples Su-1542 and Su-1543 cover 20 years as do the points of this calibration curve. The number of annual rings in the samples Su-1504 and Su-1505 is not known, but the bi-decadal calibration curve was used because the use of a "smoothed" curve might have led to a too simple impression of the true age (see Mook, 1983).

The calibration of the sample Su-1542 is shown in Fig. 1. Its conventional ¹⁴C age, 160 ± 45 yr BP, is the weighted average age of the sample (i.e. twenty youngest annual rings). The arrows indicate the corresponding calibrated AD dates. The region of uncertainty applying to one standard deviation (± 45 ¹⁴C yrs, the area between the hatched lines) covers the calendar years cal AD 1660–1700, 1720–1820, 1840–1880 and 1920–, as shown in Table 1. Of these, cal AD 1840–1880 is less probable than the others, because it only overlaps the -1σ line, and cal AD 1920– is not plausible.

The samples predating the causeway (Su-1502, Su-1503) may well represent a time range considerably longer than twenty years. Therefore, the calibration of their ¹⁴C ages was drawn from the "smoothed" 100-year calibration curve of Stuiver and Pearson (1986, Fig. 2).

When was the causeway at Haukivahonsuo

constructed? Does it consist of constructions of different age? The age of the stump from below the causeway (Su-1502) shows that it is not from earlier than the end of the 15th century; presumably there is a time lag of at least fifty years between the date, cal AD 1340–1430, and the death of the tree, because the sample material is from the best preserved inner part of the stump. The charcoal feature (Su-1503) dates back to the 11th century. The hewn board samples (Su-1504, Su-1505) may consist of either innermost or outermost rings of the tree or of both. Therefore the calibration does not solve the date of the cutting of the timber for the boards.

The construction of the causeway must be deduced solely on the basis of the timber dates Su-1542 and Su-1543. The three most probable cal AD dates of these refer to the weighted average date of the sample. Some annual rings must have decayed from the surface of the timbers. There is a time lag of more than ten years between the cal AD dates and the cutting of the trees, i.e. the construction of the causeway. It can only be said that the structure was built either in the end of the 17th century, after the middle of the 18th century or during the first half of the 19th century.

The trees of the samples Su-1542 and Su-1543 were dated by Zetterberg (this volume) dendrochronologically. The outermost rings of these trees are from the years AD 1820 and 1825 (Zetterberg's samples 01 and 16) respectively. This coincides with the latest date deduced from

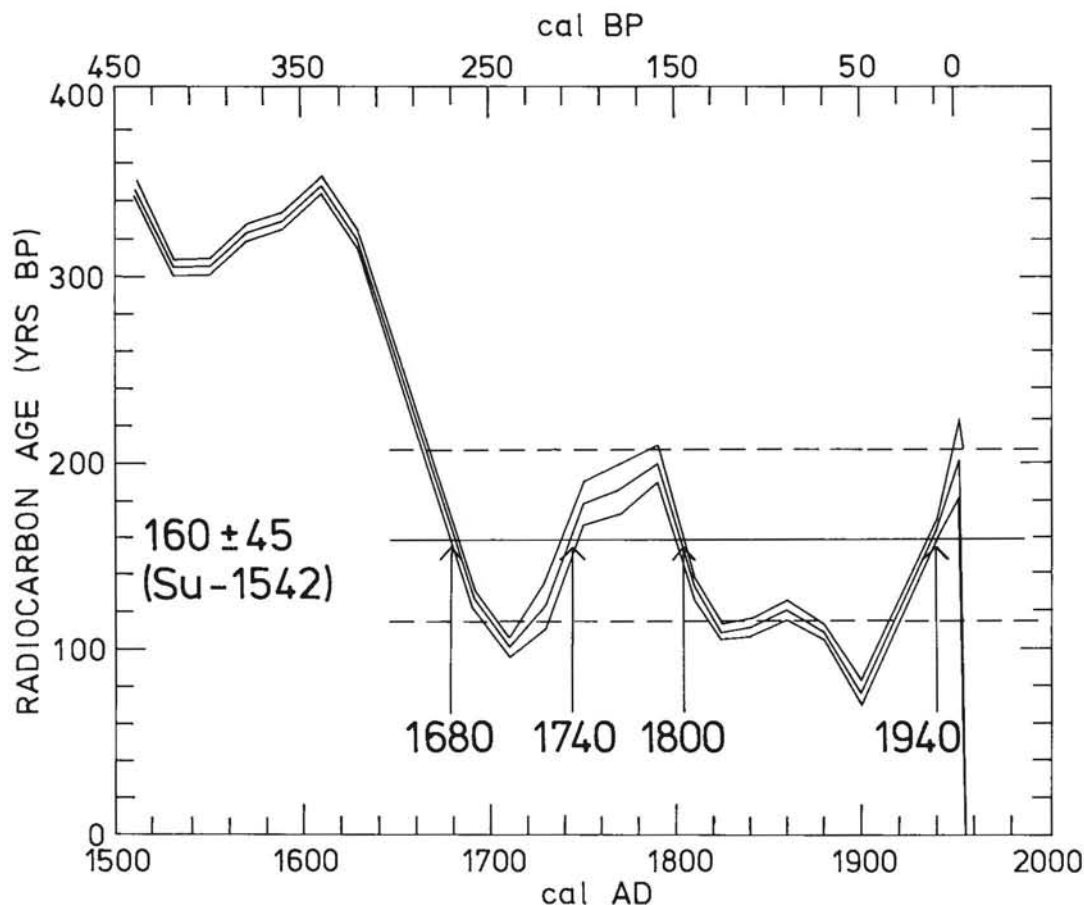


Fig. 1. Part of the high-precision calibration of the radiocarbon time scale (Stuiver & Pearson, 1986, Fig. 1). As an illustration a calibration is shown for a conventional ^{14}C age of a causeway timber sample, covering 20 annual rings. The arrows indicate the most probable cal AD dates for the weighted average ^{14}C age of the sample, 160 ± 45 yr BP. Calibration problems are discussed in text.

the calibrated ^{14}C dates for the construction of the causeway. Also historical evidence (Masonen, this volume) speaks for the construction of the causeway in the 1820s at the earliest.

