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A comment on the Expressed Population Signal

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Abstract:

This commentary highlights a regularly occurring misinterpretation of the widely used expressed population signal (EPS). Based on thorough examination of the scientific article introducing EPS, I show that I) EPS was not meant to be a measure for the suitability of tree-ring data for climate reconstruction, and II) that the frequently used – but arbitrarily chosen – threshold of 0.85 was not meant to be used in combination with EPS. Instead, the less frequently used subsample signal strength (SSS) was intended for a respective application, i.e. as a measure of decreasing predictive power of transfer functions due to reductions in the sample size of underlying tree-ring series back in time. I conclude that classical transfer function quality statistics should be preferred over the erroneous application of EPS in the context of evaluating the suitability of dendrochronological data for climate reconstructions.

Keywords: rbar; subsample signal strength; climate reconstruction; transfer function stability

Context

The Expressed Population Signal (EPS; Wigley et al., 1984) is considered a key statistic in dendrochronology. Since its introduction, the related article has been cited 1830 times (google scholar, 27th of March 2017), mostly referring to EPS. About one third of these citations originated from articles published in the last three years (1246 citations according to google scholar on 5th of November 2014). Moreover, the term ‘expressed population signal’ has at least been used in 125 articles published in *Dendrochronologia* since 2002 (Science Direct, 27th of March 2017) showing a clearly increasing trend (Fig. 1).

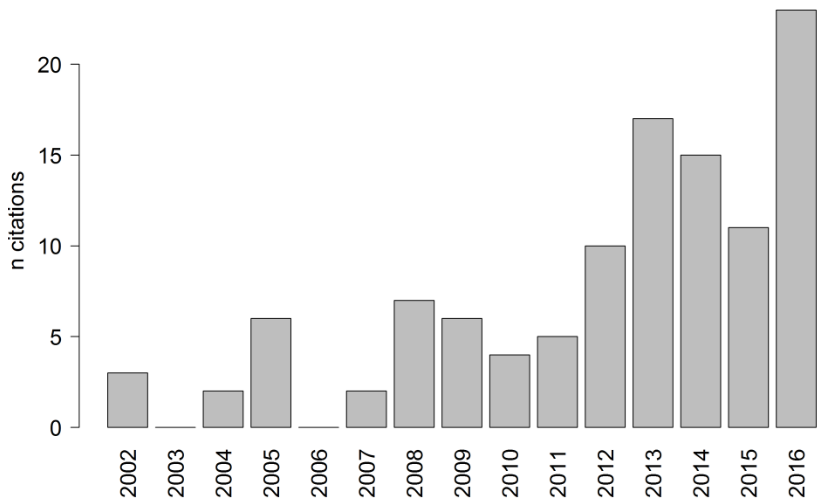

Fig. 1: Number of hits by year for the query ‘expressed population signal’ and ‘Dendrochronologia’ at Science Direct (27th of March 2017) since 2002.

Given its strong and increasing impact on dendrochronology, it seems justified to thoroughly examine the application of EPS in a dendroclimatological context. This justification is supported by studies which revealed other frequently used statistical measures in dendrochronology to be of questionable value (mean sensitivity; Bunn et al., 2013), based on slightly erroneous calculations (Gleichläufigkeit; Buras and Wilmking, 2015), or prone to a systematic underestimation of instable climate-growth relationships (reduction of error and coefficient of efficiency whose sensitivity to detect instability was shown to be lower compared to the bootstrapped transfer function stability test; Buras et al., 2017).

Theoretical background

In theory, EPS is the amount of variance of a population chronology (infinitely replicated) explained by a finite subsample. In other words, EPS is the approximated explanatory power (r) when predicting the so-called population signal based on a finite sample, thus reflecting how well a master chronology represents a theoretically infinite population.

EPS was introduced together with another, less frequently used metric, i.e. the subsample signal strength (SSS). Both statistics are closely related to each other and rely on the mean inter-series correlation (rbar) as shown in Wigley et al. (1984):

$$SSS = \left(R_{n,N}\right)^2 \approx \frac{n(1+(N-1)\cdot\bar{r})}{N(1+(n-1)\cdot\bar{r})}$$

and for N → ∞ and replacing n by N:

$$EPS = (R_N)^2 \approx \frac{N\bar{r}}{1+(N-1)\cdot\bar{r}}$$

with n being the subsample size, N being the total sample size, and $\bar{r}$ being the mean inter-series correlation.

