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ORIGINAL ARTICLE

# I-BIND: International Blue intensity network development working group

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ABSTRACT

Blue Intensity (BI) is coming of age in dendrochronology, although some methodological challenges still need resolution. In the last 20 years, 59 papers have been published focussing mainly on climatological based studies, although BI has also been shown to be useful both for historical dating and dendroecological studies. This short paper briefly reviews the BI method development of the last two decades and introduces a new collaborative initiative called I-BIND (International Blue Intensity Network Development Working Group), which is supported by the Association of Tree-Ring Research. The main aims of I-BIND are to promote continued methodological development, communicate best practice via workshops, encourage the development of BI data networks to enhance both dendroclimatology and dendro-historical dating, and to create a rich environment in which innovative and novel initiatives can be explored and discussed.

## 1. Introduction

Since the seminal paper of McCarroll et al. (2002), Blue Intensity (BI) is now slowly entering a mature phase of common usage within the dendrochronological community. In its most commonly used form, the method measures the intensity of the reflectance of blue light from the wood of scanned conifer samples so that a dark (dense) latewood would result in low reflectance values. Latewood minimum blue reflectance, in its raw form, measures similar wood properties to maximum latewood density (hereafter MXD) but is inversely correlated with it, but both provide similar proxy estimates of relative latewood density. To ensure the consistent processing (i.e. detrending) of MXD and blue reflectance data, Rydval et al. (2014) proposed the straightforward inversion of raw blue reflectance values. Although termed initially as Blue Reflectance (McCarroll et al., 2002; Babst et al., 2009), the inverted values of blue reflectance are now widely referred to as Blue Intensity (BI). There are two competing explanations for the physical and biological processes that drive BI variability. McCarroll et al. (2002) suggested that BI is related to the lignin content of latewood cell walls, whereas Björklund et al. (2021) proposed that BI represents the functional anatomical density - thus the cell wall thickness and the cell size are the crucial elements while the compounds in the cell walls are effectively insignificant. Most studies that have directly compared MXD and latewood BI (hereafter LWB), from conifers expressing no obvious heartwood/sapwood colour transition, show little difference in both climate response (Kaczka et al., 2018) and long-term trends when the data are similarly detrended (Wilson et al., 2014; Ljungqvist et al., 2020). As well as LWB, the maximum BI values of the earlywood (hereafter EWB) can also be measured providing a similar wood property proxy to minimum earlywood density (MND). MND and EWB have rarely been used in dendroclimatology, but some studies have shown substantial potential for this parameter for dendroclimatology (Björklund et al. 2017; Buckley et al., 2018; Blake et al., 2020; Cao et al., 2020; Wilson et al., 2021). For species with a strong heartwood/sapwood colour change, subtracting the EWB data from LWB creates a new variable called Delta Blue Intensity (DB - Björklund et al., 2014) which has been shown, for some species, to be a significant methodological improvement to correct for non-climatic colour change related biases (Björklund et al., 2014, 2015; Wilson et al., 2017a; Fuentes et al., 2018; Reid and Wilson, 2020; Wang et al. 2020).

A brief review of 59 published BI studies provides an interesting overview of the development of BI as a tool for tree-ring research (Table S1). Although early research exploring the use of image analysis methods to provide surrogate measures for density-related parameters were promising (Yanosky and Robinove (1986); Yanosky et al. (1987); Sheppard et al. (1996)), it was McCarroll et al. (2002) who finally detailed the substantial potential of BI for dendroclimatology. In fact, McCarroll et al. (2002) have been the only group who tested different parts of the reflected light spectrum, both visible and UV, as surrogate parameters for X-ray densitometry. Together with Campbell et al. (2007;

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2011), these early studies clearly showed the potential of using BI as a summer temperature proxy. Based on this early work using Scots pine, it is not a surprise that 49 % of BI studies have since focussed on Scots pine (*Pinus Sylvestris* L.), with 32 % of these studies from Scandinavia (Fig. 1). Scots pine was the initial focus for BI experimentation (McCarroll et al., 2002; Björklund et al., 2014, 2019, 2021; Rydval et al., 2014; Wilson et al., 2012), but Engelmann spruce (*Picea engelmannii*) and Norway spruce (*Picea abies* (L.) Karst) were also important in the formative years leading to the current accepted BI methodologies (Babst et al., 2009; Wilson et al., 2014; Österreicher et al., 2015). BI has since been successfully tested on 21 coniferous species in Europe, North America, Asia and Australasia (Table S1). Similar to studies using MXD, BI has been employed almost exclusively as a warm season temperature proxy.

