Dendrochronologia 85 (2024) 126200

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

A definition and standardised terminology for Blue Intensity from Conifers

Jesper Björklund [a,b,c], Kristina Seftigen [a,c], Ryszard J. Kaczka [d], Miloš Rydval [e], Rob Wilson [f,*]

[a] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zuercherstrasse 111, Birmensdorf 8903, Switzerland
[b] Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland
[c] Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
[d] Department of Physical Geography and Geoecology, Faculty of Science, Charles University, Prague, Czechia
[e] Czech University of Life Sciences in Prague Faculty of Forestry and Wood Sciences Prague, Prague, Czechia
[f] School of Earth and Environmental Sciences, University of St Andrews, UK

ARTICLE INFO

Keywords:
Blue Intensity
Terminology
Dendrochronology
Wood anatomy
Density

ABSTRACT

The published literature of the past 20 years expresses inconsistent terminology for the Blue Intensity (BI) method that could lead to confusion in analysis and interpretation. In this technical note we propose a standard terminology based around the prevalent use of BI for the variant that is positively correlated with wood density derived from X-ray and equivalent wood anatomical techniques. We highlight significant practical advantages of this standard terminology for data analysis, scientific interpretations as well as archiving, and provide some cautionary examples that could occur if not adhering to this terminology. In future studies using BI, we recommend to explicitly clarify that the standard terminology is used with the following phrase: The BI data produced in this study is consistent with the '2024 BI standard terminology'.

1. Introduction

Within dendrochronology, there is a growing utilisation of Blue Intensity (BI) to reconstruct past climate (e.g., Wilson et al., 2014; 2019; Björklund et al., 2015; Rydval et al., 2017; Fuentes et al., 2018; Heeter et al., 2021; 2023; Seftigen et al., 2020; Cao et al., 2022; Li and Li, 2023) as well as its use in other subfields including archaeological dating (Spyt et al., 2016; Mills et al., 2017; Wilson et al., 2017; Myglan et al., 2018; Akhmetzyanov et al., 2020). However, from our experience with the published BI literature from the past 20 years, including reviewing proposals and jargon used at conferences, many different terms are used referring to the same methodology (e.g., Blue reflectance, Blue Intensity, Blue spectrum, Blue Absorption and Blue light). Moreover, there are also inconsistent interpretations and understanding of what wood properties this methodology represents. In this technical note, we propose a standard terminology (Table 1) for the approach and a set of commonly used parameters that we encourage the dendro-community to use starting with this *Dendrochronologia* Special Issue.

Building upon early grey-scale image analysis experiments (Sheppard et al., 1996; Yanosky and Robinove, 1986), it was McCarroll et al. (2002) who first introduced the term Blue Reflectance (BR). They explored if scanned images of conifer samples could be useful as a surrogate proxy for latewood density. The term was used because, in the context of all colours explored (infrared, RGB and ultraviolet light), the light reflected in the blue range of the visible light spectrum appeared to exhibit the strongest link with corresponding X-ray based density measurements. BR provides low values when the wood is dark (low reflection) and high values (high reflection) when the wood is light. That makes BR inversely related to wood density because darker wood is denser than brighter wood. Later, the term Blue Intensity (BI) was coined by Campbell et al. (2007); (2011), referring to the same type of measurements presented in McCarroll et al. (2002). Since then, it has become common to invert BI (e.g., Björklund et al., 2014; Rydval et al., 2014; Wilson et al., 2012; 2014), and BI has in the process become synonymous with both the raw and inverted states. This has led to confusion, because it may not always be clear which state the data are in (Table S1). Thus, both states of BI need to be followed by clarification of whether they are inverted or not. An undeniable fact, however, is that the term BI has become prevalent and well established in our research community, and it therefore makes sense to continue to use this term, but to clearly define it in a prominent forum such as this Special Issue on BI.