Just to highlight the similarities and differences between EPS and SSS: both statistics express how well a subsample (n for SSS, N for EPS) represents a larger sample. The only difference is that for EPS, the larger sample is infinite in contrast to a finite N for SSS. Nevertheless, the interpretation of both is quite distinct. Wigley et al. (1984) introduced SSS to estimate the loss of the *known* explained variance of a climate reconstruction back in time due to a decreasing sample size, since trees used for reconstruction are often not of equal age. In contrast, EPS was introduced as an indicator of the strength of the *unknown* population signal which is common to a set of tree-ring data (Wigley et al., 1984). It is noteworthy, that EPS is closely related to the percent common signal (Cropper, 1982) as also mentioned in Wigley et al. (1984), but surprisingly the introducing article (Cropper, 1982) to date has only been cited six times (google scholar, 5th of November 2014 *and* 27th of February 2017).

In terms of dendroclimatological reconstructions EPS has frequently been computed over moving windows to obtain a so-called running EPS time-series which reflects the variability of EPS back in time. This procedure is of particular value for long-term reconstructions which to a large extent are based on tree-ring series derived from archeological and/or sub-fossil wood. Since these series do not overlap with the data used for the calibration of respective transfer functions and therefore cannot be used to compute the corresponding rbar for that period, an application of SSS as intended by Wigley et al. (1984) is not possible. As a consequence, running EPS is frequently used as surrogate for SSS to express the common variance of tree-ring series back in time as a quality criterion for the associated reconstruction.

Clarifying a regularly occuring misinterpretation

EPS (and running EPS) is often used in combination with a particular threshold of 0.85, above which a master chronology is assumed to represent the population signal with sufficient quality. In dendroclimatological investigations, this threshold has become a benchmark distinguishing samples and periods which are given sufficient confidence for reconstruction purposes (EPS > 0.85) from those which do not fulfill this criterion.

However, Wigley et al. (1984) stated that *“the strength of the common signal cannot be interpreted solely in climatic terms, since common variance may also arise from other factors. Furthermore there is no obvious way to determine how high SNR or* $(R_N)^2$ [EPS] *should be to ensure that a particular chronology is suitable for climate reconstruction purposes”*. This statement is underlined by Briffa and Jones (1990): *“No specific value of EPS can be thought of as adequate or minimum to ensure that a chronology is suitable for climate reconstruction”*. Furthermore, in 2013 Mérian et al. (2013) concluded: *“At last, increasing sample size affected differently the improvements of EPS and climate–growth relationships. As a consequence, EPS should not be considered as a linear estimator of the quality of the climate–growth relationships assessment“*. In summary, the regular application of EPS to represent the suitability of tree-ring data for climate reconstruction purposes appears to be invalid.

I will give three arbitrarily selected examples of erroneous EPS-applications from the literature and I am confident that most readers of this article are aware of other examples. To show that it is not my intention to focus on misinterpretations of other dendrochronologists I will start with Buras et al. (2012) who stated: *„We did that to highlight the periods of the respective chronology which express an EPS above 0.85, a value that is considered as a threshold of acceptable statistical quality for dendroclimatological analyses"*. In 2005, Lebourgeois et al. mentioned: *"All total ring and earlywood EPS-values exceed the suggested threshold of 0.85 suggesting a strong climate signal in site chronologies".* A more up-to-date example is given in Lyu et al. (2016) who stated in the context of a climatic reconstruction: *"A generally acceptable threshold of the EPS was consistently greater than 0.85 from AD 1660 to 2015 […] which affirmed that this is a reliable period".*

In the peer-review process of Buras et al. (2012, which was my first dendrochronological article) I was requested by an anonymous reviewer to highlight the period with running EPS-values being above 0.85 as this would indicate the reliable reconstruction period. I have to admit, that given the short deadline (one month) and the intensity of revisions of such early career articles, I did not in depth read the very theoretical article by Wigley et al. (1984) but rather inferred the use of EPS from other publications. For the present study I thoroughly studied Wigley et al. (1984) and must conclude that I simply copied a misinterpretation from other publications. Given the persistence of this misinterpretation I believe that I am not the only one who made this mistake.