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Pentti Zetterberg

DENDROCHRONOLOGY AND ARCHAEOLOGY: DATING OF A WOODEN CAUSEWAY IN RENKO, SOUTHERN FINLAND

Abstract

The dendrochronological dating is described from the point of view of what the archaeologist needs to know about the method. Main results of this study are: a) the wooden causeway in Renko was built after the year 1828 and the whole construction is of the same age, b) the applicability of the pine tree-ring chronology for Eastern Finland in the southern parts of the country is good, c) a new 450-year pine tree-ring chronology for Southwestern Finland is established for dating wooden material in the southern part of the country.

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1. INTRODUCTION

With the dendrochronological dating method the age of archaeological, historical and sub-fossil wooden material can be determined with an accuracy of one year. Using this method requires that the material to be dated is well enough preserved and that in the dating itself long absolute so-called annual growth ring or tree-ring calendars are available as reference material. In Northern Karelia a tree-ring calendar of over 600 years has been collected from the tree-rings of Scots pine (*Pinus silvestris L.*). This calendar, pine chronology, extends from our time to the year 1375 and can be used for dating pine material younger than the beginning of the 15th century dendrochronologically, with an accuracy of a year.

How well and in how large an area does the tree-ring calendar from eastern Finland apply to the dating of wooden material from archaeological sites? This was found out by choosing a causeway, sunk in a bog in the commune of Renko, southwest from Hämeenlinna, for dendrochronological dating. Previous estimates of the age of the site varied from the 19th century to as far back as the Middle Ages.

The dendrochronological dates of the causeway in Renko described more thoroughly in this

study were presented earlier in a preliminary paper read at the Nordic meeting for archaeologists (Zetterberg 1988a) in October 1987, as an example of applying scientific methods in archaeology.

2. THE WOODEN CAUSEWAY AT HAUKI-VAHO, RENKO

The site of the causeway is about 40 kms southeast of Hämeenlinna (figure 1) in the village of Lietsa in the commune of Renko, (map 2131 01 LIETSA, co-ordinates $x=674590$, $y=250290$, $z=126$ m a.s.l.). The causeway was formerly sunk in a bog, but later drainage left it above the surface of the bog. The site has attracted interest before. Matti Vakkilainen, who has studied and invented the oldest road net of Finland, originally discovered this causeway and assumed that it could be a part of the ancient road between Loppi and Urjala, probably even medieval (Vakkilainen 1982, pp. 242–244). Accordingly the causeway of Lietsa would have been part of a side-road joining the so-called *Hämeen Härkätie* ('Häme Cattle road') in these parts. For more about these previous views see Masonen in this volume.



Figure 1. A location of the causeway in Haukivaho, Renko, B Seitsemien in Ikaalinen (the verifying material of the dendrochronological dating), C Lammi (subfossil bog pine material). The reference material used in the dating has been collected from Ilomantsi and Lieksa, northeast from Joensuu.

In order to find out the exact age of the construction, the Finnish Road Museum (Tie- ja Vesirakennuslaitos) had an archaeological excavation carried out (Tiemuseo/ Masonen 1985). In this connection, samples were taken from the causeway for precise dendrochronological dating of the construction.

2.1 Sample collection from the logs of the causeway

The samples for the dendrochronological dating were taken mainly by sawing disks from the logs of the construction, only three of the 21 samples were taken by a core-drill. The samples were collected from different layers and parts of the causeway in order to discover possible different ages. Figure 2 (drawn on the basis of the excavation report; Tiemuseo/Masonen 1985, p. 13) shows the places of the sample logs in different stratigraphical layers of the construction. The logs were about 10–30 cm thick and many of them were several meters long (see figure 3). All of the logs were rather decayed, so that there was very little to be seen of the original surface of the tree and for example bark was found in only a few specimens. Except for surface dam-

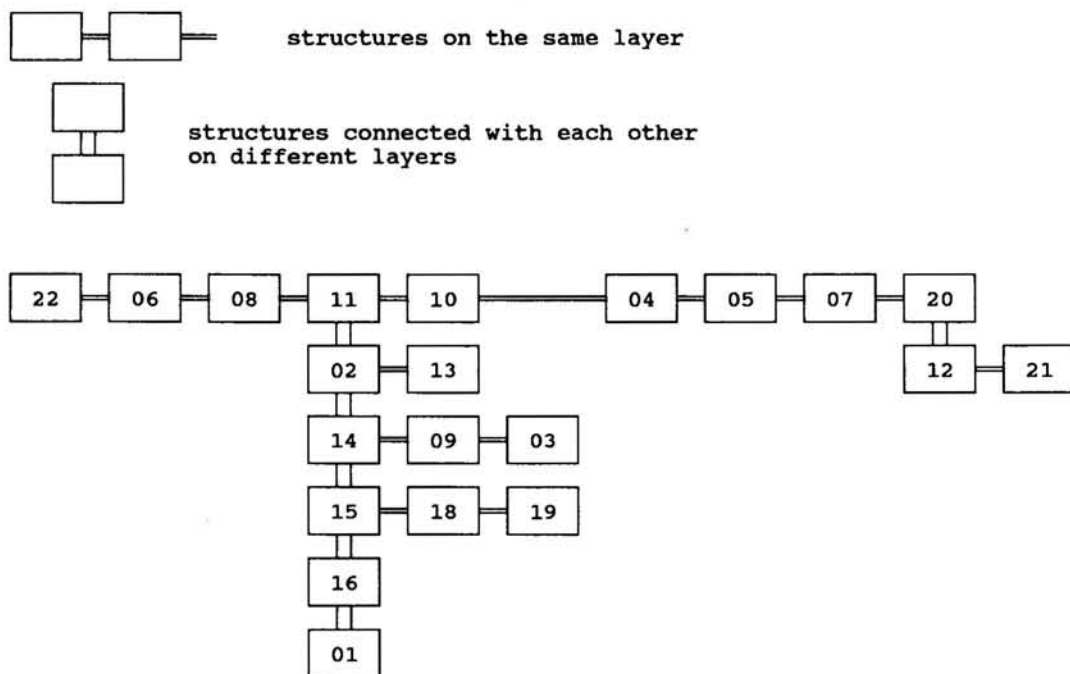


Figure 2. Sample logs in different stratigraphical parts of the wooden causeway in Haukivaho, Renko. Only those logs are presented that were studied dendrochronologically. Figure drawn on the basis of the archaeological excavation report of Finnish Road Museum (Tiemuseo/Masonen 1985).