Herein we propose that BI should always represent the inverse of BR (Rydval et al., 2014), and thus be positively correlated with wood density. The use of BI, as the inverse of BR, not only offers a range of practical advantages, but it would also represent a more intelligible

* Corresponding author.
E-mail address: rjsw@st-andrews.ac.uk (R. Wilson).

https://doi.org/10.1016/j.dendro.2024.126200
Received 18 January 2024; Received in revised form 22 March 2024; Accepted 26 March 2024
Available online 3 April 2024
1125-7865/

terminology relating to what wood properties BI is measuring. Below we provide the rationale for our proposed terminology with regards to wood anatomical properties, followed by a list of some of the practical advantages. This list also discusses related pitfalls that could occur from the past confused usage of the term.

2. Current understanding of what BI represents

We define BI in this technical note, as the inverted state of reflected light in the blue spectrum from an RGB image. BI data are generated from scanned images of cross-sections of wood samples which have been sanded to allow the clear identification of ring boundaries and anatomical features at the macroscopic level (Fig. 1). BI employed in dendrochronology is thus effectively the macroscopically registered optical properties of the wood surface, which mainly depend on the microscopic xylem structure as represented by the proportion of cell wall in the woody surface. There are multiple software programmes that can generate BI data (e.g. CooRecorder, WinDENDRO, LignoVision) but, detailing the nuanced methodological differences between these image analysis packages is beyond the scope of this note (for more details, see Campbell et al., 2011; Rydval et al., 2014; Björklund et al., 2015; Kaczka et al., 2018; Frank and Nicolussi 2020; Heeter et al., 2022). As CooRecorder is the most used package (at the time of writing), the concepts discussed herein relate specifically to this software package. However, the same general principles should apply to any package that can quantify light intensities from images.

The fact that we can see tree rings in conifer images is related to the changing dimensions of the cells and cell walls moving from earlywood (EW) to latewood (LW) providing a sharp contrast from one ring to the next – i.e. small thick-walled cells in the latewood immediately followed by large thin-walled cells in the earlywood of the next ring. BI thus primarily represents the average light intensity with the dark cell walls and light cell lumina in the image and essentially represents the proportion of cell wall in the analysed sample. In addition to this anatomical dependence, BI data also depend on the specific intensity values from the dark cell walls as well as those from the light cell lumina or voids. The cell voids are often filled with either wood dust from sanding or chalk powder. Ideally the light intensity variations of this void filling are entirely irrelevant to signal interpretations, as they do not represent the properties of specific rings. However, the overall "lightness" of wood dust or chalk does affect the overall mean of the BI values (Björklund et al., 2019). Moreover, variations in light intensity of the cell walls can also be important. Factors that may affect the colour of the cell wall include heartwood and sapwood, resin content, fungal staining, lignin content, oxidation processes, quality of the sanding or razor cuts, etc. Many of these factors have a large effect on BI values, but the only factor that potentially expresses useful year-to-year variability is the cell wall material itself which is fixed in the specific tree rings.

McCarroll et al. (2002) hypothesised that BI represents the lignin content, but repeated tests of this hypothesis has found no empirical support. In fact, variations in lignin content, directly measured (Gindl et al., 2000), or inferred (Björklund et al., 2021a), appear to be only weakly associated with climate or with X-ray based wood density. Thus, the current understanding is that BI represents the proportion of cell wall dimensions with respect to the lumen voids, where changes in BI of the cell wall and BI of the cell void should be considered as distorting factors obscuring the desired information. This interpretation is strengthened by experiments comparing data from quantitative wood anatomical techniques, showing a strong connection with BI, even though quantitative wood anatomy, by definition, does not consider changes in surface reflection of walls and voids (Buckley et al., 2018; Björklund et al., 2019, 2021a; Seftigen et al., 2022). It is further corroborated when examining results produced using intentional black staining (e.g., Rydval et al., 2024). If this understanding is accurate, BI, X-ray densitometry and anatomical densitometry essentially represent the same wood properties, and that any differences between the derived data most likely represent distortions associated with the way data are measured and derived using each approach.

