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ScienceDirect

Dendrochronologia 27 (2009) 229–231

DENDROCHRONOLOGIA

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Response to comment on "Late 20th century growth acceleration in greek firs *(Abies cephalonica)* from Cephalonia Island, Greece: A CO_2 fertilization effect?" by David Frank, Ulf Büntgen, Jan Esper

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Frank et al. object to the hypothesis advanced by Koutavas (2008) that unusual recent growth trends in radial increments of eight firs from Cephalonia Island, Greece could have resulted from a CO_2 fertilization effect. Their comment raises issues of (i) sample density and replication, (ii) insufficient analysis of the role of climate and other factors, and (iii) artifacts due to the use of ratios in standardization.

Frank et al. reinforce Koutavas' (2008) point that additional data are desirable to test the CO_2 fertilization hypothesis in these sites, and that results from eight initial trees should be considered preliminary. The International Tree-Ring Data Bank considers chronologies of as few as ten series to contain meaningful dendrochronologic information. Drawing upon eight series of relatively long-lived trees (100–200 years) and with significant mean intercorrelation (0.522) is not optimal, but also not without validity, especially when the results are presented as a "short article on preliminary research" which *Dendrochronologia* defines as "concise but complete descriptions of limited investigations or preliminary research reports".

Frank et al. assert that Koutavas' (2008) study suffers from "non-systematic consideration of environmental factors" including climate. This statement is inconsistent with rigorous climatic analysis undertaken in that study, which ruled out significant covariation between temperature or precipitation and the exponentially detrended index chronology. Contrary to the claim of Frank et al., the lack of "robust identification" of climatic influences on long-term growth trends does not weaken, but rather bolsters the argument that non-climatic factors (possibly CO_2) are at play. Frank et al. erroneously assert that precipitation increased in the study area during the second half of the 20th century, and go on to imply that this may have played some role in the recent growth trends. This remark is contrary to evidence for significant aridification in the Mediterranean region in the late 20th century (e.g. Xoplaki et al., 2004; see also Fig. 3a in Koutavas (2008) for precipitation trends in the study area). In particular, declining precipitation in spring and summer when moisture is critical for growth is centrally important for the role of CO_2 because a key mechanism for CO_2-mediated growth enhancement is by promoting intraleaf water conservation and improving water-use efficiency (Woodward, 2007; and references therein). Frank et al. suggest that declining growth trends in these samples during the early 20th century are hard to reconcile with rising CO_2 during this period. More precisely, CO_2 increased by 16 ppm between 1900 and 1950 AD, while it increased by 68 ppm between 1950 and 2005 AD. As pointed out by Koutavas (2008), the growth response to CO_2 need not be linear and may well be subject to crossing of a threshold. Decreasing growth prior to ~1950 AD is in fact consistent with climatic forcing as late spring–early summer precipitation was declining during this time. The real anomaly is the growth reversal in the late 20th century, which occurred in the face of persistent aridification and accelerated rise of atmospheric CO_2.

DOI of original article: 10.1016/j.dendro.2009.05.001

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doi:10.1016/j.dendro.2009.05.002

Frank et al. suggest that ring-width variability in higher frequencies than those considered by Koutavas (2008) might reveal additional hints of climatic controls on growth that could be relevant. This analysis has been performed on an expanded dataset from these sites assembled since publication (A. Koutavas, manuscript in preparation). According to the results (presented at AmeriDendro 2008 and available at http://akoutavasresearch.googlepages.com/mediterraneantreerings) following 30 yr spline detrending the index chronology from the greek firs was found to correlate positively with June precipitation and negatively with June temperature, indicating that growth is favored by cool and wet June conditions, as is often the case in semiarid water-limited environments. Given that late 20th century trends in this region are towards warmer and drier June (and more generally spring and summer), one would predict from this association a decline, not an increase in growth as observed. This further strengthens the argument that CO_2 may be exerting a positive influence on growth, quite plausibly by enhancing water-use efficiency and counteracting the background drying trend. Although Frank et al. have chosen not to consider in their comment any of this additional evidence and analysis (which was made available to them), these results neutralize much of their criticisms of ‘‘few data’’ and ‘‘non-systematic considerations’’ and offer insights of special relevance for the role of CO_2 as an agent of growth. The authors unfortunately offer no climatic analysis of their own to support alternative interpretations, nor any compelling arguments for other important environmental influences, except in the most general terms. Confounding growth influences are rarely possible to rule out entirely in dendrochronologic studies, however in this case related claims are entirely speculative as there is no evidence to support influences from logging, grazing, wildfires, insect outbreaks, or tectonic activity in association with the major trends in the data.