The existence of x-ray measurements additionally helped to improve the understanding of BI, solidifying the notion that BI can be employed as a stand-alone tree-ring parameter. The constant effort to improve the understanding of both the biological and physical principals behind BI is continuing by a growing number of labs experimenting with these parameters which is reflected in a steady growth of publications dedicated fully or partially to such improvements (Shepard et al. 1996; McCarroll et al., 2002; Campbell et al., 2007, 2011; Babst et al., 2009; Rydval et al., 2014; Wilson et al., 2014; Björklund et al., 2014; Kaczka et al., 2018; Björklund et al., 2019; Reid and Wilson, 2020; Björklund et al., 2020; Wang et al., 2020b; Frank and Nicolussi, 2020; Wilson et al., 2021). The development of new tools, especially the incorporation of BI measurement into standard tree-ring software packages such as Windendro (Regent Instruments, Canada), Cdendro & CooRecorder (Cybis Elektronik & Data AB, Sweden), and LignoVision (Rinntech-Metriwerk GmbH & Co. KG Germany) as well as BI focussed workshops associated with conferences such as TRACE (2018, 2019, 2021) and WorldDendro (2018), have helped to propagate the method to the wider dendrochronological community. More and more papers are being published that detail direct exploration of BI data (as well as tree-ring width) and since the second half of 2010s, a >60 % increase in BI focused papers is noted (Fig. 1). Such studies have substantially improved our understanding of tree-growth/climate response for multiple species and locations. This review also highlights the advantage that BI has over other wood properties parameters, like density and quantitative wood anatomy, in that more data can be produced in a substantially shorter period of time, leading to the development of regional networks, a trend which has increased substantially in recent years (Rydval et al. 2016; Wilson et al., 2014, 2019, 2021; Janecka et al., 2020; Seftigen et al., 2020; Wang et al., 2020a; Harley et al., 2020). Interestingly, in the last two decades, only a handful of studies using BI were dedicated to topics other than growth-climate response or/and climate reconstruction. Wilson et al. (2017) and Mills et al. (2017) used LWB, measured from Scots pine in Scotland, to demonstrate that BI could be employed to enhance dating and provenancing of historical wood. Further evidence detailing the potential of LWB to improve historical dating has been presented by an expanding number of groups (Spyt et al. 2016; Myglan et al., 2018; Akhmetzyanov et al., 2020). A dendroecological study assessing the effect of the larch bud moth revealed that the defoliation of European larch is better registered by BI than tree-ring widths (Arbellay et al., 2018). These rare non-climate related studies clearly detail the potential of BI in research areas other than dendroclimatology.

