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# Comment on "Late 20th century growth acceleration in Greek firs (*Abies cephalonica*) from Cephalonica Island, Greece: A $CO_2$ fertilization effect?"

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## Introduction

In the recent article "Late 20th century growth acceleration in Greek firs (*Abies cephalonica*) from Cephalonia Island, Greece: A $CO_2$ fertilization effect?" (Dendrochronologia 26(2008) 13–19) by Koutavas, a dataset of radial stem growth increment was presented. Eight individual trees, after detrending to remove the biological age trend, show a growth increase that is hypothesized to be related to $CO_2$ fertilization. Such a conclusion, if correct, would be of great relevance towards understanding the impact of anthropogenic emissions on forest productivity, with consequences on the global carbon cycle, ecosystem functioning, land–atmosphere interactions, and climate model experiments. However, as suggested by the author, these results reflect a preliminary assessment of $CO_2$ fertilization effects on tree growth. Here in, we expand upon known challenges in growth attribution, and bring attention to subtle though important methodological considerations, in using such tree-ring data to make conclusions about $CO_2$ impacts on radial tree growth. These issues are: (i) few data, (ii) non-systematic consideration of environmental forcing factors and, (iii) end-effects in detrending. We suggest that these three factors reduce support for the conclusion that the Greek fir data from Cephalonia Island contain $CO_2$ fertilization signals.

## (i) Few data

Replicate tree-ring data at the tree, site, and regional to hemispheric levels, is perhaps a unique characteristics among the various proxy archives, which have allowed advances in signal strength estimation and chronology error. Typical dendrochronological analyses rely upon 20 series to produce robust mean-value functions and approach the population signal. However, the more, the better. Statistics including the expressed population signal (EPS; Wigley et al., 1984), while based mainly upon high-frequency agreement, may be useful to assess chronology fidelity. The Koutavas (2008) analysis is based upon a total of eight measurement series from different trees. The EPS statistic computed on this dataset after detrending with general exponential in ARSTAN (Cook 1985) curves is 0.72 (averaged over nine intervals from 1870 to 1990; Fig. 1), indicating that 72% of the theoretical population chronology's variance is explained, but not reaching the commonly applied guideline of 0.85. Corresponding mean inter-series correlation (Rbar) of the eight samples is 0.26. As degrees of freedom are inherently reduced in analyses in lower frequency domains, and more generally the common signal in tree-ring data decreases at longer time-scales (e.g., Frank and Esper, 2005), such statistics likely even present an optimistic picture of the amount of data sufficient to analyze longer-term signals, such as $CO_2$ fertilization effects. Well replicated datasets

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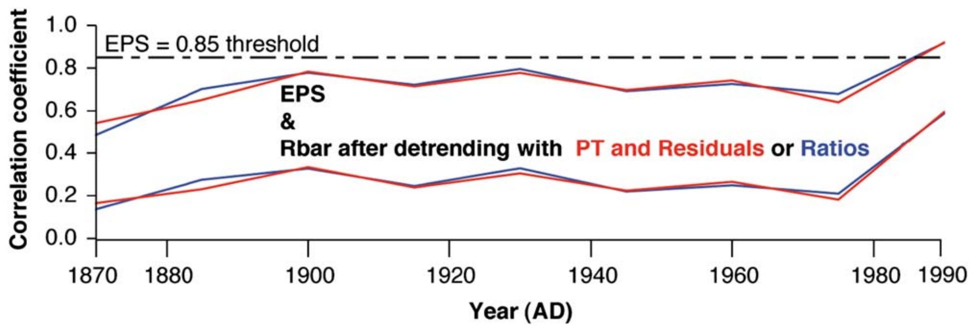


**Fig. 1.** Signal strength assessment of the eight ring width measurement series (after exponential detrending) expressed as EPS and Rbar values computed over 30-year windows lagged by 15 years. The horizontal line denotes a commonly applied EPS guideline of 0.85. EPS and Rbar are shown for both ''ratio'' and ''power-transformation and residuals'' detrended chronologies (see text).

collected at broader spatial scales would be required to minimize the chance for sample size, local disturbance, and climatic factors to bias conclusions regarding effects of global anthropogenic $CO_2$ increases (see point (ii) below). A total of eight trees from three nearby sites is not sufficient to address this or related research questions.