Frank et al. propose that end-effects from the use of ratios in detrending has artificially inflated the growth increase described by Koutavas (2008) and that one way to circumvent this problem might be to use the method of power-transformed residuals described by Cook and Peters (1997). I agree that this method offers a useful test for identifying and minimizing such detrending problems. Unfortunately Frank et al. provide an incomplete and confusing application of this method, neglecting to note that direct juxtaposition and comparison between growth indices derived as ratios, and those derived as residuals, are meaningless unless steps are taken to appropriately scale the two index series. As pointed out by Cook and Peters (1997), the need for scaling arises from the recognition that while ratios are scale-free (dimensionless), residuals are not. The situation is more complex when residuals are calculated after the original measurements are power-transformed to make them homoskedastic (Cook and Peters, 1997), an operation which yields measurements in units of length (mm) raised to a fractional exponent. As the value of this exponent varies from series to series, final averaging into an index chronology further complicates its interpretation in relation to growth.

Whether power-transformed or not, however, it is easily appreciated that residuals convey a different measure of growth that ratios do. For instance, a residual of 2 mm represents a 20% change when the baseline growth increment is 10 mm, but 200% when the baseline is 1 mm. A ratio of 2 on the other hand indicates 100% departure (doubling) from expected growth. Thus comparing and differencing residuals and ratios without proper scaling can lead to confusing outcomes. Cook and Peters (1997) suggested that one way to accomplish this scaling was to equalize the mean and variance of the index chronology based on residuals with that based on ratios, an approach which they then applied to data from Campito Mountain. Frank et al. describe no steps to scale residuals and ratios in their Fig. 2, nor do they offer any indication that they considered this essential step. Similarly, results shown in their Fig. 3 based on data from the Pyrenees (whose relevance to the Ionian Sea is unclear) defy proper evaluation in the absence of full methodological details. Such details are not described in Frank et al.’s comment, nor in their cited article by Büntgen et al. (under review), which curiously does not cite the work of Cook and Peters (1997). Did the authors consider the need for scaling residual to ratios prior to differencing them? If so, how was this accomplished? And how do the authors derive ‘‘dimensionless indices’’ after differencing dimensional power-transformed residuals from ratios? These and related questions require more extensive consideration and discussion, lest they convey the wrong notion that power transformation is a technique that can be used ‘‘straight out of the box’’ for immediate comparison with more traditional standardization methods. Such a simplified view risks doing more harm than good as concerns artifacts and misinterpretations of standardized tree-ring data.

Importantly, Frank et al. stop short of carrying their own argument to its logical conclusion. Would results differ if power-transformed residuals were used instead of ratios in the Koutavas (2008) study? Would the noted late 20th century growth acceleration be eliminated? To complete this argument I provide in Fig. 1, a comparison of the index chronology based on ratios (from Koutavas, 2008) with that calculated using the adoptive power transform option in ARSTAN. As can be seen in this figure, after scaling the residual chronology to the same mean and variance as the ratios (Cook and Peters, 1997), remaining differences are minor. Both ratios and scaled residuals indicate accelerating growth after 1950

