Source: Haneca K, Verheyden A, Beekmann H, Gärtner H, Helle G, Schleser G (eds.) (2007) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th – 22nd 2006, Tervuren, Belgium. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 74, p. 277 - 284.

Reconstructing the flow of the River Nile from *Juniperus procera* and *Prunus africana* tree rings (Ethiopia) – an explorative study on cross-dating and climate signal

T.H.G. Wils[1] & Z. Eshetu[2]

[1]*University of Wales Swansea, School of the Environment and Society, Department of Geography, Singleton Park, Swansea SA2 8PP, United Kingdom*

[2]*Ethiopian Institute of Agricultural Research (EIAR), PO Box 2003, Addis Ababa, Ethiopia*

E-mail: 371407@swansea.ac.uk

Introduction

The people of Egypt and the Northern Sudan strongly depend on the waters of the River Nile for irrigation and electric power. Therefore, to fight poverty in this region, an adequate water resources management is essential. This requires longer reliable discharge records (Sutcliffe & Lazenby 1994).

The amount and variability in Main Nile River discharge at Aswân is mainly controlled by water availability in Northwest Ethiopia through its most important tributary the Blue Nile River (Said 1993). On a smaller spatial scale this water availability controls tree growth. Although seasonality in temperature is negligible in Ethiopia, certain tree species produce yearly rings, such as *Juniperus procera* Endl. and *Prunus africana* (Hook f.) Kalkman. Besides tree growth, ring definition and isotopic signature strongly depend on moisture availability and seasonality therein (Conway et al. 1998, Couralet et al. 2005, Krishnamurthy & Epstein 1985). These observations suggest the possibility to reconstruct River Nile discharge from growth rings of trees growing in Ethiopia.

This paper presents a preliminary study to cross-date *Juniperus procera* and *Prunus africana* trees from Northwest Ethiopia and to explore the water stress signal contained in them as a proxy for river discharge. Weak ring definition, asymmetrical growth, scarceness of previous research in this area and scarceness of the trees themselves – and hence the ethics of sampling many trees – provide a challenge for dendroclimatology that cannot be dealt with in standard ways. What is presented is *not* intended as a hard conclusion, but rather as a soft discussion to explore opportunities to divert from the standard method of cross-dating, chronology building and environmental signal interpretation as described by Fritts (1976) and Cook and Kairiukstis (1990).

Materials

Stem discs from three young trees, two *Juniperus procera* and one *Prunus africana*, growing at different sites near Mekane Selame (10°35’N, 38°45’E), 30 km east of the Blue Nile River, Ethiopia, were studied. Completely concentric rings were scarce on both *Juniperus* samples, but more dominant on the *Prunus* sample. However, most rings could be measured along one carefully selected radius. Cross-dating of these trees was difficult due to weak ring definition (see *e.g.* figure 1), the lack of a chronology from the Blue Nile basin and the small number of samples available.