The measurement of BI parameters is especially attractive to the dendrochronological community because, compared to standard methods for measuring wood density and wood anatomical properties, BI data generation is relatively easy, quick, and cheap. This makes BI data an affordable option to almost any laboratory. The potential of BI data therefore revolves around the fact that it is a tree-ring parameter (like ring-width) for the masses and is not constrained to be measured by only a few laboratories with specialised equipment. The downside, however, is that BI data are not problem free, and the potential of data misuse is substantial. BI parameters have clearly been useful in many dendroclimatological studies (Campbell et al., 2007, 2011; Helama et al., 2013; McCarroll et al., 2013; Rydval et al., 2014, 2017a, 2017b, 2018a, 2018b; Björklund et al., 2014, 2015; Wilson et al., 2012, 2014, 2017a, 2019; Linderholm et al., 2015; Österreicher et al., 2015; Babst et al., 2016; Brookhouse and Graham, 2016; Dannenberg and Wise, 2016; Dolgova, 2016; Fuentes et al., 2016; Wilson et al., 2016; Arbellay et al., 2018; Buckley et al., 2018; Buras et al., 2018; Anchukaitis et al., 2017; Fuentes et al., 2018; Kaczka et al., 2018; Wiles et al., 2019; Blake et al., 2020; Schwab et al., 2018; Kaczka et al., 2017; Heeter et al., 2020; Heeter et al., 2019; Nagavciuc et al., 2019; Piermattei et al., 2020; Reid and Wilson, 2020; Seftigen et al., 2020; Tsvetanov et al., 2020; Wilson et al., 2021). However, despite many of these studies presenting calibration results at least as strong as those often found using MXD, such reflectance-based measures are liable to substantial potential bias due to non-climatic related discoloration of the samples and caution is needed in sample and data processing (Björklund et al., 2014). The potential impact on long term trends that could theoretically be extracted from BI based records is profound. In this regard therefore, the utilisation of BI is still very much in an early stage and methods for overcoming these issues are not yet fully realised although several studies have shown that these biases can be overcome (Björklund et al., 2015; Rydval et al., 2017a, 2017b; Wilson et al., 2017a; Fuentes et al., 2018; Reid and Wilson, 2020; Wang et al. 2020). A coordinated initiative to ensure continued methodological development and communication of best practise is needed.

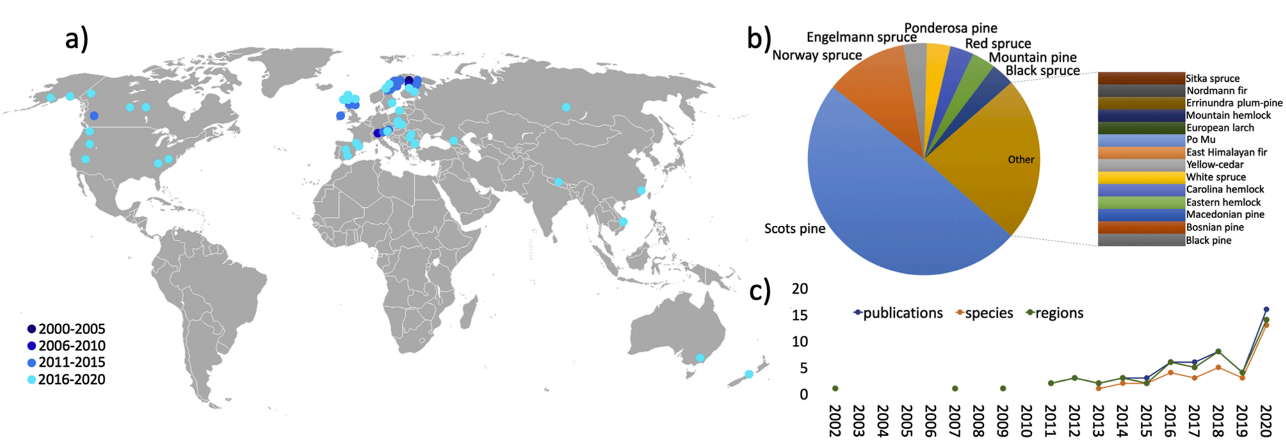


**Fig. 1.** Blue Intensity publications between 2002 and 2020: a) geographical location of the studies; b) the percentage of employed conifer species; c) number of the publications, locations and species over time (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

## 2. I-BIND - international blue intensity network development working group

Methodological improvement is paramount for the continued utility of BI for dendrochronology. Currently, standard high-resolution scanner systems are used to capture images (1200–3200 DPI resolution) from conifer samples, from which ring-width and BI data are measured using a range of software packages (CooRecorder, WinDendro, LignoVision etc). However, scanned image quality is rarely good enough to robustly capture micro-rings of one or two cells thickness and it is now well known that the quality of both MXD and LWB potentially suffers, if rings are narrow, when using lower resolution approaches (Björklund et al., 2019). High-resolution camera-based systems may well be the next methodological step to improve image resolution and BI data quality, but substantial methodological experimentation is still needed to derive an optimal resolution (i.e. too high is also not ideal) with associated image colour calibration. Moreover, image analysis programs need to be improved to capitalize on the information that can be extracted from high-resolution images.