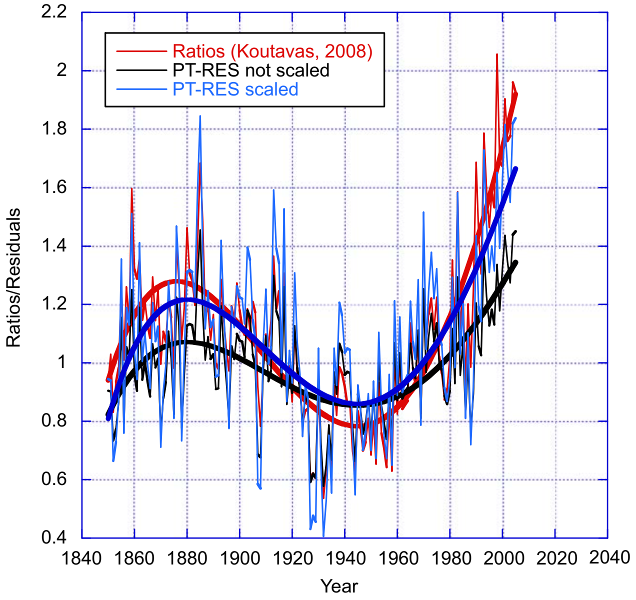

Fig. 1. Comparison of greek fir chronologies from Mount Ainos, Greece based on the dataset of Koutavas (2008). The red curve displays indices calculated as ratios using negative exponential detrending from Koutavas (2008). In black are shown residuals (PT-RES) calculated with the adaptive power transform option in program ARSTAN, using negative or general exponential detrending. In blue the PT-RES series has been scaled to the same mean and variance as the ratios after Cook and Peters (1997). The low-frequency trends in each series are modeled with fourth order polynomials (solid curves). The polynomial fits account for 38% of the total variance in the PT-RES compared to 72% in the ratios, indicating that the residuals have significantly more variance in high frequencies than the ratios. This shift in the PT-RES variance towards higher frequencies is consistent with more aggressive variance stabilization achieved by the adaptive power transformation. Divergences in the low-frequency trends between ratios and PT-RES, which are relatively minor, must account for this effect prior to interpreting them as evidence of index inflation.

AD, and in both versions growth after 1990 AD is unprecedented in the duration of the dataset as noted by Koutavas (2008). Some loss of amplitude in the low-frequency response is discernible in the residuals, and this may arise partly from end-value inflation by ratios as Frank et al. note. However, other sources may be contributing to this effect, including the more aggressive tendency (by design) of the power transformation to add high-frequency variance (to the detriment of low frequencies) in order to achieve homoskedastic variance stabilization (Cook and Peters, 1997). Fig. 1 also helps illustrate that the calculation of differences between ratios and residuals is strongly sensitive to the presence or absence of scaling, and that absence of scaling can lead to spurious results. Finally, Frank et al. have misunderstood inferences made by Koutavas (2008) regarding the role of age in the timing of growth increases in individual samples. Those inferences were drawn by examination of the raw ring widths so that the standardization approach is inconsequential.

In summary, Frank et al.'s comment is a useful reminder of some key strengths and weaknesses of dendrochronology as a discipline. Among its strengths is its great potential for replication, and among its weaknesses the sometimes subjective and controversial application of standardization techniques. The method of calculating indices as power-transformed residuals (Cook and Peters, 1997) is a valuable addition to the standardization toolbox, but its application must be done judiciously, with full appreciation of its intricacies, and with detailed description of the methodology. The data and the interpretations of Koutavas (2008) pass this alternative standardization test with ease, and are now further supported by additional sampling. In this light the presence of anomalous growth increases in the late 20th century is hard to refute. Combined with the recognition that recent climatic trends in these sites have been distinctly unfavorable for growth, the case for CO_2 fertilization, while not proven, remains a viable and credible hypothesis. Frank et al.'s admonishments that conclusions regarding such effects are not to be drawn from "eight trees from three sites in the Mediterranean", miss the point. While these preliminary results are not to be mistaken for proof that CO_2 fertilization effects are currently operating on a global scale, they comprise an incremental step towards better documentation, characterization and understanding of such effects and their future role in issues of global change. Such incremental steps are fundamental to the process of scientific inquiry.

References

Cook, E.R., Peters, K., 1997. Calculating unbiased tree-ring indices for the study of climatic and environmental change. The Holocene 7, 361–370.

Koutavas, A., 2008. Late 20th century growth acceleration in greek firs (*Abies cephalonica*) from Cephalonia Island, Greece: a CO_2 fertilization effect?. Dendrochronologia 26, 13–19.

Woodward, F.I., 2007. An inconvenient truth. New Phytologist 174, 469–470.

Xoplaki, E., González-Rouco, J.F., Luterbacher, J., Wanner, H., 2004. Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. Climate Dynamics 23, 63–78.