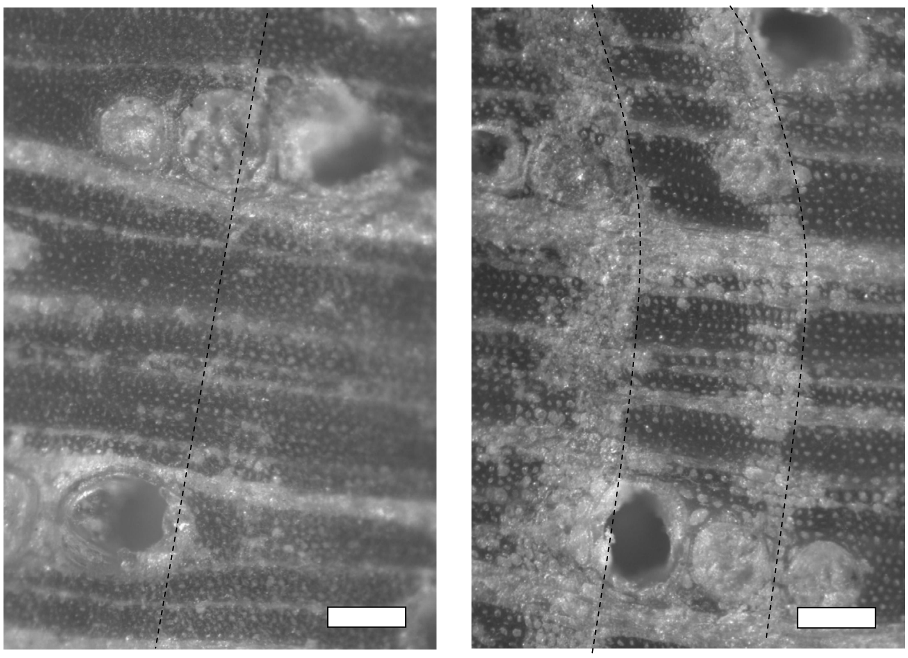

Figure 1: Weak (left) and relatively strong (right) ring definition in Prunus africana. *Growth is from left to right. Ring boundaries are indicated. Magnification is 10x and scale bars are 100 μm.*

Methods

Evaluation of conventional cross-dating and dendroclimatology

Fritts (1976:21) stated that 'cross-dating is possible because the same or similar environmental conditions have limited the ring widths in large numbers of trees, and the year-to-year fluctuations in limiting environmental factors that are similar throughout a region produce synchronous variations in ring structure.' In other words, cross-dating is based on the assumption that there is a large-scale external factor which controls the high-frequency variability in tree-ring width. Hence, it is not only possible on ring widths, but on all time series which can be assumed to be controlled by such a factor.

By convention, cross-dating is conducted without explicitly using information about the nature of the external factor. The ring width series are just matched up, but determining the best match is quite subjective (Baillie 1995, Grissino-Mayer 2001, Pilcher 1990, Wigley et al. 1987). After cross-dating, the ring width series are detrended and standardized and a chronology is calculated expressing some kind of central tendency thought to represent the common signal (Cook et al. 1990). In dendroclimatology attempts are made to interpret the common signal in terms of climatic variables and, if possible, ring widths are calibrated against those (Fritts 1976, Fritts et al. 1990).

In science-philosophical terms, the *assumption* underlying cross-dating is not tested, though there are numerous cases that samples are not cross-datable, but those are just 'laid aside as unsuitable for dendrochronological work' (Fritts 1976:21). Combined with the subjectivity of judging a match, cross-dating cannot be regarded as an objective practice. However, although it clearly does not comply to Popper's falsificationism (Popper 1980), cross-dating has proven to be a very valuable tool in dendrochronology. Besides, after all the underlying assumption is tested by *applying* instead of falsifying it, otherwise Fritts (1976) would not lay samples aside. Feyerabend's critic to the 'Popperian Church' and the abstract concept of objectivity (Feyerabend 1993) seems to make sense in dendrochronology.

Nevertheless, inferences about the nature of the common signal are generally treated as *hypothesises* to be tested independently against climate data. In fact, this independence is an illusion, as cross-dating is based on the assumption that there is a common signal and enhances it. So, if the assumption is right, there is as a matter of course a correlation between the chronology and some climate data or another large-scale external factor, whereas if the assumption is not right, the cross-date is definitely wrong. Yet, this pseudo-independent hypothesis testing has also proven valuable and strongly diverging from it may enlarge circular reasoning beyond the limit of touching the empirical reality. However, some aspects of the process can be changed.

A new approach

This study changes the order within the procedure of cross-dating, chronology building and environmental signal interpretation, to improve cross-dating and to avoid comparing a chronology distorted by misdated series to climate data. The process can be described as a multi-proxy approach to cross-dating.

Five sources of information are used or proposed to use: ring width series, wood anatomy, historical and modern river discharge records, historical (written documentary and oral legendary) accounts on famines and stable isotopes. Initially an attempt is made to match up the ring width series on the basis of mutual synchrony and wood anatomical properties. Wood anatomy is an important feature, as it contains information about potentially missing or false rings.