## (ii) Non-systematic consideration of environmental factors

Crossdating, one of the most fundamental principles of dendrochronology, is only possible due to the common environmental forcing of tree growth. While dendroclimatic reconstructions are mainly restricted to natural distribution boundaries where tree growth is primarily controlled by a single dominant environmental (i.e., climatic) factor, in broader areas of the globe growth is controlled by a more complex mixture of environmental regulations (Nemani et al., 2003; Cook and Pederson, 2009).

The analysis performed by Koutavas (2008) did not reveal the robust identification of, for example, temperature, precipitation or drought influences on high- to low-frequency radial growth, thereby limiting the climatological explanation of both the common high-frequency signal and the multi-decadal trends in the mean series. However, it was noted by Koutavas (2008) that during the second half of the 20th century, in contrast to global trends, temperature has decreased (albeit precipitation has increased) in this area, leaving it unclear how the changing climate and environment has influenced tree growth. Importantly, the downward growth trend from about 1850 to 1950 in the tree-ring data is inverse to the hypothesized influence of increasing $CO_2$ concentrations during this time. We suggest that more analyses would be required to explain trends in these data and more thorough consideration of environmental variation from multiple climatic elements (e.g., Anchukaitis et al., 2006). We agree with Koutavas (2008) that confirmation of possible $CO_2$ effects from additional and more-highly replicated sites would be necessary to detect large-scale environmental signals including the anthropogenic $CO_2$ increase. Such sites will minimize the likelihood for spurious conclusions driven by local noise from sources such as site-specific ecology, geological activity, stand-dynamics, logging, pasturing, insect as well as fire outbreaks, and other possible disturbance factors.

## (iii) End effects in detrending

Necessary removal of the biological age trend remains one of the most challenging aspects of dendrochronological investigations. There is little evidence to suggest an optimal or universally applicable method to remove age-related growth trends inherent in raw tree-ring width (and density) measurement series (Fritts, 1976; Cook and Kairiukstis, 1990; Frank et al., 2007), and accordingly this remains an active area of research (Briffa et al., 2001; Esper et al., 2003, 2009; Helama et al., 2005; Melvin and Briffa, 2008). Of key relevance to investigating global change-related phenomena is the possible occurrence of ''end-effect'' problems in the age-trend fitting and detrending processes. Particularly relevant to the present study, is potential index value inflation that may have emerged when dividing annual growth increments by a detrending curve whose values do not locally fit actual growth and approach zero. A proposed solution to this problem is the ''adaptive power-transformation'' (Cook and Peters, 1997) that removes heteroscadastic properties by raising tree-ring series to a fractional power, and then permits differencing the measured (transformed) growth and estimated age trend. This procedure (power-transformation and residuals; PTres) does not enjoy the benefits of division (i.e., ''ratios'') whereby the heteroscedastic behavior is automatically mitigated during detrending (hence the need for the power-transformation), but also does not suffer from the possible explosion of index values