As BR represents data that are inversely correlated with relative wood density, its use can lead to confusion (including detrending approaches, climate calibrations, archiving, etc.) and it would be advantageous to use the proposed terminology of BI, and so to work with data that are positively correlated with wood anatomical density data. As BI variables can be measured from the earlywood, latewood and full ring, the new terminology can also be extended to those parameters which correspond to standard terms used for density and quantitative wood anatomy (Table 1). We also briefly note here that, from the literature, there is a prevalent assumption that BI is always extracted from the latewood, and therefore BI is used to implicitly represent latewood BI. However, as the usage of BI is diversifying to other parameters from the rings, we emphasize the good practice to name the parameter also with a prefix, be it earlywood (EW), latewood (LW) or maximum (MX), or any other designation that reveals more specifically which part of the ring the BI is measured from.

3. Practical advantages of BI and potential pitfalls of BR

Consistency for data networks: There is an expanding network of BI chronologies for many regions of the world (Kaczka and Wilson, 2021). At this time, however, only 35 BI chronologies have been archived within the International Tree-Ring Databank (ITRDB). From a survey of these data, it is not always clear whether BR or BI parameters

Table 1
Proposed terminology of BI parameters and their corresponding density and anatomical parameters. The BR terms are also detailed but correspond inversely to the relevant density parameters. We recommend to henceforth use the BI terminology for wood densitometric data produced using the light intensities from the visible light spectrum. Abbreviations of MX – Maximum, MN – Minimum, LW – Latewood and EW – Earlywood are commonly used to define statistical or morphological parts of the tree-ring each parameter refers to.

Blue Intensity (BI)	X-ray Density (D)	Wood anatomical Density (a_D)	Blue Reflectance (BR)	Corresponding to
MXBI - Maximum Blue Intensity	MXD	aMXD	MNBR	Maximum density in each ring
LWBI - Latewood Blue Intensity	LWD	aLWD	LWBR	Mean Latewood density
MNBI - Minimum Blue Intensity	MND	aMND	MXBR	Minimum density of each ring
EWBI - Earlywood Blue Intensity	EWD	aEWD	EWBR	Mean Earlywood density
DeltaBI* = LWBI – EWBI Delta Blue Intensity	DeltaD	aDeltaD	DeltaBR* = EWBR - LWBR	The difference calculated between Latewood density and Earlywood density
TRBI - Total ring Blue Intensity	TRD	aTRD	TRBR	Density of the full ring from the beginning of the Earlywood to the end of the Latewood

* Note that in contrast to all other BR parameters, Both DeltaBR and DeltaBI are positively correlated with their corresponding counterpart, that is DeltaD.