The ring width series are then compared *individually* to Blue Nile River discharge to test independently the hypothesis that ring width and discharge are associated. If this hypothesis is rejected, it is hypothesised that the causality that leads to association between ring width and discharge exists, but is obscured by misdating of the ring width series. This improved hypothesis is tested by searching for a cross-date which is confirmed by mutual synchrony, wood anatomy, river discharge and historical accounts on famines. If such a non-contradicted cross-date can be found, the improved hypothesis is accepted and the ring width series is adjusted accordingly. If not, the improved hypothesis is rejected and the sample is in a Frittsian (1976) way 'laid aside'.

The final stage would be checking and if necessary adjusting the cross-date by synchronising stable isotope series, which theoretically contain a stronger common signal and should therefore cross-date better. However, stable isotope series are not yet available.

After this combined cross-dating and environmental signal interpretation a chronology can be calculated from the different ring width series, which as a matter of course correlates with Blue Nile River discharge.

This multi-proxy approach to cross-dating diverges from the conventional method in a number of aspects. Wood anatomical properties are highly used during matching-up. Ring width series are individually tested against climate data. Rejected hypothesises are interpreted as possibly caused by misdating, which is tested using mutual synchrony of the ring width series, wood anatomy and historical accounts on famines. Finally, stable isotopes are proposed to be used as a cross-datable proxy to improve the original cross-date. Thus, inferences about the nature of the common signal are still treated as hypothesises tested independently against climate data, but this testing takes place earlier and misdating is explicitly treated as a potential cause of hypothesis rejection.

Results

Initial matching-up of the ring width series using wood anatomical properties was relatively straightforward. The first *Juniperus procera* series (JP1) needed no adjustments at all. The *Prunus africana* (PA) series needed re-measurement of the period 2003-2005 to include two partial rings (see figure 2A and table 1). The second *Juniperus procera* (JP2) series needed merging of four rings in 2004 as density variations were assumed intra-annual and re-measurement of the period 1970-1971 to include a ring which seemed an intra-annual density variation at first measurement (see figure 2A and table 1).

Table 1: Wood anatomical features supporting the adjustments made to the original ring width series and correlations (r) between the series and annual Blue Nile River discharge for the initial and final cross-date. The master series is a weighted mean after log-transforming and equalising mean and standard deviation of the raw ring width series, the weights being the correlation coefficients between the standardized series and Blue Nile River discharge.

Tree	Year(s)	Wood anatomical feature	r (initial)	r (final)
JP1	1994-1997	Density variations	0.13	0.33
	1972	Very small partial ring		
JP2	2004	Density variations	0.01	0.16
	1996-1998	Density variations		
	1969-1971	Density variations		
PA	2003-2005	Partial rings	0.24	0.34
	1995-1997	Unclear ring boundaries		
	1972	Unclear ring boundaries		
Master series			0.27	0.47