Although substantial success has been noted when using the DB parameter to overcome colour related non-climatic trend biases (Björklund et al., 2014, 2015; Wilson et al., 2017a; Fuentes et al., 2018; Blake et al., 2020; Reid and Wilson, 2020; Wang et al. 2020) or band-pass approaches (Rydval et al., 2017a, 2017b), sample discolouration still provides perhaps the greatest challenge to the utilisation of BI data and it is likely that true unbiased estimates of relative wood density may only be derived from wood anatomical approaches (Björklund et al., 2020). The challenge for the dendrochronological community is to continue experimenting with BI data, ideally in conjunction with MXD and/or wood anatomical data to finalise a robust methodology that is available and affordable to all.

Finally, despite its strong climate signal, MXD has never been used for historical dating. The ease of BI generation, and the similarity of this variable to capture a strong inter-annual climate signal and minimise site specific disturbance effects (Rydval et al., 2018a), could potentially lead to a revolution in BI based historical dating (Wilson et al., 2017b). Further, MXD data have rarely been measured from low elevation sites where moisture limitation may be the primary control on growth (Rocha et al., 2020; Seftigen et al., 2020) but where much of the source timber material could come from for historical structures. With relative ease, BI data could be measured from living and historical samples from both low and high elevations and across multiple conifer species to create a new rich dataset for climatology and historical dating (and associated provenancing). The continued development of the BI method as a coherent and fully reliable scientific tool and the creation of regional networks is therefore vital for both dendroclimatology and historical dating. However, success can only be facilitated by a more coordinated collaboration between laboratories.

With these issues in mind, and with the support of the Association of Tree-Ring Research, we have created the I-BIND (International Blue Intensity Network Development) Working Group which has the following aims:

1 To promote the methods of BI generation for Tree-Ring Laboratories around the globe and encourage labs to embrace the method and ensure best practise.
2 To encourage the further development of the BI methodology through workshops and collaboration
3 To encourage collaboration for the creation of regional (e.g. European, Africa, South, North America, Asia and Australasian etc.) networks of BI chronologies – not just from temperature limited treeline locations, but also from more moisture stressed limited sites at low elevations/latitudes.
4 To explore the utilisation of BI for historical dating and dendroprovenancing.
5 To test innovative and novel initiatives (e.g. application of BI on broadleaf species, further exploration of new species etc.).

An initial start-up meeting of the I-BIND Working Group and an associated workshop took place as part of the 2021 “virtual” TRACE conference (June 14–18). Follow up Workshops and meetings will occur annually and will run in conjunction with the Q-NETA (Quantitative wood anatomy) Working Group. Both initiatives essentially focus on the measurement of similar wood properties and collaboration between both will hopefully lead to common protocols for maximising efficient wood property measurement for dendrochronology.

## Declaration of Competing Interest

The authors report no declarations of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.dendro.2021.125859.