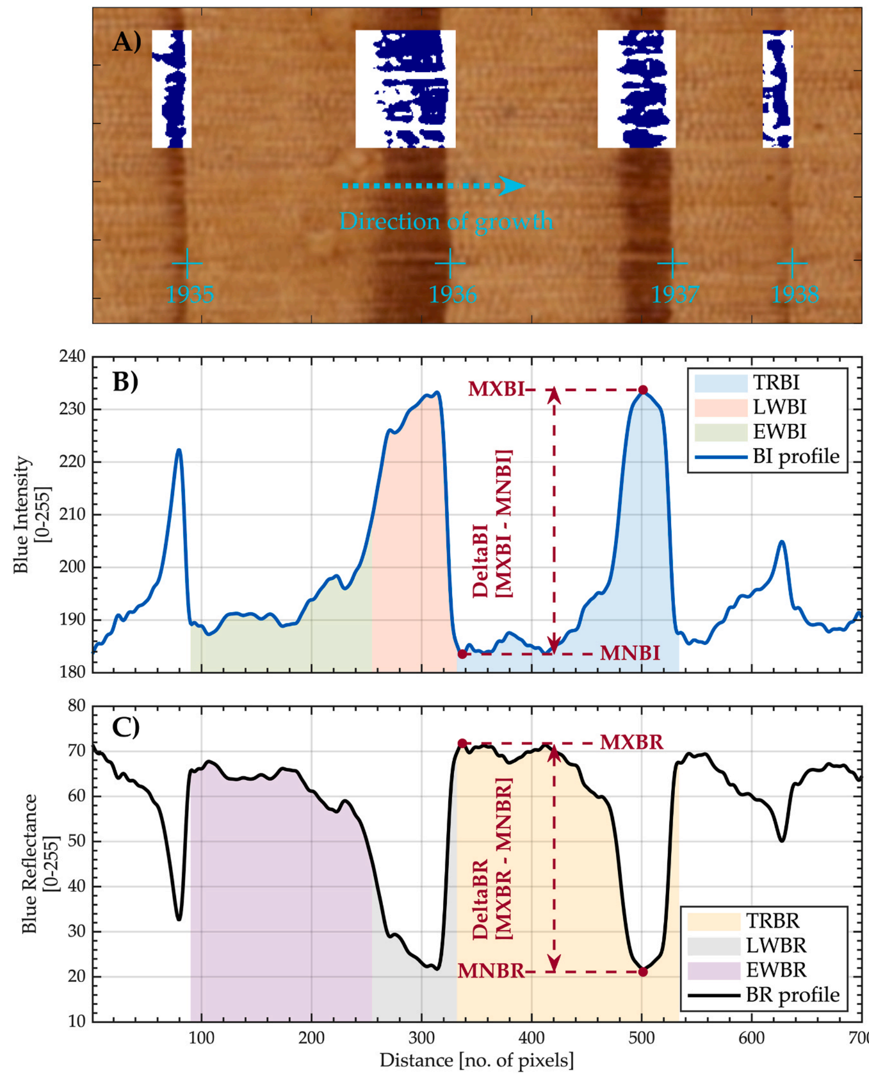

Fig. 1. Schematic figure of the various BI and BR parameters, and examples from where they are extracted and how they are related. A) cross-sectional image of a coniferous wood. From this image it is possible to, in principle, quantify light intensity as a running average from right to left, building up measurement profiles, as are depicted in B) and C). In principle, the Windendro software utilizes such an approach. Alternatively, we can define measurement boxes depicted in A) and take the average light intensity measurements from the darkest pixels which correspond to LWBI and LWBR. This approach is termed the "sorted pixels" algorithm in CooRecorder (Rydval et al. 2014).

have been archived. For those sites where the data-inversion type is explicitly detailed in the information files, it is apparent that there is a mix of BR and BI datasets. For example, the archived BI data used by Wilson et al. (2014) have not been inverted (i.e. BR data – representing the "raw" non-inverted form of reflectance values), while the data used in Wilson et al. (2019) are inverted (i.e. BI). These variant differences in archived datasets represent the development and usage of BI data over the past decade and although the "inversion state" of the data is documented in these examples, it could easily be missed if individuals were to download such datasets *en masse* for large-scale network analyses. For other archived datasets, there is often no explicit description of the "inversion state". It is therefore vital that clear labelling of datasets as either BR or BI is performed before archiving. Ideally, we propose that only BI data should be archived to remove this issue entirely.

Minimize biases from inappropriate detrending options: Some detrending options within standard packages such as ARSTAN, SigFree, dplR, are set up to remove only negative trends while retaining positive trends. The basic theory being that negative trends represent the biological age trend often observed in conventional tree-ring parameters (e.g., TRW, MXD), while positive trends represent a direct response to some aspect of environmental forcing. As latewood BI represents latewood density and anatomical parameters which express a declining age trend, the use of such detrending options would be an appropriate approach for removing such age trends. However, non-detrended BR variables, as they are inversely correlated with density, generally show a positive age-related trend. We highlight these varying parameter trends (Fig. 2a and 2b) using a regional dataset from the northern Cairngorms (NCAIRN), Scotland, based on an update of sites used by Rydval et al. (2017). If a detrending option was used that retained positive trends (the default detrending option in ARSTAN via the Age-dependent spline), this will result in unintended consequences for the final chronology. Following on from the previous point about the archiving of BR vs. BI datasets, the implications of processing BR data with the assumption that they are BI, are profound.