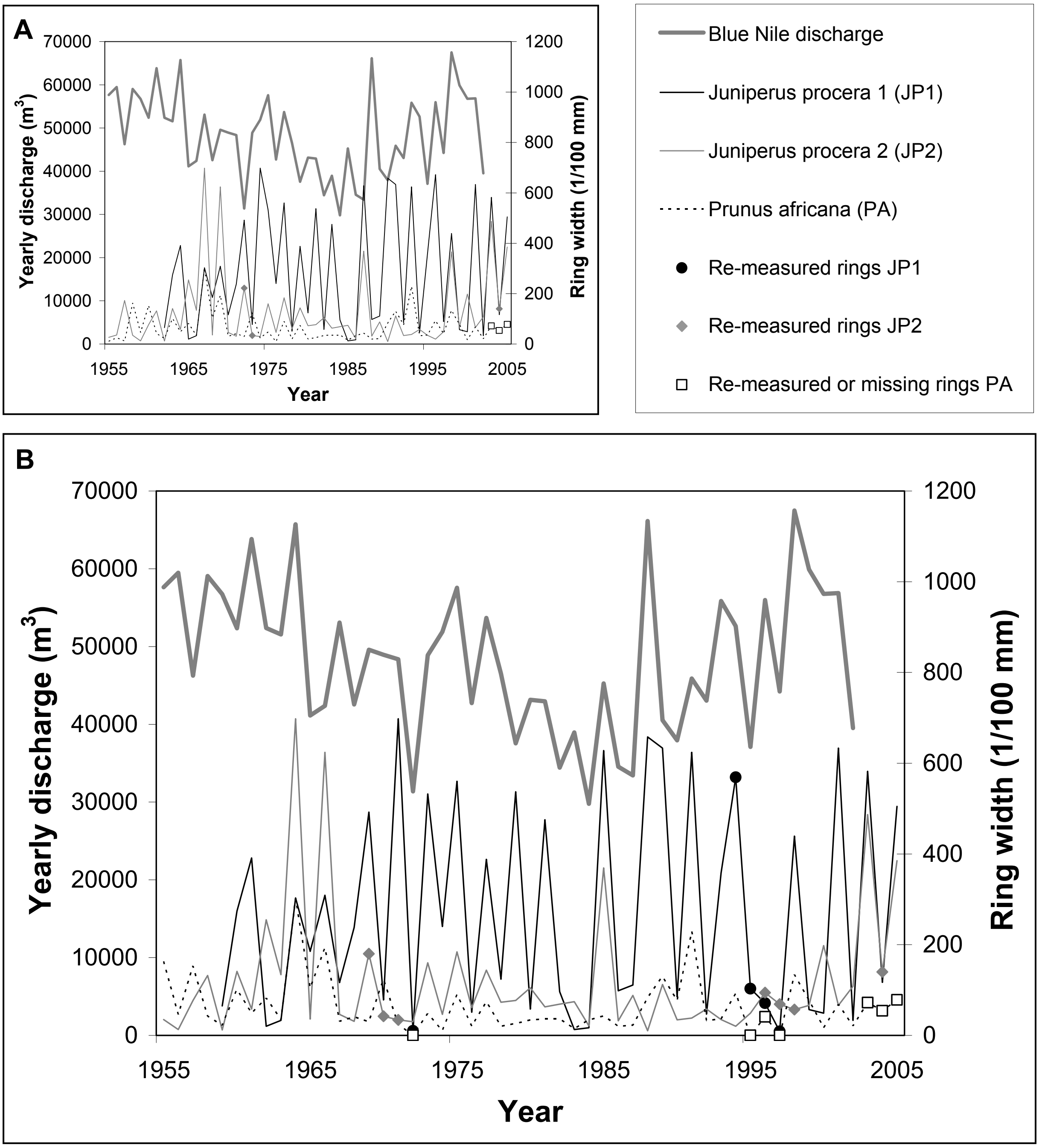

Figure 2: Graphs showing the ring width series of the initial (A) and final (B) cross-date and annual Blue Nile River discharge (measured at Roseires and, after construction of the Roseires Dam, at El Deim, Ethiopian-Sudanese border). Re-measured and inserted missing rings are indicated. The wood anatomical evidence supporting these adjustments is summarized in table 1.

Comparison of the initially cross-dated series with Blue Nile River discharge suggested that there were some shifts in the ring width series (see figure 2A). Therefore, the original hypothesis – ring width and discharge are associated – was rejected, and the improved hypothesis – the association is obscured by misdating of the ring width series – was examined.