## References

Akhmetzyanov, L., Sánchez-Salguero, R., García-González, I., Buras, A., Dominguez-Delmás, M., Mohren, F., Den Ouden, J., Sass-Klaassen, U., 2020. Towards a new approach for dendroprovenancing pines in the Mediterranean Iberian Peninsula. Dendrochronologia 60, 125688.
Anchukaitis, K.J., Wilson, R., Briffa, K.R., Büntgen, U., Cook, E.R., D'Arrigo, R., et al., 2017. Last millennium Northern Hemisphere summer temperatures from tree rings: part II, spatially resolved reconstructions. Quat. Sci. Rev. 163, 1–22.
Arbellay, E., Jarvis, I., Chavardès, R.D., Daniels, L.D., Stoffel, M., 2018. Tree-ring proxies of larch bud moth defoliation: latewood width and blue intensity are more precise than tree-ring width. Tree Physiol.
Babst, F., Frank, D., Büntgen, U., Nievergelt, D., Esper, J., 2009. Effect of sample preparation and scanning resolution on the Blue Reflectance of Picea abies. TRACE Proc 7, 188–195.
Babst, F., Wright, W.E., Szejner, P., Wells, L., Belmecheri, S., Monson, R.K., 2016. Blue intensity parameters derived from Ponderosa pine tree rings characterize intra-annual density fluctuations and reveal seasonally divergent water limitations. Trees 30 (4), 1403–1415.
Björklund, J.A., Gunnarson, B.E., Seftigen, K., Esper, J., Linderholm, H.W., 2014. Blue intensity and density from northern Fennoscandian tree rings, exploring the potential to improve summer temperature reconstructions with earlywood information. Clim. Past 10 (2), 877–885.
Björklund, J., Gunnarson, B.E., Seftigen, K., Zhang, P., Linderholm, H.W., 2015. Using adjusted blue intensity data to attain high-quality summer temperature information: a case study from Central Scandinavia. Holocene 25 (3), 547–556.
Björklund, J., Von Arx, G., Nievergelt, D., Wilson, R., Van den Bulcke, J., Günther, B., et al., 2019. Scientific merits and analytical challenges of tree-ring densitometry. Rev. Geophys. 57 (4), 1224–1264.
Björklund, J., Seftigen, K., Fonti, P., Nievergelt, D., von Arx, G., 2020. Dendroclimatic potential of dendroanatomy in temperature-sensitive Pinus sylvestris. Dendrochronologia 60, 125673.
Björklund, J., Fonti, M.V., Fonti, P., Van den Bulcke, J., von Arx, G., 2021. Cell wall dimensions reign supreme: cell wall composition is irrelevant for the temperature signal of latewood density/blue intensity in Scots pine. Dendrochronologia 65, 125785.
Blake, S.A., Palmer, J.G., Björklund, J., Harper, J.B., Turney, C.S., 2020. Palaeoclimate potential of New Zealand Manoao colensoi (silver pine) tree rings using Blue-Intensity (BI). Dendrochronologia 60, 125664.
Brookhouse, M., Graham, R., 2016. Application of the minimum blue-intensity technique to a southern-hemisphere conifer. Tree. Res. 72 (2), 103–107.
Buckley, B.M., Hansen, K.G., Griffin, K.L., Schmiege, S., Oelkers, R., D'Arrigo, R.D., et al., 2018. Blue intensity from a tropical conifer's annual rings for climate reconstruction: an ecophysiological perspective. Dendrochronologia 50, 10–22.
Buras, A., Spyt, B., Janecka, K., Kaczka, R.J., 2018. Divergent growth of Norway spruce on Babia góra mountain in the western carpathians. Dendrochronologia 50, 33–43.
Campbell, R., McCarroll, D., Loader, N.J., Grudd, H., Robertson, I., Jalkanen, R., 2007. Blue intensity in Pinus sylvestris tree-rings: developing a new palaeoclimate proxy. Holocene 17, 821–828.

Campbell, R., McCarroll, D., Robertson, I., Loader, N.J., Grudd, H., Gunnarson, B., 2011. Blue intensity in Pinus sylvestris tree rings: a manual for a new palaeoclimate proxy. Tree-Ring Res. 67 (2), 127–134.

Cao, X., Fang, K., Chen, P., Zhang, P., Björklund, J., Pumijumnong, N., Guo, Z., 2020. Microdensitometric records from humid subtropical China show distinct climate signals in earlywood and latewood. Dendrochronologia 64, 125764.

Dannenberg, M.P., Wise, E.K., 2016. Seasonal climate signals from multiple tree ring metrics: a case study of Pinus ponderosa in the upper Columbia river Basin. J. Geophys. Res. Biogeosci. 121 (4), 1178–1189.

Dolgova, E., 2016. June–September temperature reconstruction in the Northern Caucasus based on blue intensity data. Dendrochronologia 39, 17–23.