Figure 3. Pine logs in the causeway of Haukivaho, Renko, revealed during the archaeological excavation. Photo 23.9.1985 by the author.

age, the logs had been fairly well preserved in the wet bog until recently. Peat analysis defines Haukivahonsuo prior to drainage as a sedge bog or a sedge pine swamp with few trees. In most places the peat was slightly or medium decomposed, nearly clean sedge-peat (*Carex*) with few remnants of wood (peat analysis by the author). Draining some years ago had dried the surface of the bog; under conditions richer in oxygen the decaying of the logs of the causeway has begun to advance quickly and in a few years the entire material will be destroyed.

The samples were taken in two stages in the autumn of 1985 by the author and the archaeologist Jaakko Masonen with his assistants. From some of the logs collected for the dendrochronological dating samples were also taken for radiocarbon dating (see Kankainen in this volume).

2.2 Tree-ring analysis and identification of tree species

For the dendrochronological dating, a tree-ring analysis and identification of the tree species (see e.g. Schweingruber 1982) were made at the

Laboratory of Dendrochronology of the Karelian Institute, University of Joensuu. The primary condition for material to be dated dendrochronologically is that it is from tree species the same as the reference material, in this case Scots pine. Only one of the sample logs from the causeway was from Common spruce (*Picea abies* Karst.), the rest were of Scots pine. According to field observations also some birch logs (*Betula* sp.) had been used in building the causeway; no samples of these were taken for the dendrochronological study.

The dendrochronological tree-ring analysis consists of measuring the width diameter of the rings and controlling the ring pattern through comparisons. This was done with a microcomputer, using the programme 'CATRAS' (Aniol 1983). From every sample the widths of all the rings were measured with a tree-ring microscope (Kutschenreiter) with an accuracy of a hundredth of a millimeter. Of the samples taken with a core-drill the rings were measured from two taken in the direction of the radius. The least decayed spots were sought in the disks and the tree-rings measured from three different radii chosen in this way. The ring-width series

Table 1. Statistical parameters of the tree-rings of the logs of the causeway in Haukivaho, Renko, examined dendrochronologically. All the parameters have been calculated with the computer program CATRAS (Aniol 1982). NB: sample 03 unfit for dating (a damaged tree), 12 unfit for measurement, logs 09 and 14 from the same tree, sample 17 was not examined.

Sample code	Tree species x)	Tree-ring				
		Number	Mean width	Standard deviat.	1.-ord. autoc.	Mean sensit.
01	P.sy	148	73.3	43.1	.914	.193
02	---	142	66.4	54.5	.941	.208
03	---	208	27.4	22.7	.911	.244
04	---	279	43.8	33.5	.953	.213
05	---	200	52.8	57.5	.959	.219
06	---	142	66.2	62.2	.950	.171
07	---	216	44.3	33.2	.899	.233
08	---	134	68.7	38.7	.895	.198
09	---	70	71.1	29.3	.774	.234
10	---	91	122.4	123.8	.959	.164
11	---	162	54.3	41.6	.934	.231
12	---	-	-	-	-	-
13	---	85	48.4	28.1	.901	.197
14						
15	---	101	76.0	37.2	.874	.191
16	---	61	41.4	30.7	.888	.256
18	---	87	46.3	14.8	.760	.154
19	P.ab	54	53.3	26.4	.848	.191
20	P.sy	72	93.2	42.4	.902	.146
21	---	51	79.5	46.5	.938	.125
22	---	140	71.8	87.5	.959	.175

x) P.sy = *Pinus sylvestris*, P.ab = *Picea abies*.

were then recorded straight into a microcomputer and later drawn into a so-called ring-width diagram. In this, the width of the rings is indicated by vertical lines, the ends of which are joined by a broken line (see Zetterberg 1986a, figure 2).

The ring-width pattern taken from the same log was carefully compared in order to discover any measuring errors or locally absent, so-called missing rings. If errors or incomplete annual growth rings were found, the series were corrected accordingly. In the present material, three incomplete rings were discovered: those from AD 1652, 1654 and 1710 were missing in some of the samples taken from two logs (04 and 07). In those years the diameter growth of these trees was so weak that ring formation was only partial all over the trunk. This phenomenon has been found especially in old Scots pines dying stand-

ing (e.g. Lakari 1915, p. 59, Leikola 1969) and is caused by the cambium layer having temporarily ceased to be active but having become active again, without the tree having died (Kärkkäinen 1985, p. 19).

The controlling done, ring series taken from the same sample log were put together into an average series, which is the basic material used in the dendrochronological dating. Here it has to be noted that the surface of the logs may have decayed away in different ways at different spots, thus the number of tree-rings measured from the same log could be quite different in different measuring radii. In table 1, some statistical parameters of each log's average series are given. The logs examined had an average of 129 tree-rings, the oldest one nearly 280. All of the sample logs had more than 50 tree-rings. Mean widths of the tree-rings measured from different

trees vary from 27.4 to 122.4 mm/100. The first-degree autocorrelation given in table 1 is fairly high and in all tree-ring series more than 0.760. In most cases it is more than 0.900. Thus, in the material the width of the tree-ring from a certain year is strongly affected by the width of the ring of the preceding year. This is very typical for Scots pine.

Samples unsuitable for dating were, in addition to the above-mentioned sample 19, samples 03 and 12. Sample 03 was from a log seriously damaged by forest fire while the tree was alive. After having been damaged the tree no longer grew normally, because it was pursuing up the fire scars. Samples 09 and 14, which had very similar tree-ring patterns were found to come from the same log, cut into at least two pieces. These samples also were quite near each other in the construction (see figure 2). The sample from log 12 was not fit for measurement.