The NCAIRN latewood BI and BR data were detrended using the ARSTAN default age-dependent spline (Melvin et al., 2007) which is set to retain positive trends. The resulting chronologies were transformed to z-scores over their full period. When these resultant chronologies are compared (Fig. 3a), the inverse interannual signal between BR and BI is clear. However, both chronologies express a slight increasing trend through the 20th century, a direct implication of forcing positive trend retention through this default detrending option. If the BR chronology is

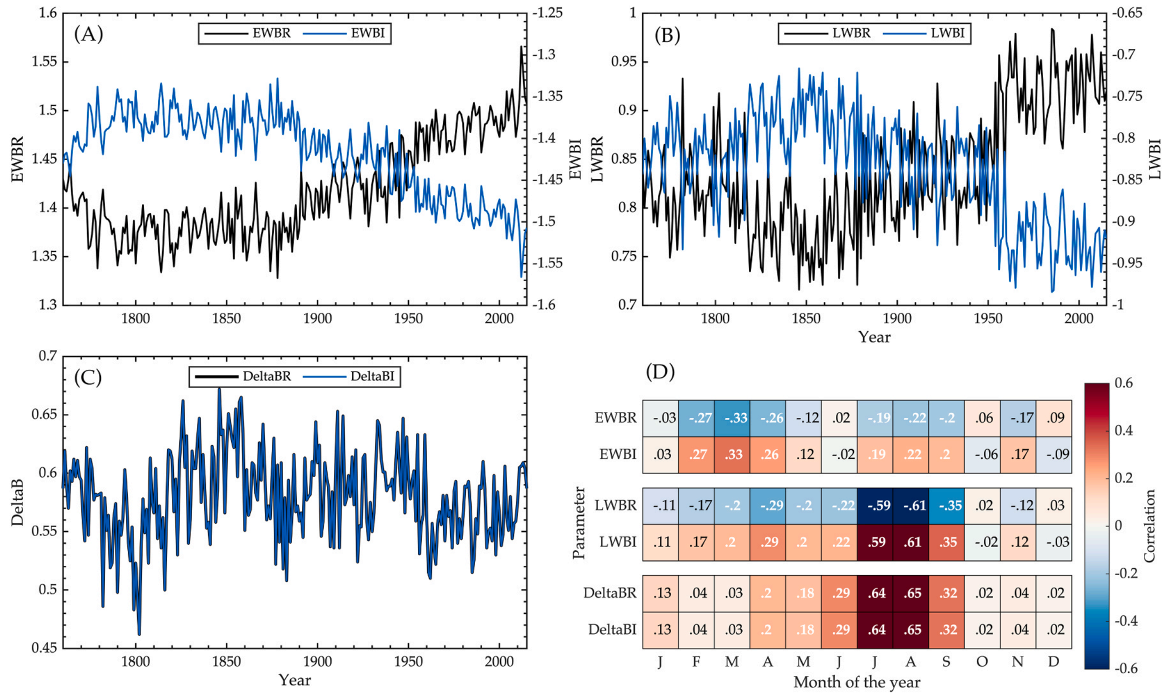

Fig. 2. Raw non-detrended chronologies of (A) earlywood and (B) latewood BR and BI, along with C) corresponding Delta BI and Delta BR. Note that the two Delta parameters are calculated differently (see main text) but are identical. (D) correlations of the various parameters with monthly temperatures. Note that both the tree-ring and climate data have been filtered using a 35-year high-pass filter prior to correlation analysis. Significant correlation coefficients ($p < 0.05$) are presented in a white font. All examples are based on updated regional composite BR/BI records for the northern Cairngorms, Scotland (Rydval et al. 2017) with a sample depth of 224 series.

inverted after detrending (Fig. 3b), then the implications of this detrending bias are clear with BI showing the "true" trends related to summer temperatures in the region (Rydval et al., 2017), while the BR chronology now expresses a significant decreasing trend because the age-related declining trend expressed in the latewood properties has not been removed. We should note that such biases would not be relevant when using standard spline (Cook and Peters, 1981) or even regional curve standardisation (Briffa et al., 1996) approaches.