The question remains, how this misinterpretation has entered the dendrochronological literature? Probably it is based on the very similar nomenclature used for SSS and EPS and the following statement given in Wigley et al. (1984): *"As a rough guide, let us assume that chronology uncertainty of order 15% due to a reduction in the number of cores is acceptable* *(corresponding to a threshold $(R_{n,N})^2 \approx 0.85$). For explained climate variance of 50% based on an N-core chronology, reduction in the number of cores to the point where $(R_{n,N})^2 \approx 0.85$ would only reduce the explained climate variance to around 43 % (0.85 x 50 %), a noticeable reduction, but in most cases, probably not a statistically significant one".* It is important to note, that $(R_{n,N})^2$ refers to SSS and not to EPS. Concluding, although Wigley et al. (1984) never introduced a threshold for EPS but gave an arbitrary example of how to apply SSS in the context of dendroclimatological reconstructions, a high proportion of articles which make use of EPS do it in combination with this threshold.

It is a difficult task to estimate the impact of the reported misinterpretation on dendrochronology, since it is not possible to observe how much data have not been considered for dendroclimatological analyses and/or reconstructions because of low EPS values. From personal experience and conversations with other dendrochronologists, I infer that low EPS values are often observed for wood-anatomy and shrub-ring data. This is to some extent explained by a possibly low rbar of these data but also caused by their mostly low sample size which is to be explained by the relatively high effort needed to obtain such data. Nonetheless, several studies have reported meaningful and robust correlations with environmental parameters for both wood anatomy and shrub-ring data. For traditional tree-ring width data – which often are characterized by relatively high rbar and sample size – the effect of the reported EPS misinterpretation is likely low, since values above 0.85 are often reached. But for wood anatomy and shrub-ring data which frequently do not reach EPS values above 0.85 the effect may be significant, wherefore the potential of these data for dendroclimatological purposes yet might be underestimated.

Conclusions

Based on this brief literature survey, it seems that a widely used statistic in dendrochronology – the expressed population signal (EPS) – is regularly misinterpreted. EPS is a measure of how well a finite sample of tree-ring data represents an infinite population chronology, but it will not necessarily indicate whether a tree-ring chronology is suitable for climate reconstruction purposes. In a similar manner, running EPS indicates the variability of the population signal strength back in time, which does not necessarily reflect the strength of the reconstructed climatic signal. In spite of this, running EPS may help to identify reconstruction periods with low predictive power. That is, since low EPS values indicate low sample size and/or low rbar, respective periods will likely – but not necessarily – have a lower predictive power.

As a consequence, the evaluation of the reconstruction ability of tree-ring chronologies has to be based on other metrics such as bootstrapped climate-growth correlation coefficients (as e.g. in the 'treeclim'-package, Zang and Biondi, 2015), the significance and explanatory power of transfer functions (e.g. Fritts, 1976), and the results of cross-calibration verification tests (e.g. Buras et al., 2017). Once transfer functions have successfully passed validation tests, subsample signal strength (SSS) is the appropriate measure to estimate the loss of explanatory power due to a decreasing sample size back in time (Wigley et al., 1984; Briffa and Jones, 1990). For the case of reconstructions based on archeological and/or subfossil material, running EPS should be used carefully to identify periods with low reliability.

Concluding, (running) EPS is a valuable means for assessing the representation of a population signal, but it will not reveal whether this signal is closely related to the reconstructed parameter or any other source of common growth variation. Given the high frequency of EPS citations in a dendroclimatological context and the steadily increasing trend of respective EPS-application it is time to clarify this potential misunderstanding.

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Figure captions

Fig. 1: Number of hits by year for the query ‘expressed population signal’ and ‘Dendrochronologia’ at Science Direct (27th of March 2017) since 2002.