3. THE PINE CHRONOLOGY FROM EASTERN FINLAND AS THE KEY TO THE DATING

The reference chronology of more than 600 years used in the dating is based mainly on material collected from living trees in different habitats in the eastern parts of Northern Karelia, in the communes Ilomantsi and Lieksa, and some dendrochronologically dated historical wooden constructions in Northern Karelia (Eronen & al. 1986). The oldest stand of living trees where samples were collected is more than 400 years old. From this stand in the easternmost part of Ilomantsi, near the Koivusuo nature park 28 Scots pines that began their life at the turn of the 17th century, have been used for constructing the reference chronology. The age structure, habitat factors, vegetation and soil of the woods of the living trees used for the reference chronology have been described more thoroughly earlier (Zetterberg 1987a). The material obtained from living trees has been combined with material from timber floating booms in the Pielsjoki River (from the 18th and 20th centuries) (Eronen & al. 1986, Zetterberg and Meriläinen 1987), a museum specimen (wooden mortar) from the beginning of the 20th century (Zetterberg 1987b) and two wooden buildings from the 17th century (Zetterberg 1986a).

This combined average series, pine chronology or tree-ring calendar, consists of annual averages of tree-rings from over a hundred trees

having lived at different times and extends to the year 1375 AD.

4. DENDROCHRONOLOGICAL DATING OF THE LOGS OF THE CAUSEWAY IN RENKO

4.1. Principles of the dating method

The tree-ring mainly reflects the conditions of the growth period, though other factors, are also of great importance. During an unfavourable year a thin layer of new wood grows under the bark of the tree, during a favourable year a thicker one. As weather conditions are similar in wide areas, the ring width pattern of trees growing in a certain area at the same time are very similar. When the ring width pattern of a sample of unknown age is compared with a reference series in which the calendar year of every tree-ring is known, the period can be determined when the ring width pattern to be dated formed. These, put in brief, are the grounds of the dendrochronological dating. The synchronization of the tree-ring pattern can be made visually on a light board by comparing the tree-ring diagrams and with statistical methods. This procedure is called cross-dating. In Finland, these methods have been described more thoroughly in articles by Heikkinen (1984) and Zetterberg (1986ab).

The results presented below have been gained by using the before-mentioned computer program developed in the dendrochronological laboratory of Hamburg and by confirming the results with the visual light-board method. The algorithm of the program CATRAS that tests the similarity between the series to be compared is mainly based on methods presented by Baillie and Pilcher (1973) and Aniol and Schmidt (1982). Of the test values given by the programme those based on correlation between indexed series are used below.

4.2 Results of dating

The dendrochronological dating procedure itself can be divided into three stages. In the first stage ages were gained for trees, the ring pattern of which could be synchronized directly with the material from Northern Karelia. Such tree individuals were a minority in the entire material. In the second stage two average tree-ring series, or chronologies, made of separate materials and

based on several individuals were synchronized both with the reference chronology from Northern Karelia and with each other. During the third stage of the dating the trunks still undated were synchronized with local material dated during the earlier stages of the procedure. The stages of the dating and their results are presented more thoroughly below.

4.2.1 Stage one: direct dating with the help of the reference chronology of eastern Finland

Four logs could be dated directly by comparing the tree-ring pattern with the reference chronology of eastern Finland. The diameter growth of these trees thus followed fairly similar lines as the Scots pines at a distance of more than 400 kilometers in Northern Karelia. The same good year of growth and especially the poor ones can be found with sufficient reliability both in these four tree individuals and in the entire large material of eastern Finland. The last tree-rings preserved in these trees had grown in the summers of 1813, 1817, 1820 and 1821. These slightly deviating dendrochronological ages are due to the surface of different trunks having decayed in different ways. The number of the annual rings decayed was estimated when the annual ring analysis was made. The results of the first dating

Table 2. Statistical comparison of the ring patterns of the wooden causeway in Renko with the reference chronology of eastern Finland. The results of the first dating stage. In all these cases the visual synchronization confirmed the results. See notes for Table 1.

Sample code	N:o of rings	Test value	Last year
01	148	3.71	1820
02	142	-	-
04	279	4.86	1817
05	200	-	-
06	142	-	-
07	216	-	-
08	134	-	-
09	70	-	-
10	91	-	-
11	162	-	-
13	85	-	-
15	101	3.46	1813
16	61	-	-
18	87	-	-
19	54	-	-
20	72	-	-
21	51	-	-
22	140	3.92	1821

stage with their test values computed with the program CATRAS are presented in table 2.

The dating thus gave clear indications of the young age of the construction. Four trunks, all dated to the same period, were located in different parts of the construction, from the bottom layer to the top, which also indicates contemporaneity (see Fig. 2).

4.2.2. Stage II: Relative dating of the tree-ring patterns of all of the samples

The first dating stage resulted in less than a fifth of the material being dated (four of 21). The rest could thus be of different age, coming from parts of the construction older or younger than this one. In the second stage of the dating the ring patterns of all logs were synchronized with each other in order to find out their mutual age relations. Had the causeway been built in several stages, the comparison ought to have revealed several groups, inside which the ring patterns of contemporary logs would fit well into each other, while between trees from entirely different periods no similarity in tree-ring pattern could be observed.

The results of the second stage of the dating are presented in table 3. Ring-width series have been compared using the above-mentioned program CATRAS. Test values exceeding the minimum value 3.0 have been chosen for the table. In looking at the table one has to keep in mind that in synchronizing random positions may sometimes receive a test value of over 4.0 or even higher. Especially when short series are compared and there is a short overlap in time (less than 50 years) in the series to be compared this possibility becomes greater. Thus all test values given in the table do not always straight away prove similarity in age! The longer the tree-ring series, the more clearly the correct position synchronization is discerned from the incorrect ones and the less probable it is that the test receives a result over the limit value. In the experience of the author test values over 5.5 generally mean (with the above-mentioned limitations) with a fair certainty that the compared tree-ring series are of the same age.

Table 3 shows that on the basis of the test values sample trunks 01, 04 and 07 and respectively 06, 10, 16 and 22 are mutually of the same age, as well as probably the logs 05 and 11. In all of these cases visual synchronization confirmed that they were mutually of the same age. As the trees had been growing simultaneously, a similar variety of thin and thick tree-rings could

Table 3. The second stage of the dating of the wooden causeway in Renko. The ring pattern of all the logs are synchronized with each other. Statistical test values ≥ 3.0 shown.

