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Facilitating tree-ring dating of historic conifer timbers using Blue Intensity

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ABSTRACT

Dendroarchaeology almost exclusively uses ring-width (RW) data for dating historical structures and artefacts. Such data can be used to date tree-ring sequences when regional climate dominates RW variability. However, the signal in RW data can be obscured due to site specific ecological influences (natural and anthropogenic) that impact crossdating success. In this paper, using data from Scotland, we introduce a novel tree-ring parameter (Blue Intensity – BI) and explore its utility for facilitating dendrohistorical dating of conifer samples. BI is similar to latewood density as they both reflect the combined hemicellulose, cellulose and lignin content in the latewood cell walls of conifer species and the amount of these compounds is strongly controlled, at least for trees growing in temperature limited locations, by late summer temperatures. BI not only expresses a strong climate signal, but is also less impacted by site specific ecological influences. It can be concurrently produced with RW data from images of finely sanded conifer samples but at a significantly reduced cost compared to traditional latewood density. Our study shows that the probability of successfully crossdating historical samples is greatly increased using BI compared to RW. Furthermore, due to the large spatial extent of the summer temperature signal expressed by such data, a sparse multi-species conifer network of long BI chronologies across Europe could be used to date and loosely provenance imported material.

1. Introduction

Dendrochronology is multidisciplinary in nature and has many applications in the environmental sciences including ecology, geomorphology and climatology (Schweingruber, 1996; Hughes et al., 2010; Speer, 2010; Stoffel et al., 2010). The common fundamental keystone to all dendrochronological sub-disciplines is the ability to ensure exact calendar dating of the tree-ring (TR) series. Crossdating is the ability to pattern-match or synchronise TR sequences between samples of the same species across a climatically homogenous region to allow the identification of the exact year in which a particular TR was formed (Stokes and Smiley, 1968; Fritts, 1976). One of the earliest uses of dendrochronological methods was the dating of historical structures and artefacts (so-called dendroarchaeology) and a large body of published work now exists

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detailing the development of this sub-discipline (Baillie and Pilcher, 1973; Baillie, 1982; Pilcher et al., 1984; Kuniholm, 2001).

Until now, dendroarchaeology has almost exclusively utilised ring-width (RW) as the main tree growth variable for crossdating. RW is inexpensive to produce, not only directly from samples (via microscope graticules or measuring stages), but can also be measured from sample casts (Crone, 2008), photographs (Mills, 1988; Levanič, 2007) and scanned images (Rydval et al., 2014). The success of dendroarchaeology from many regions across both the Old (Baillie, 1995; Kuniholm and Striker, 1987; Manning and Bruce, 2009) and New (Douglass, 1929; Nash, 1999) Worlds highlights the importance of this variable for historical dating.

Crossdating is possible because trees of the same species within the same region respond in a similar way to climate. This means that during years of favourable growth conditions, all trees, on average, will develop a relatively wide ring, whereas thinner rings will develop when environmental conditions are less favourable. RW patterns, therefore, can be synchronised between trees in the same area and the strength of the common signal between trees and across wide regions often reflects the strength of the climatic influence on growth.

The sensitivity of tree-growth to climate is a function of the tree's geographical location which influences what aspect of climate most limits tree productivity. As a general rule, in high latitude/altitude situations, growth is limited by summer temperatures, whereas at low latitude/altitude sites, tree-growth is more commonly limited by moisture availability. Many transect and regional network studies have shown this change in general tree response to climate with elevation and/or latitude (Fritts et al., 1965; LaMarche, 1974; Lingg, 1986; Kienast et al., 1987; Wilson and Hopfmueller, 2001; Babst et al., 2012; St. George, 2014). In regions of complex topography, however, the varying response of tree-growth to climate for a single species can complicate between-site crossdating and dendroarchaeological dating. For example, Wilson et al. (2004) showed for the Bavarian Forest in Germany, that when using RW, low elevation moisture limited Norway spruce trees (<700 m.a.s.l.) could not be crossdated with high elevation temperature sensitive trees above 1100 m.a.s.l despite these two regions being only about 50 km apart.