Less confusion when interpreting climate calibration results: In the Northern Hemisphere, conifer trees growing in temperature-limited environments near treeline will express positive correlations for both ring-width and MXD with summer temperatures (Briffa et al., 2002). LWBR, however, will correlate negatively with temperatures while LWBI will be consistent and positively correlated with temperature and, of course, MXD (see Fig. 2d). This observation is arguably not that confusing, but in situations where the parameter/climate relationship may differ from this, the use of BR vs. BI data could become crucial when interpretating such relationships. For example, Wilson et al. (2021) assessed several conifer species from Tasmania and New Zealand for the utility of BI to enhance previous dendroclimatic reconstructions based solely on TRW. Despite naming the data BI for both earlywood and latewood, Wilson et al. (2021) in fact used non-inverted data – i.e. BR. Although this was clearly stated in the methods, the use of a standard terminology such as LWBI or LWBR (Table 1), would, in this example, have facilitated the interpretation of the results, because the relationship between LWBI and summer temperatures was opposite to what we typically see for conifers in the Northern Hemisphere. However, as LWBR (denoted as non-inverted LWB in Wilson et al., 2021) was used, the presented positive correlations would appear, at a quick glance, to be consistent with Northern Hemisphere conifers, but this approach reflects a double negative. A negative association with climate plus a negative association with wood density leading to LWBR expressing a positive temperature correlation.

An additional layer of complexity comes to light when utilising the delta BI or delta BR parameters, which are identical (Fig. 2c) but derived from the different BI or BR variants, respectively. Delta BI was originally defined as the difference between latewood BI and earlywood BI (Björklund et al., 2014). Because the variance of earlywood BI is generally smaller than that of latewood BI in conifers, the delta BI and latewood BI are usually highly positively correlated. Delta BR, however, is calculated by subtracting latewood BR from earlywood BR, making latewood BR and delta BR negatively correlated. In cases where the earlywood and latewood signals are unusually similar, as is sometimes found in SH conifers (Blake et al., 2020; Wilson et al., 2021), the interpretation of environmental signals of delta-, latewood- and earlywood BR can be especially challenging, and the use of standardised BI terminology would minimise potential confusion. This is not to say that the interpretations detailed in Wilson et al. (2021) were incorrect, but rather a cursory skim of the paper could lead to erroneous conclusions and understanding.

When making an interpretation of a correlation between BI and environmental variables, it makes sense to work out how the wood anatomical dimensions would be affected by those environmental conditions, and then examine how the anatomy relates to BI and wood density (*sensu* Björklund et al., 2017). Because the relationships between the environment and the wood anatomy can be complex in themselves, it is practical to make the interpretation process as straightforward as possible, and thus to ensure the relationship of BI and wood density is as simple as possible.

4. Conclusion

The published BI literature from the last two decades is littered with different terms and varied data formats associated with data inversion which has led to potential confusion in the dendrochronological community (see Table S1). A standard terminology to clarify which wood properties are being measured is needed. Whether one is measuring BI, density or equivalent wood anatomical parameters, these methods