Code	01	02	04	05	06	07	08	09	10	11	13	15	16	18	19	20	21
02	-																
04	5.6	-															
05	3.8	3.3	-														
06	3.9	-	4.1	3.7													
07	5.5	-	3.2	-	-												
08	-	-	-	-	-	-	3.6										
09	-	-	-	-	-	-	-	-									
10	-	-	-	-	6.0	-	-	-									
11	-	-	3.4	7.4	3.0	3.3	-	-	3.8								
13	3.7	-	-	-	4.3	-	3.4	-	-	-							
15	3.4	-	5.4	3.1	4.7	-	3.9	-	3.6	-	3.1						
16	-	-	-	-	6.0	-	-	-	-	-	-	-					
18	4.0	-	3.7	-	-	-	-	-	-	-	4.8	3.7	-				
19	-	-	-	-	-	-	-	-	-	-	-	-	-	3.3			
20	4.0	-	-	-	3.0	-	-	-	-	-	2.6	-	-	-	-	-	-
21	-	-	-	-	3.4	-	-	-	-	-	-	-	3.8	-	-	-	-
22	4.0	-	3.5	-	7.2	3.2	-	-	3.8	-	-	6.2	-	4.4	3.3	-	-

be seen in them. Figure 2 shows the place of these logs synchronized with each other.

From logs that were found to be of the same age, though their absolute age was still unknown, it was possible to construct an average tree-ring series at this stage. Two such relative, (i.e. unbound to age) series were drawn up as parallels. The average series were counted from completely separate materials and are thus totally independent of each other. In the first series (No. 1) there are three logs (01, 04 and 07) and in the second one (No. 2) four (06, 10, 16 and 22).

In the average series from several trees the individual variations in growth become less significant and the so-called general features stand out. Thus, for example the years during which the growth of most trees was weaker than the average, are shown as a value smaller than the others

also in the average series. The greater number of trees the average series is based on, the more significant the general features become. It is therefore more certain to synchronize an average series based on several tree individuals with the reference chronology than one based only on an individual tree. Table 4 shows the sample logs used for counting, as well as some statistical parameters.

When the two average series from Renko and the reference series were compared with the chronology from Northern Karelia they could both be synchronized either with the reference chronology or each other, so that the last year in No. 1 is 1820 and in No. 2 1825. Although the test value between one of the Renko average series and the reference chronology is not very high ($t = 3,39$) the fitting into each other of the average series only in this position (No. 1/No. 2

Table 4. Statistics of the two separate mean ring width chronologies established from three and four logs respectively from the wooden causeway in Renko.

Renko chronology	Sample codes	N:o of rings	Mean width	Stand. dev.	1.-ord autoc.	Mean sensit
N:o 1	01, 04, 07	282	53.3	34.3	.941	.179
N:o 2	06, 10, 16, 22	151	78.8	85.1	.966	.167

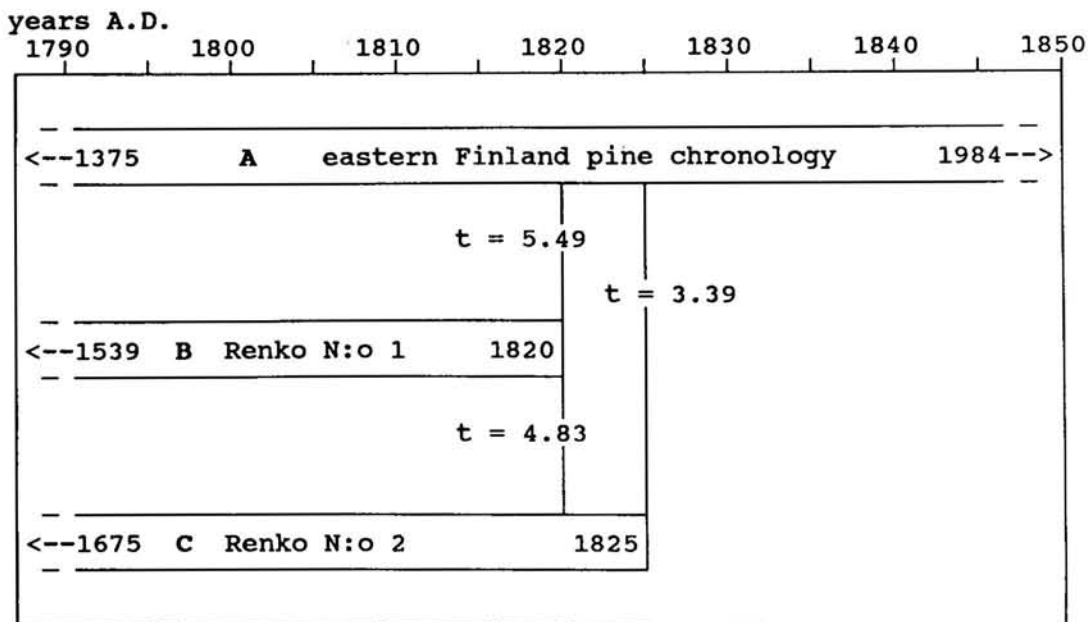


Figure 4. Comparison between two average tree-ring series (B and C) independent from each other (separate materials) that were constructed from the archaeological material of Renko and the reference chronology of eastern Finland. Comparison of the Renko series with each other gives the same result without contradiction (see text).

$t = 4.83$) confirms the dating (see figure 4). Therefore the synchronization of all three series is analogous without contradiction. A situation like this has been described by Baillie (1982, p. 85) as 'replication'. A critical dendrochronological cross-dating method is therefore always based on this consistent analogy between more than two series.

Once the relative positions of the logs included in these dated average series had been found out, the calendar years for the last tree-rings of seven logs were obtained at this stage: 01: 1820, 04: 1817, 06: 1816, 07: 1784, 10: 1766, 16: 1825 and 22: 1821. It has to be noted that the ages for logs 01, 04 and 22 at this second stage of the dating were the same as the ones obtained already at the first stage by comparing them directly with the reference chronology from Northern Karelia.