An additional limiting factor influencing the utility of RW for dendroarchaeology is that RW variability is an aggregated product of multiple environmental factors (e.g. climate, site ecology, natural and anthropogenic disturbance, etc.) influencing tree-growth throughout the year (Cook, 1985). From a dating perspective, it is desirable for the common regional scale climatic influence upon growth to dominate the variability in RW series and the impact of local factors (natural and anthropogenic) to be minimal. Optimising the climatic influence expressed in TR series and minimising the "noise" of all other factors therefore facilitates crossdating. This is strategically performed through careful site selection in dendroclimatological studies (Fritts, 1976), but for dendroarchaeology, the exact provenance of historic timbers may never be ideal to optimise the climatic influence expressed by RW data and so the climate related signal is often weaker with resultant detrimental implications for dating.

RW is not the only variable that can be measured from tree rings however. Density based parameters (Polge, 1970; specifically maximum latewood density) have been successfully used over the last 30 years as an effective proxy of past summer temperatures (Briffa et al., 1992, 2001; Wilson and Luckman, 2003; Esper et al., 2012; Schneider et al., 2015). Stable isotopes, in recent years, have also been shown to provide additional information expressing a whole new swath of climatic information that can be extracted from TR samples (McCarroll and Loader, 2004; Treydte et al., 2007; Young et al., 2015). However, measuring ring density or stable isotopes requires specialised equipment (which few TR laboratories possess) and are much more expensive to produce compared to RW.

A novel TR variable that has been championed for dendroclimatology in recent years is Blue Intensity (BI - McCarroll et al., 2002; Björklund et al., 2014; Rydval et al., 2014; Wilson et al., 2014). BI is similar to maximum latewood density (MXD) as they both essentially measure the combined hemicellulose, cellulose and lignin content (related to cell wall thickness) in the latewood of conifer trees. The intensity of the light reflectance in the blue part of the spectrum is a good proxy of the amount of these compounds (especially lignin) and cell wall thickness as they readily absorb blue light. Therefore, dense, darker latewood will result in less reflected blue light. BI and MXD are therefore related (inversely correlated) and have been shown to express a much stronger relationship with summer temperatures than RW as they express a "purer" climate signal and are less influenced by other site specific non-climatic factors (Björklund et al., 2014; Rydval et al., 2014; Wilson et al., 2014). BI data can be generated at the same time as RW data at no additional cost by measuring directly from images (scans or photographs) of finely sanded conifer wood samples and can theoretically be generated by any dendrochronological laboratory with minimal investment (see Campbell et al. (2011); Rydval et al. (2014) and Österreicher et al. (2015) for different approaches for BI measurement). As BI generally expresses a stronger summer temperature signal than RW, at least at inter-annual time-scales (Rydval et al., 2014, 2016b; Wilson et al., 2012; 2014) and is less susceptible to site specific ecological "noise", we hypothesise that the use of BI will substantially improve our ability to successfully date historical structures where conifer wood is the main construction material.

In this paper, we present the first exploration of using BI data to aid dendro-historical dating using a Scottish case study. In Scotland, the dendrochronological dating of imported archaeological oak using RW has been reasonably successful, aided by a network of reference chronologies across northern Europe (Crone and Mills, 2012). However, dating native timber is less straightforward, in part due to chronological and geographical gaps in native reference chronologies (Mills and Crone, 2012). Using just RW data, historical dating of native pine in Scotland has been an especially formidable challenge (Crone and Mills, 2002, 2011) and until recently only a few structures, built with local pine, had been dated (Mills and Crone, 2012). While in part this is related to the need for the development of a network of native pine reference chronologies (Mills, 2008) it also appeared to be related to intrinsic characteristics of pine used in Scottish buildings, including the predominant use of young (<80-year) timbers, which make dating more difficult (Crone and Mills, 2011; Mills and Crone, 2012). BI has changed this situation substantially, and its use has significantly increased the chance of attaining a robust date for historical structures – whether the conifer construction material was sourced in Scotland or from other regions in Europe.

This paper first details the current status of the Scottish pine TR network and the defined regional reference chronologies used for historical dating. The dating potential of BI versus RW is then examined using four independently sampled living sites and six historical structures. A sub-sampling exercise, using the full Scottish pine data-set, is then performed to model how many timbers would theoretically need to be measured and dated from a historical phase/structure to "guarantee" a successful crossdate using either RW and BI. The paper ends by examining the wider implications of using BI data for crossdating and provenancing across Europe in light of the significant amount of trade and transportation of conifer construction material over the last 500 years throughout the whole region.