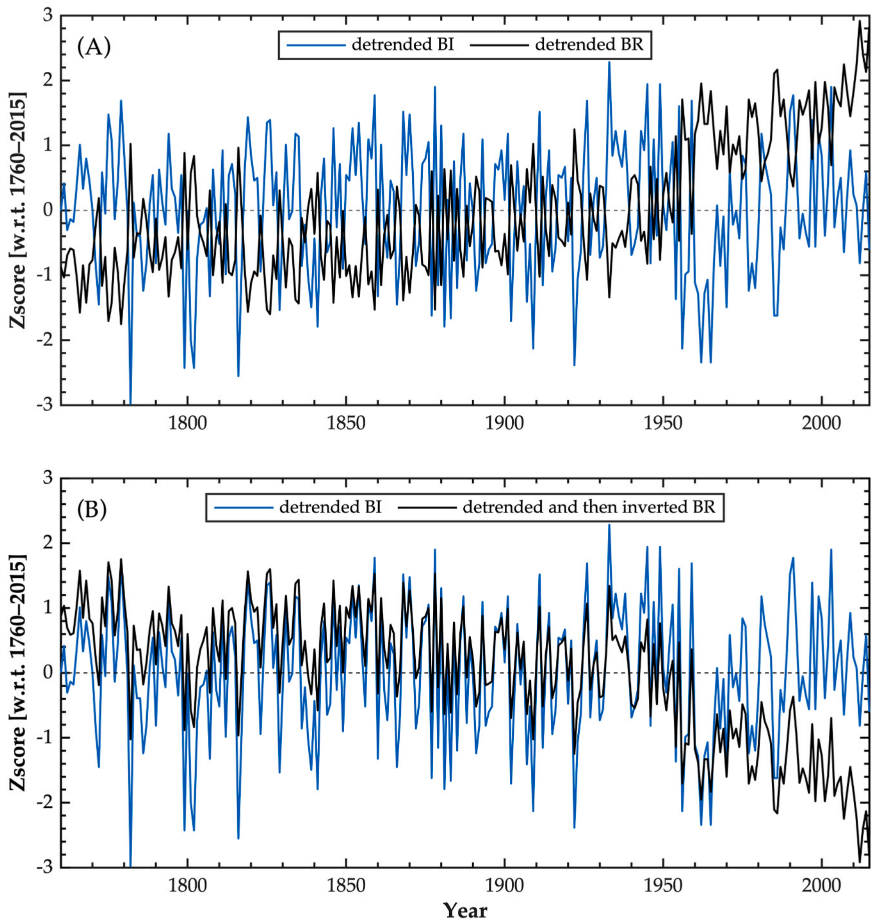

Fig. 3. An example of unintended consequences when detrending raw BR compared to BI while retaining only positive trends in the data. (A) ARSTAN default detrending option - age-dependent spline (Melvin et al. 2007) with positive trend retention. Although the resulting chronologies are inversely correlated, they are no longer perfectly mirrored due to the additional artificially introduced trend difference. (B) Comparison of the detrended and subsequently inverted BR chronology (panel A) which shows positive high frequency correlations with its BI counterpart but expresses a significant decline in recent decades.

fundamentally measure similar wood properties. Standard terms already exist for wood density and anatomical parameters but the current situation for BI is confusing. We have proposed a unified set of standard terms for the different BI parameters that are measured from conifer wood samples (Table 1) which can be directly compared to equivalent variables for density and wood anatomical parameters. As the BR parameters will be inversely correlated with their BI, density and anatomical counterparts, there is no logic to using a parameter that is inversely correlated with the wood properties it represents. Such a unified use of appropriate terms for each of the parameters measured will therefore not only make it clear what we are measuring within the rings and how they are interpreted, but also facilitate the archiving of BI data. We encourage dendrochronologists to adopt this proposed standard terminology and use the following phrase: The BI data produced in this study are consistent with the '2024 BI standard terminology'.

As a final consideration, although all published research to date regarding BI relates to conifers, the possibility of applying the BI technique to hardwoods is being explored and experimentation in this area is ongoing. We further recommend that the same BR/BI conventions in terminology introduced herein be applied to any future BI parameters developed for hardwoods.

CRediT authorship contribution statement

Jesper Björklund: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Miloš Rydval:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Rob Wilson:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Kristina Seftigen:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization. **Ryszard Kaczka:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

RW acknowledges funding from NSF/NERC project (NE/W007223/1) – Understanding Trans-Hemispheric Modes of Climate Variability: A Novel Tree-Ring Data Transect spanning the Himalaya to the Southern Ocean. KS and JB were supported by the Svenska Forskningsrådet Formas (grant no. 2019–01482) and the Stiftelsen Margit Althins stipendiefond (GS2021–0023).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dendro.2024.126200.

References

Akhmetzyanov, L., Sanchez-Salguero, R., García-Gonzalez, 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.

Björklund, J., Fonti, M.V., Fonti, P., Van den Bulcke, J., von Arx, G., 2021a. 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.

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., Seftigen, K., Schweingruber, F., Fonti, P., von Arx, G., Bryukhanova, M.V., Cuny, H.E., Carrer, M., Castagneri, D., Frank, D.C., 2017. Cell size and wall dimensions drive distinct variability of earlywood and latewood density in Northern Hemisphere conifers. N. Phytol. 216 (3), 728–740.

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.

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.