4.2.3. Stage III: Problematic cases in dating

The most difficult samples in the dendrochronological dating are those with a short ring pattern or those from tree individuals with a way of growing different from others. Also samples

from which it has not been possible to eliminate the effect of incomplete annual rings remain to be dated at the last stage. This occurs when the ring of a certain year is missing in all the pattern measured from samples from the same tree. Dating such samples is generally the stage that takes clearly the longest time, this too was the case when the causeway in Renko was studied.

In order to date the problematic cases the ring pattern measured from the logs were carefully compared one by one with both the ring pattern from the logs already dated and with average chronologies combined from the dated logs. In this way possible anomalies (such as missing rings) could be sought and corrected and the ring pattern from the logs still undated could be synchronized with those dated previously. The last tree-rings in these five logs were from the years 1813–1828; thus they did not essentially change the previous picture of the age of the causeway in Renko. Including these logs dated at the last stage, it was possible to date 12 of the 19 pine logs examined. The entire results of the research are shown in figure 5. In looking at the results, it has to be noted that from all the sample logs the surface had more or less decayed away.

years A.D.

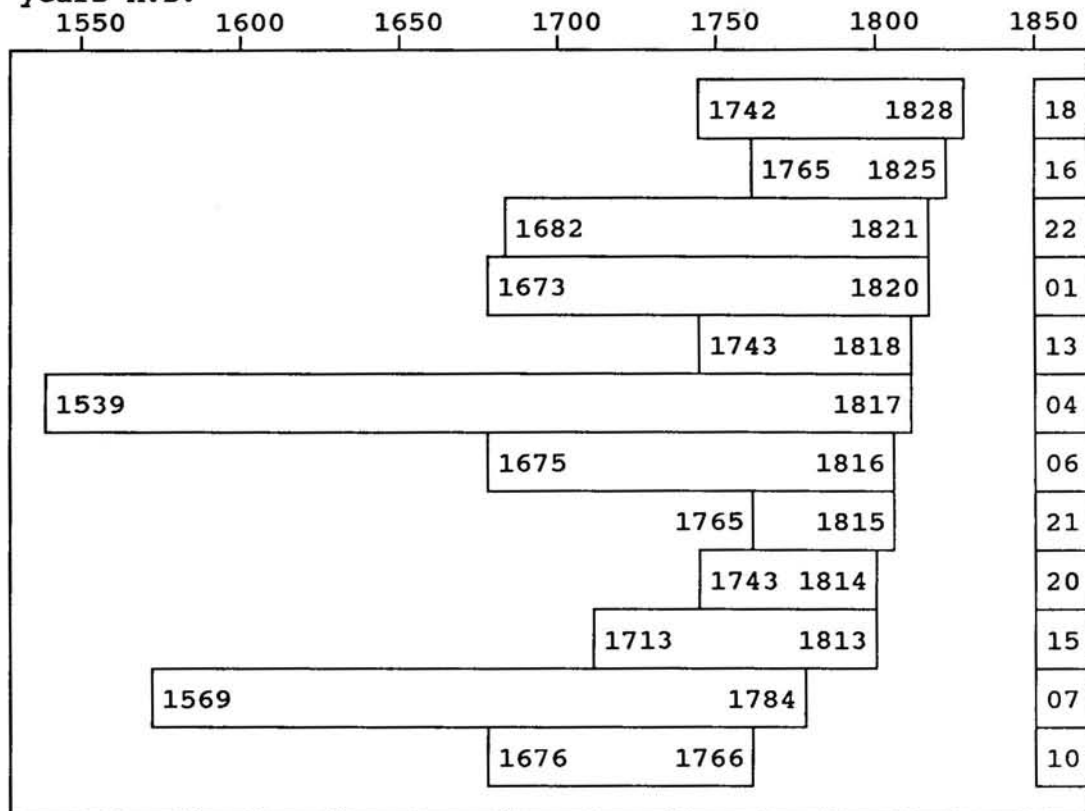


Figure 5. Tree-ring pattern of the logs of the causeway in Renko, dated dendrochronologically. Sample codes on the right. The years of the oldest and youngest rings in the ring patterns examined are at the ends of the bars. NB: Some wood has decayed away from the surface of all the logs. Thus, the youngest tree-ring examined is not the last one that grew before the tree was felled.

4.3. Verification of the dating

In order to verify the results of the dating, the entire material was synchronized with another reference chronology completely independent from the material from Northern Karelia. For this purpose, a reference chronology was counted from a small material collected by the author from Multiharju in the nature park of Seitsemien in 1984. The material consists of only five Scots pines aged 306–278 years, thus its general representativeness is not as good as that of the reference chronology of Northern Karelia. However, the distance between Seitsemien and Renko being only 130 km, it could be expected that the tree-ring series of these two locations, Renko and Seitsemien would be similar enough to permit synchronization.

Comparison between the two before-men-

tioned average series counted from the causeway in Renko and the reference chronology from Seitsemien gave at hand that the dating resulted in exactly the same years (1820 and 1825) as when these series are compared with the reference chronology of Northern Karelia. The same years in all cases (see table 5) were also obtained when the individual logs from Haukivaho in Renko were synchronized with the independent verifying series. In almost all cases the similarity described by the test value was slightly greater than when the material was directly compared with the reference chronology of Northern Karelia. Altogether six samples could be dated directly by comparing their tree-ring series with this reference chronology from Seitsemien based on a small material.

The dating may thus be considered as verified. Furthermore, the similarity between the Renko and Seitsemien materials is great enough to

Table 5. Verification of the dating of the wooden causeway in Renko. Individual logs were synchronized with the independent verifying series from the nature park Seitsemien. Cf. Table 2.

Sample code	N:o of rings	Test value	Last year
01	148	3.89	1820
02	142	-	-
04	279	3.63	1817
05	200	-	-
06	142	4.89	1816
07	216	-	-
08	134	-	-
09	70	-	-
10	91	-	-
11	162	-	-
13	85	2.65	1818
15	101	3.55	1813
16	61	-	-
18	87	-	-
19	54	-	-
20	72	-	-
21	51	-	-
22	140	4.23	1821

permit combining these two materials (figure 6). Combined these series cover the period from the year 1984 to the year 1539. This new combined long tree-ring calendar was counted directly from the tree-ring widths without any standardization of data, for dating purposes only. The tree-ring series of all the individuals have been used as they are, as wholes. Thus for example the young dates of the trees in Seitsemien (ca. 1675–1710) can be seen clearly in the average series as high values (see appendix).