Two rings seemed to be missing in the 1990s. The anatomical properties of the samples suggested in all three cases that these rings could exist but were originally not measured due to weak ring definition (see table 1). Further, one ring seemed to be missing in the extremely dry year 1972. According to historical accounts, this was a year of extreme drought and famine in Ethiopia, known as Wollo drought, which was one of the causes of the communist revolution and subsequent fall of the monarchy in 1974. On JP1 this ring was found as a very small partial ring, whereas on PA it could be masked by unclear ring boundaries (see table 1). JP2 did not contain any evidence to justify inserting a missing ring in 1972, but a density variation was present in 1970 (see table 1). Hence, the improved hypothesis could not be rejected: probably the tree rings contain a water stress signal which is however obscured by errors in the initial cross-date.

Therefore, the initial cross-date was adjusted to comply with all available evidence. The final cross-date is presented in figure 2B. Correlation coefficients between each series and the initial and final cross-date are given in table 1.

Discussion

The ease with which the ring width series were matched-up without referring to river discharge clearly suggests the existence of a common signal. The wood anatomical and historical support for the final cross-date and the *high* degree of synchrony between the final cross-date and Blue Nile River discharge support the idea that this common signal is water-stress related. Therefore, the original hypothesis of this paper and the cross-dating strategy seem to hold.

An important question to ask is however to what degree this approach is circular. Does this approach really *test* the existence of a water-stress signal in the ring widths?

The moment of testing is as described in the methods section shifted to before chronology building. Hence, it is not the common signal that is compared with climate data, but the individual signals. Those are heavily influenced by other factors than climate alone. However, the practice of initial cross-dating *assumes* a common signal and *enhances* it, so by effect the initially cross-dated individual series do already represent a *common* signal, especially in the high-frequency domain.

After rejecting the original hypothesis, the improved hypothesis is tested by partly using the same data. This is a practice which is very common in dendroclimatology (and science in general), *e.g.* during cross-dating and interpretation of the common signal, as in both cases hypotheses are constantly being tested and rewritten *within* a certain dataset. It reflects the ambiguity of the data, in this study especially of the wood anatomy, and hence supports the generalization as representing the empirical reality rather than as fitting to a certain approach in hypothesis testing.

Further, no claims are made about the synchrony between ring width and discharge alone. Only the *high* degree of it after *justifiable* adjustments is treated as a *justification* to adjust the ring width series and to express the *conjecture*, not the claim, that probably the tree rings contain a water stress signal which is however obscured by errors in the initial cross-date. In other words, although there are some testing stages, the approach as a whole does not *test* the existence of a climate signal in the ring width series, but rather pieces together bits of evidence to express a conjecture. In that sense, the approach is weakly circular, however not to such a degree that the results are complete nonsense. In fact, it is close to the way archaeologists and historians tend to work. Besides, conventional dendroclimatology itself is not completely free from circular reasoning (see evaluation of it above). Using common sense, when three samples do cross-date, but on comparison with climate data seem to be shifted exactly in years which either show problematic ring definition or experienced extreme drought, claiming to have found no climate signal would be nonsensical.

The essential weakness of the approach is that in testing the improved hypothesis other potential causes for rejection of the original hypothesis are ignored. Acceptation of the improved hypothesis – such as in this study – does not necessarily imply that it is right. Therefore, it is better to say the study *failed to reject* the improved hypothesis.

In standard dendroclimatology cross-dating is treated as a technique, whereas environmental signal interpretation is treated as a test of hypothesises. This is a justifiable approach if trees are easily cross-datable and environmental signal interpretation is not straightforward, *i.e.,* in the temperate regions. In the case of Northwest Ethiopia the opposite appears to occur. Cross-dating is excessively difficult, whereas environmental signal interpretation is relatively straightforward (Conway et al. 1998, Couralet et al. 2005, Krishnamurthy and Epstein 1985). Therefore the presented approach, which treats the initial cross-date as more hypothetical and the environmental signal as more probable than the conventional approach, fits this specific case.

The most important benefits of the approach are that it prevents comparing an internally misdated chronology with climate data and helps identifying weakly defined ring boundaries. This is especially important in the (sub)tropics. Nevertheless, adjustments *after* comparison of ring width series and climate data should be made with great caution and preferably in explorative studies only. It is strongly recommended that final studies rely on enough replication to make such adjustments unnecessary.