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Karlén, W., Shiyatov, S.G., 1996. Tree-ring variables as proxy-climate indicators: problems with low-frequency signals. In Climatic Variations and Forcing Mechanisms of the Last 2000 Years. Springer Berlin Heidelberg, pp. 9–41.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E. A., 2002. Tree-ring width and density data around the Northern Hemisphere: part 1, local and regional climate signals. Holocene 12 (6), 737–757.

Buckley, B.M., Hansen, K.G., Griffin, K.L., Schmiege, S., Oelkers, R., D'Arrigo, R.D., Stahle, D.K., Davi, N., Nguyen, T.Q.T., Le, C.N., Wilson, R.J., 2018. Blue intensity from a tropical conifer's annual rings for climate reconstruction: an ecophysiological perspective. Dendrochronologia 50, 10–22.

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., Hu, H., Kao, P.K., Buckley, B.M., Dong, Z., Chen, X., Zhou, F., Fang, K., 2022. Improved spring temperature reconstruction using earlywood blue intensity in southeastern China. Int. J. Climatol. 42 (12), 6204–6220.

Cook, E.R., Peters, K., 1981. The smoothing spline: a new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. Tree-Ring Bull. 41, 45–53.

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., 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.

Gindl, W., Grabner, M., Wimmer, R., 2000. The influence of temperature on latewood lignin content in treeline Norway spruce compared with maximum density and ring width. Trees 14, 409–414.

Heeter, K.J., Harley, G.L., Abatzoglou, J.T., Anchukaitis, K.J., Cook, E.R., Coulthard, B.L., Dye, L.A., Homfeld, I.K., 2023. Unprecedented 21st century heat across the Pacific Northwest of North America. Npj Clim. Atmos. Sci. 6 (1), 5.

Heeter, K.J., Harley, G.L., Maxwell, J.T., Wilson, R.J., Abatzoglou, J.T., Rayback, S.A., Rochner, M.L., Kitchens, K.A., 2021. Summer temperature variability since 1730 CE across the low-to-mid latitudes of western North America from a tree ring blue intensity network. Quat. Sci. Rev. 267, 107064.

Heeter, K.J., King, D.J., Harley, G.L., Kaczka, R.J., 2022. Video tutorial: measuring blue intensity with the CooRecorder software application. Dendrochronologia 76, 125999.

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.

Kaczka, R.J., Wilson, R., 2021. I-BIND: international blue intensity network development working group. Dendrochronologia 68, 125859.

Li, T., Li, J., 2023. August temperature reconstruction based on tree-ring latewood blue intensity in the Southeastern Tibetan Plateau. Forests 14 (7), 1441.

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. Alp. Res. 34, 450–453.

Melvin, T.M., Briffa, K.R., Nicolussi, K., Grabner, M., 2007. Time-varying-response smoothing. Dendrochronologia 25 (1), 65–69.

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.

Rydval, M., Björklund, J., von Arx, G., Begović, K., Lexa, M., Nogueira, J., Jiang, Y., 2024. Ultra-high-resolution reflected-light imaging for dendrochronology. Dendrochronologia 83, 126160.

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

Seftigen, K., Fonti, M.V., Luckman, B., Rydval, M., Stridbeck, P., Von Arx, G., Wilson, R., Björklund, J., 2022. Prospects for dendroanatomy in paleoclimatology–a case study on Picea engelmannii from the Canadian Rockies. Climate 18 (5), 1151–1168.

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.

Spyt, R., Kaczka, R.J., Ksciuczyk, K., Zawadzka, M., 2016. Zastosowanie intensywności odbicia światła niebieskiego w datowaniu drewna historycznego. Stud. i Mater. IY. Cent. Edukac.Przyr. -Le. śnej 18 (3 [48]).

Wilson, R., Allen, K., Baker, P., Boswijk, G., Buckley, B., Cook, E., D'Arrigo, R., Druckenbrod, D., Fowler, A., Grandjean, M., Krusic, P., 2021. Evaluating the dendroclimatological potential of blue intensity on multiple conifer species from Tasmania and New Zealand. Biogeosciences 18 (24), 6393–6421.

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, 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. Can. Holocene 24 (11), 1428–1438.

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

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.