Frank, T., Nicolussi, K., 2020. Testing different Earlywood/Latewood delimitations for the establishment of Blue Intensity data: a case study based on Alpine Picea abies samples. Dendrochronologia 64, 125775.

Fuentes, M., Björklund, J., Seftigen, K., Salo, R., Gunnarson, B.E., Linderholm, H.W., Aravena, J.C., 2016. A Comparison Between Tree-ring Width and Blue Intensity High and Low Frequency Signals From Pinus sylvestris L. From the Central and Northern Scandinavian Mountains. STR16/04, p. 38.

Fuentes, M., Salo, R., Björklund, J., Seftigen, K., Zhang, P., Gunnarson, B., et al., 2018. A 970-year-long summer temperature reconstruction from Rogen, west-central Sweden, based on blue intensity from tree rings. Holocene 28 (2), 254–266.

Harley, G.L., Heeter, K.J., Maxwell, J.T., Rayback, S.A., Maxwell, R.S., Reinemann, T.E., H Taylor, A., 2020. Towards broad-scale temperature reconstructions for Eastern North America using blue light intensity from tree rings. Int. J. Climatol.

Heeter, K.J., Harley, G.L., Van De Gevel, S.L., White, P.B., 2019. Blue intensity as a temperature proxy in the eastern United States: a pilot study from a southern disjunct population of Picea rubens (sarg.). Dendrochronologia 55, 105–109.

Heeter, K.J., Harley, G.L., Maxwell, J.T., McGee, J.H., Matheus, T.J., 2020. Late summer temperature variability for the Southern Rocky Mountains (USA) since 1735 CE: applying blue light intensity to low-latitude Picea engelmannii Parry ex Engelm. Clim. Change 162 (2), 965–988.

Helama, S., Arentoft, B.W., Collin-Haubensak, O., Hyslop, M.D., Brandstrup, Ch.K., Makela, H.M., Tian, Q., Wilson, R., 2013. Dendroclimatic signals deduced from riparian versus upland forest interior pines in North Karelia. Finland. Ecological Research 28, 1019–1028.

Janecka, K., Harvey, J.E., Trouillier, M., Kaczka, R.J., Metslaid, S., Metslaid, M., et al., 2020. Higher winter-spring temperature and winter-spring/summer moisture availability increase Scots pine growth on coastal dune microsites around the south Baltic Sea. Front. Forests Global Change 3 (578912), 1–16.

Kaczka, R.J., Spyt, B., Janecka, K., Musioł, R., 2017. The Blue Intensity proxy for & 400 years growing season temperature reconstruction from the Tatra Mountains. TRACE 15, 23–30. Scientific Technical Report 16/04, GFZ German Research Centre for Geosciences.

Kaczka, R.J., Spyt, B., Janecka, K., Beil, I., Büntgen, U., Scharnweber, T., Nievergelt, D., Wilmking, M., 2018. Different maximum latewood density and blue intensity measurements techniques reveal similar results. Dendrochronologia 49, 94–101.

Linderholm, H.W., Björklund, J., Seftigen, K., Gunnarson, B.E., Fuentes, M., 2015. Fennoscandia revisited: a spatially improved tree-ring reconstruction of summer temperatures for the last 900 years. Clim. Dyn. 45 (3–4), 933–947.

Ljungqvist, F.C., Thejll, P., Björklund, J., Gunnarson, B.E., Piermattei, A., Rydval, M., et al., 2020. Assessing non-linearity in European temperature-sensitive tree-ring data. Dendrochronologia 59, 125652.

McCarroll, D., Pettigrew, E., Luckman, A., Guibal, F., Edouard, J.-L., 2002. Blue reflectance provides a surrogate for latewood density of high-latitude pine tree rings. Arct. Antarct. Alpine Res. 34, 450–453.

McCarroll, D., Loader, N.J., Jalkanen, R., Gagen, M.H., Grudd, H., Gunnarson, B.E., et al., 2013. A 1200-year multiproxy record of tree growth and summer temperature at the northern pine forest limit of Europe. Holocene 23 (4), 471–484.