5. DISCUSSION

5.1. The age of the causeway in Haukivaho, Renko and the age relations between the logs, summary

The year rings of the logs in the causeway in Renko, Haukivaho, thus provided a 'terminus post quem', i.e. the year after which the causeway was built, in this case 1828. The causeway could not have been built before this year, as the logs then were growing as trees. The result also tallies well with the radiocarbon dating of the wooden material (see Kankainen in this volume) and the age of the construction based on written sources (see Masonen in this volume).

As a definite result 12 of the 21 sample logs from the causeway studied could be dated with an accuracy of one year. When sample logs of unsuitable tree species and those unfit for study were left out, the undated ones amounted to less than a third. The tree-ring patterns of these trees displayed such disturbances that they did not fit into any part of the reference chronologies. The result can be compared with experiences of dendrochronological dating from elsewhere; for instance, an average of 10–20 % of Irish oaks are impossible to date because of irregularities in growth (Baillie 1982, p. 205). It has to be noted, however, that dating the logs that now remained undated may become possible later when along with other dating results tree-ring material of pine of known absolute age will be collected from this area.

Another main result of the dendrochronologi-

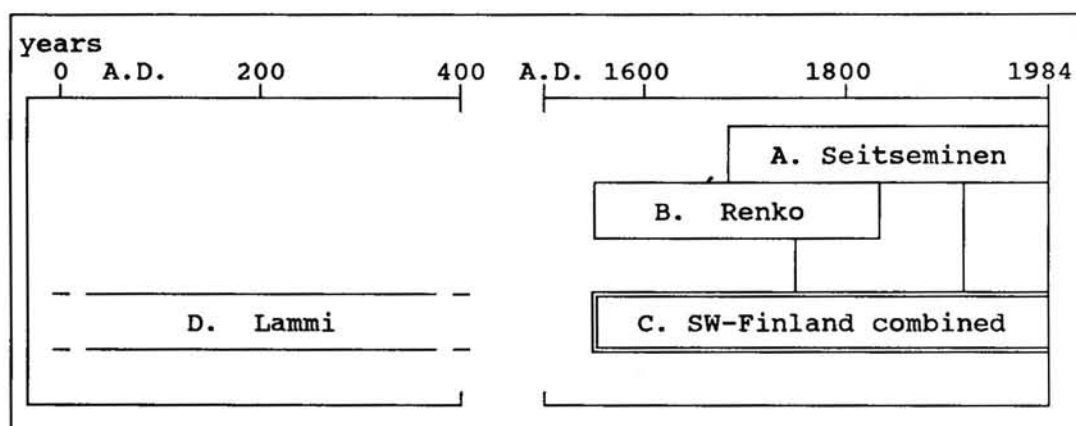


Figure 6. Construction of the Southwestern Finland pine chronology. Sequence A. is a mean ring-width chronology based on living trees in the Seitsemien nature park at Ikaalinen, B. is from the dating of the wooden causeway in Renko. Sequence C. is a floating chronology based on subfossil bog pines at Lammi. The approximate age of this subfossil chronology is based on conventional radiocarbon dates.

cal dating from the archaeological point of view is, in addition to the age of the construction, that the whole construction is of the same age. The bottom layers, against expectations, were not older than the upper ones. Thus the dating to 1821 based on five dated logs and obtained already in the first stage of the study, proved to be almost correct. Amongst the logs studied later only some had rings formed after this year.

Although part of the material could not be dated with certainty, it was possible to date most of the logs of the causeway as being of the same age. This opens views for the application of dendrochronology of archaeological sites considerably older than the one discussed here. Although it would not yet be possible to obtain the absolute age of a site thousands of years old, it is possible to obtain the relative dating of wooden material quite accurately with the help of dendrochronology.

5.2. The applicability for dating of the pine chronology for eastern Finland

The purpose of choosing for dating a subject at a distance of more than 400 km from the habitats of the reference material was to test the applicability of the pine chronology constructed for eastern Finland in other parts of the country. It was assumed that such a long distance would make dating difficult or even impossible, simply because the climatic factors affecting the growth of the trees would be different and the tree-ring series would be too different for dating purposes.

When this work was started, there was no experience of adapting the pine chronology from eastern Finland for dating at distances of over 100 km. Recently, further results of adapting have been obtained: materials from Loppi (Zetterberg, 1988b), Kalajoki (Zetterberg, manuscript) and Pyhäjoki (Tie- ja Vesirakennuslaitos/Zetterberg 1987) have been dated using the pine chronology from eastern Finland. The tree-ring calendar based on pines in a certain area can thus be adapted in quite a large area. Similar results have been obtained in Sweden: when comparing material collected from living pines in different areas, it was found out that the country could be divided into seven dendrochronologically homogenic areas, the largest of which have a range of several hundreds of kilometers (Bartholin 1984).

In this case, however, the distance between the habitats of the material to be dated was too

long to make it possible to date all individual trees directly with the eastern Finland reference chronology. This is understandable, as a fairly large part of the variations in the diameter growth of a particular tree individual can be explained with its own biological activities and occasional occurrences affecting only this tree, such as cone years, plant diseases, insect damages, fire and other damages, change in the plant sociological status etc.

On the other hand, a series, i.e. an average one, describing the average yearly diameter growth is made from several tree individuals by finding out their relative dating and combining the tree-ring series. Accordingly in such a series the 'random noise' caused by individual changes in growth has decreased leaving general changes in growth. These are caused by the general climate and take place in a wide area at the same time. The results from Renko show that the more samples from different tree individuals are available in the material to be dated, the more likely the success of the dating even with a reference chronology constructed at a greater distance. This fact has to be considered already when planning a dating of archaeological material and especially when taking samples.