Conclusion

From the acquired evidence and following an unorthodox approach there appears to be a basis for reconstructing River Nile discharge from *Juniperus procera* and *Prunus africana* tree rings from the Ethiopian section of the Blue Nile basin. This paper discusses 'standard dendroclimatology' in an attempt to create new opportunities for tree species which are difficult to cross-date. Regarding the discussing nature, this paper does not have any higher claims than the ambiguity that is presented.

Acknowledgements

We thank Dr. Alemu Gezahegn, director of Forest Research, and Mr. Negash Mammo, director of the Forestry Research Centre, both at the Ethiopian Institute of Agricultural Research in Addis Ababa for their dedicated and logistic support. We thank Dr. Ute Sass-Klaassen, Wageningen University and Research centre, for help in interpreting *Juniperus procera* growth patterns and Dr. Declan Conway, University of East Anglia, for fruitful discussions and providing discharge data. We thank Dr. Iain Robertson and Dr. Neil Loader, University of Wales Swansea, for constructive criticism to the manuscript. We thank the

University of Wales Swansea Studentship program and the Association for Tree-Ring Research (ATR) for funding. Finally, we would like to thank the people of Ethiopia for their hospitality, help, love and courage.

References

Baillie, M.G.L. (1995): A slice through time: dendrochronology and precision dating. The Bath Press, Bath. 176 p.

Conway, D., Brooks, N., Briffa, K.R., Merrin, P.D. (1998): Historical climatology and dendroclimatology in the Blue Nile River basin, Northern Ethiopia. Water resources variability in Africa during the XXth century, Proceedings of the Abidjan '98 Conference, November 1998, Abidjan, Côte d'Ivoire. IAHS Publications no. 252: 243-251.

Cook, E.R., Kairiukstis, L.A. (eds.) (1990): Methods of Dendrochronology, Applications in the Environmental Sciences. Kluwer Academic Publishers, Dordrecht, The Netherlands. 394p.

Cook, E.R., Shiyatov, S.G., Mapeza, V.S. (1990): Estimation of the Mean Chronology. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht, The Netherlands: 123-132.

Couralet, C., Sass-Klaassen, U., Sterck, F., Bekele, T., Zuidema, P.A. (2005): Combining dendrochronology and matrix modelling in demographic studies: an evaluation for *Juniperus procera* in Ethiopia. *Forest ecology and management 216:* 317-330.

Feyerabend, P.K. (1993): Against Method. Verso, London. 279 p.

Fritts, H.C. (1976): Tree rings and climate. Academic Press, London. 567 p.

Fritts, H.C., Guiot, J., Gordon, G.A., Schweingruber, F.H. (1990): Methods of Calibration, Verification, and Reconstruction. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht, The Netherlands: 163-217.

Grissino-Mayer, H.D. (2001): Evaluating crossdating accuracy: a manual and tutorial for the computer program Cofecha. *Tree-ring research 57(2):* 205-221.

Krishnamurthy, R.V., Epstein, S. (1985): Tree ring D/H ratio from Kenya, East Africa, and its palaeoclimatic significance. *Nature 317:* 160-162.

Pilcher, J.R. (1990): Sample preparation, Cross-dating and Measurement. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kuwer Academic Publishers, Dordrecht, The Netherlands: 40-51.

Popper, K.R. (1980): The logic of scientific discovery. Hutchinson, London. 479 p.

Said, R. (1993): The river Nile: geology, hydrology and utilization. Pergamon Press, Oxford. 320 p.

Sutcliffe, J., Lazenby, J. (1994): Hydrological data requirements for planning Nile management. In: Howell, P.P., Allan, J.A. (eds.): The Nile, sharing a scarce resource, Cambridge University Press, Cambridge: 163-192.

Wigley, T.M.L., Jones, P.D., Briffa, K.R. (1987): Cross-dating methods in dendrochronology. *Journal of Archaeological Science 14:* 51-64.