Mills, C.M., Crone, A., Wood, C., Wilson, R., 2017. Dendrochronologically dated pine buildings from Scotland: the SCOT2K native pine dendrochronology project. Vernac. Archit. 48 (1), 23–43.

Myglan, V.S., Zharnikov, Z.Y., Sidorova, M.O., Barinov, V.V., Tainik, A.V., 2018. Application of the blue-intensity method for dating wooden buildings in Siberia. Archaeol. Ethnol. Anthropol. Eurasia 46 (4), 109–113.

Nagavciuc, V., Roibu, C.C., Ionita, M., Mursa, A., Cotos, M.G., Popa, I., 2019. Different climate response of three tree ring proxies of Pinus sylvestris from the Eastern Carpathians, Romania. Dendrochronologia 54, 56–63.

Österreicher, A., Weber, G., Leuenberger, M., Nicolussi, K., 2015. Exploring blue intensity – comparison of blue intensity and MXD data from alpine spruce trees. In: Wilson, R.M., Helle, G., Gärtner, H. (Eds.), TRACE – Tree Rings in Archaeology, Climatology and Ecology, vol. 13. Scientific Technical Report 15/06, GFZ German Research Centre for Geosciences, pp. 56–61.

Piermattei, A., Crivellaro, A., Krusic, P.J., Esper, J., Vítek, P., Oppenheimer, C., et al., 2020. A millennium-long 'Blue Ring'chronology from the Spanish Pyrenees reveals severe ephemeral summer cooling after volcanic eruptions. Environ. Res. Lett. 15 (12), 124016.

Reid, E., Wilson, R., 2020. Delta blue intensity vs. Maximum density: a case study using Pinus uncinata in the Pyrenees. Dendrochronologia 61, 125706.

Rocha, E., Gunnarson, B.E., Holzkämper, S., 2020. Reconstructing summer precipitation with MXD data from Pinus sylvestris growing in the Stockholm Archipelago. Atmosphere 11 (8), 790.

Rydval, M., Larsson, L.Å., McGlynn, L., Gunnarson, B.E., Loader, N.J., Young, G.H., Wilson, R., 2014. Blue Intensity for dendroclimatology: should we have the blues? Experiments from Scotland. Dendrochronologia 32 (3), 191–204.

Rydval, M., Gunnarson, B.E., Loader, N.J., Cook, E.R., Druckenbrod, D.L., Wilson, R., 2017a. Spatial reconstruction of Scottish summer temperatures from tree rings. Int. J. Climatol. 37 (3), 1540–1556.

Rydval, M., Loader, N.J., Gunnarson, B.E., Druckenbrod, D.L., Linderholm, H.W., Moreton, S.G., et al., 2017b. Reconstructing 800 years of summer temperatures in Scotland from tree rings. Clim. Dyn. 49 (9–10), 2951–2974.

Rydval, M., Druckenbrod, D.L., Svoboda, M., Trotsiuk, V., Janda, P., Mikoláš, M., et al., 2018a. Influence of sampling and disturbance history on climatic sensitivity of temperature-limited conifers. Holocene 28 (10), 1574–1587.

Rydval, M., Druckenbrod, D.L., Svoboda, M., Trotsiuk, V., Janda, P., Mikoláš, M., et al., 2018b. Influence of sampling and disturbance history on climatic sensitivity of temperature-limited conifers. Holocene 28 (10), 1574–1587.

Schwab, N., Kaczka, R.J., Janecka, K., Böhner, J.P., Chaudhary, R.P., Scholten, T., Schickhoff, U., 2018. Climate change-induced shift of tree growth sensitivity at a central Himalayan treeline ecotone. Forests 9, 26. https://doi.org/10.3390/f9050267.

Seftigen, K., Fuentes, M., Ljungqvist, F.C., Björklund, J., 2020. Using Blue Intensity from drought-sensitive Pinus sylvestris in Fennoscandia to improve reconstruction of past hydroclimate variability. Clim. Dyn. 55, 579–594.