Sometimes it may be easy to date a tree individual in a case where the tree followed very general lines in its annual diameter growth. Such a tree individual was sensitive against general changes in the climate, but local disturbances (e.g. fires) and individual irregularities in growth are missing. Experiences of this kind have been gained i.a. from dating a wooden museum mortar in Northern Karelia (Zetterberg 1987b). Thus, it is even possible to date archaeological objects made of one tree.

5.3. A pine chronology for Southwestern Finland

An important result of this work was a new pine chronology for Southwestern Finland, extending several hundreds of years back in time. This tree-ring calendar can be used for dendrochronological dating with an accuracy of a year in the whole of southern Finland and on the other hand for finding out more precise data on past climatic conditions. One of the goals of dendrochronological research in this area is to bridge the time gap between the oldest end of the new absolute pine chronology of Southwestern Finland and the youngest end of the subfossil bog pine material examined before (Zetterberg 1986b). A radiocarbon dating has been made (Tolonen

1987) Hel-1931: 1560±100 BP from the material of the youngest part of the Lammi tree-ring average series over four hundred years long, now still 'floating' in time. The time gap has quite recently been diminished, when with the material from the so-called 'Vanhakirkko' in Loppi, southern Finland, the year 1407 was reached (Zetterberg 1988b). When in the future it will be possible to synchronize the Lammi material with the absolute chronology, there will be an accurate calendar of the diameter growth of pine in Southwestern Finland from the beginning of the Christian Era onward.

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Appendix. Southwestern Finland pine chronology

	Tree-ring width										Number of samples									
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1530										253										1
1540	208	203	181	171	155	173	145	128	145	94	1	1	1	1	1	1	1	1	1	1
1550	94	65	89	80	66	70	68	78	99	104	1	1	1	1	1	1	1	1	1	1
1560	97	115	84	98	94	99	87	95	92	101	1	1	1	1	1	1	1	1	1	1
1570	159	139	91	102	81	79	93	94	84	58	2	2	2	2	2	2	2	2	2	2
1580	61	46	52	58	46	42	35	37	35	30	2	2	2	2	2	2	2	2	2	2
1590	42	42	48	41	49	43	37	28	34	33	2	2	2	2	2	2	2	2	2	2
1600	39	33	43	34	48	51	53	59	59	55	2	2	2	2	2	2	2	2	2	2
1610	50	60	44	41	38	27	31	27	26	20	2	2	2	2	2	2	2	2	2	2
1620	25	20	19	26	29	27	27	27	21	27	2	2	2	2	2	2	2	2	2	2
1630	29	30	25	29	29	24	24	32	24	27	2	2	2	2	2	2	2	2	2	2
1640	21	20	14	13	17	16	21	23	26	25	2	2	2	2	2	2	2	2	2	2
1650	30	19	4	14	10	26	28	24	32	30	2	2	2	2	2	2	2	2	2	2
1660	46	42	50	57	57	58	55	49	50	39	2	2	2	2	2	2	2	2	2	2
1670	36	46	51	76	65	116	171	148	199	208	2	2	2	3	3	4	5	5	5	6
1680	223	247	228	226	209	207	214	188	185	179	6	7	8	8	8	8	8	8	8	8
1690	138	161	155	158	182	149	127	112	113	121	8	8	8	8	8	8	8	8	8	10
1700	129	99	112	114	124	137	138	157	103	79	10	10	10	10	10	10	10	11	11	11
1710	86	86	80	83	95	94	83	68	61	59	11	11	11	12	12	12	12	12	12	12
1720	72	71	86	92	82	73	53	57	65	73	12	12	12	12	12	12	12	12	12	12
1730	65	54	56	52	55	60	72	75	90	76	12	12	12	12	13	13	13	13	13	13
1740	63	48	60	68	61	65	67	63	79	73	13	13	14	15	15	15	15	15	15	15
1750	85	87	97	95	85	87	74	81	63	72	15	15	15	15	15	15	15	15	15	15
1760	58	54	59	66	72	66	63	50	41	45	15	15	15	15	15	15	16	16	15	15
1770	40	36	47	51	52	66	72	74	76	61	15	15	15	15	15	15	15	15	15	15
1780	64	62	64	66	68	63	57	52	60	57	15	15	15	15	15	14	14	14	14	14
1790	49	50	47	52	60	47	47	52	54	62	14	14	14	14	14	14	14	14	14	14
1800	52	50	50	47	53	63	39	49	42	49	14	14	14	14	14	14	14	14	14	14
1810	43	41	48	53	53	58	56	65	71	89	14	14	14	14	13	13	13	12	11	11
1820	64	70	67	57	56	73	93	77	87	106	11	10	9	8	8	8	7	7	7	6
1830	101	100	72	89	81	46	56	58	65	62	6	6	6	6	6	6	6	6	6	6
1840	63	68	77	81	91	93	117	88	105	105	6	6	6	6	6	6	6	6	6	6
1850	92	101	93	78	96	102	94	96	94	87	6	6	6	6	6	6	6	6	6	6
1860	100	97	57	70	77	89	89	62	82	85	6	6	6	6	6	6	6	6	6	6
1870	80	83	91	89	79	84	72	80	77	63	6	6	6	6	6	6	6	6	6	6
1880	67	62	99	78	62	69	66	76	61	65	6	6	6	6	6	6	6	6	6	6
1890	72	63	66	69	72	70	75	67	70	63	6	6	6	6	6	6	6	6	6	6
1900	55	72	43	43	37	49	58	52	52	63	6	6	6	6	6	6	6	6	6	6
1910	47	46	61	55	52	51	54	53	47	53	6	6	6	6	6	6	6	6	6	6
1920	55	58	65	53	48	44	34	47	35	37	6	6	6	6	6	6	6	6	6	6
1930	40	38	40	42	42	34	40	35	33	41	6	6	6	6	6	6	6	6	6	6
1940	34	40	28	32	32	38	38	40	47	50	6	6	6	6	6	6	6	6	6	6
1950	47	40	44	55	68	48	32	44	43	44	6	6	6	6	6	6	6	6	6	6
1960	40	34	37	34	32	30	34	37	35	32	6	6	6	6	6	6	6	6	6	6
1970	40	38	51	47	36	34	45	31	45	50	6	6	6	6	6	6	6	6	6	6
1980	32	38	26	25	28						6	6	6	6	6					