Sheppard, P.R., Graumlich, L.J., Conkey, L.E., 1996. Reflected-light image analysis of conifer tree rings for reconstructing climate. Holocene 6 (1), 62–68.

Tsvetanov, N., Dolgova, E., Panayotov, M., 2020. First measurements of Blue intensity from Pinus peuce and Pinus heldreichii tree rings and potential for climate reconstructions. Dendrochronologia 60, 125681.

Wang, F., Arseneault, D., Boucher, É., Gloaguen, G.G., Deharte, A., Yu, S., Trou-kechout, N., 2020a. Temperature sensitivity of blue intensity, maximum latewood density, and ring width data of living black spruce trees in the eastern Canadian taiga. Dendrochronologia 64, 125771.

Wang, F., Arseneault, D., Boucher, É., Yu, S., Ouellet, S., Chaillou, G., et al., 2020b. Chemical destaining and the delta correction for blue intensity measurements of stained lake subfossil trees. Biogeosciences 17 (18), 4559–4570.

Wiles, G.C., Charlton, J., Wilson, R.J., D'Arrigo, R.D., Buma, B., Krapek, J., et al., 2019. Yellow-cedar blue intensity tree-ring chronologies as records of climate in Juneau, Alaska, USA. Can. J. For. Res. 49 (12), 1483–1492.

Wilson, R., Loader, N.J., Rydval, M., Patton, H., Frith, A., Mills, C.M., et al., 2012. Reconstructing Holocene climate from tree rings: the potential for a long chronology from the Scottish Highlands. Holocene 22 (1), 3–11.

Wilson, R., Rao, R., Rydval, M., Wood, C., Larsson, L.Å., Luckman, B.H., 2014. Blue intensity for dendroclimatology: the BC blues: a case study from British Columbia, Canada. Holocene 24 (11), 1428–1438.

Wilson, R., Anchukaitis, K., Briffa, K.R., Büntgen, U., Cook, E., D'arrigo, R., et al., 2016. Last millennium northern hemisphere summer temperatures from tree rings: part I: the long term context. Quat. Sci. Rev. 134, 1–18.

Wilson, R., D'Arrigo, R., Andreu-Hayles, L., Oelkers, R., Wiles, G., Anchukaitis, K., Davi, N., 2017a. Experiments based on blue intensity for reconstructing North Pacific temperatures along the Gulf of Alaska. Clim. Past 13 (8), 1007–1022.

Wilson, R., Wilson, D., Rydval, M., Crone, A., Büntgen, U., Clark, S., Ehmer, J., Forbes, E., Fuentes, M., Gunnarson, B.E., Linderholm, H.W., 2017b. Facilitating tree-ring dating of historic conifer timbers using Blue Intensity. J. Archaeol. Sci. 78, 99–111.

Wilson, R., Anchukaitis, K., Andreu-Hayles, L., Cook, E., D'Arrigo, R., Davi, N., et al., 2019. Improved dendroclimatic calibration using blue intensity in the southern Yukon. Holocene 29 (11), 1817–1830.

Wilson, Rob, Allen, Kathy, Baker, Patrick, Boswijk, Gretel, Buckley, Brendan, Cook, Edward, D'Arrigo, Rosanne, Druckenbrod, Dan, Fowler, Anthony, Grandjean, Margaux, Krusic, Paul, Palmer, Jonathan, 2021. Evaluating the dendroclimatological potential of blue intensity on multiple conifer species from Australasia. Biogeosci. Discus. 1–41. https://doi.org/10.5194/bg-2021-119.

Yanosky, T.M., Robinove, C.J., 1986. Digital image measurement of the area and anatomical structure of tree rings. Can. J. Bot. 64 (12), 2896–2902.

Yanosky, T.M., Robinove, C.J., Clark, R.G., 1987. Progress in the image analysis of trerings. In: Jacoby, G.C., Hornbeck, J.W. (Eds.), Proceedings, International Symposium on Ecological Aspects of Tree-Ring Analysis. National Technical Information Service. Springfield, Virginia, pp. 658–665.