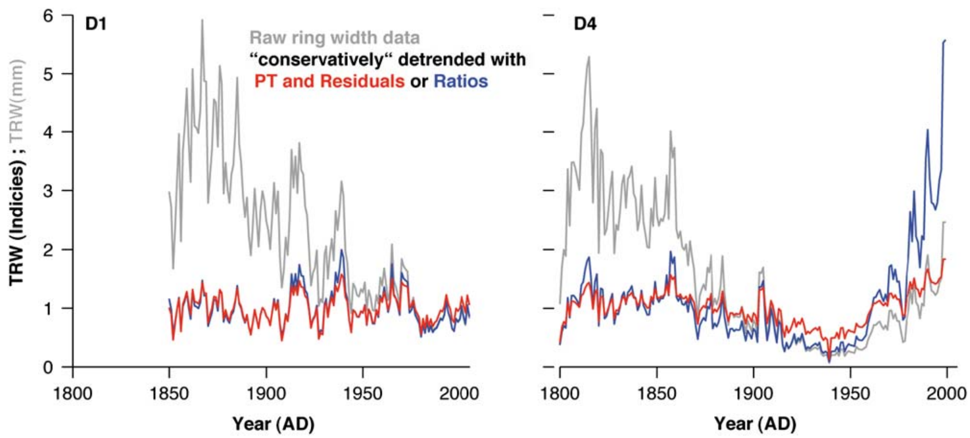


**Fig. 2.** Two examples of raw data series (grey) shown after detrending with ratios (blue) and PTres (red). Tree D1 indicates no inflation of index values towards the recent end of the series, whereas tree D4 shows significant inflation of recent index values when detrending with ratios is performed.

towards the recent end of a time-series. As a simple test of this, and similar to the methods in the original analysis, we performed detrending by exponential curves using both ''ratios'' and PTres. Results are shown for two series. For series D1 (Fig. 2, left), little difference is observed between the ratios and PTres detrending suggesting minimal end-effect biases. For series D4 (Fig. 2, right), index values computed by the ratios method approach six at the end of this series, well exceeding values derived from the PTres computation. Interestingly, the commonly applied detrending in ARSTAN with a negative exponential curve defaults to a linear fit and produces index values near 14 (not shown). These examples suggest that the series in the mean chronology of Koutavas (2008) are likely, to varying degrees, impacted by index value inflation as suggested by Cook and Peters (1997). Furthermore, age-related effects speculated by Koutavas (2008) are consistent with the growth curve approaching zero at an earlier time (due to the age-related trend) which thus results in a calendrically earlier inflation of tree-ring indices in the older trees. While the power-transformation is not a panacea (Cook and Peters, 1997; Frank et al., 2006; Büntgen et al., 2005) and other end-effect problems may remain in the detrending process (e.g., Melvin and Briffa, 2008), this example suggests that some of the growth increase hypothesized to be a $CO_2$ fertilization effect, may be a detrending artifact.

To support this indication, we performed a similar analysis on a more extensive, though comparable, Mediterranean conifer dataset of 989 ring width increment series from 28 higher elevation sites from across the Pyrenees (Fig. 3; Büntgen et al., in review). The difference series between the normalized ratio and PTres chronologies after individual spline detrending (Fig. 3A) and regional curve standardization (RCS; Fig. 3B) further confirm the significance of the end-effect bias, as originally suggested by Cook and Peters (1997). Interestingly, the pattern of index inflation obtained by the 300-year spline analysis suggests a short but rapid effect within the last decades of the chronologies. In contrast, with the RCS detrending, a longer increasing trend in the difference series over more than a century is evident. Reasons for this require further exploration. Also, it should be noted that the greater scatter of the individual RCS differences series (Fig. 3B; thin grey lines) is indicative of the greater quantities of data required to robustly perform RCS detrending, which are often not evident when using correlation-based measures of signal strength (see point (i) above).

## Conclusions

While anthropogenic $CO_2$ emissions over the past 160 or so years, may potentially have influenced the radial growth of trees, this conclusion should not be based on eight trees from three sites in the Mediterranean. This seems to particularly be the case as tests of the detrending method suggest that values towards the recent end of the chronology as shown in Koutavas (2008) were likely inflated by end-effect problems as outlined in Cook and Peters (1997).

A recent review by Huang et al. (2007) indicates that for the nine tree-ring studies considered that reached conclusions of fertilization effects, eight of these studies utilized detrended data. Further investigation is necessary to determine if common detrending biases have influenced the conclusions of diverse regional studies. Consideration of widely distributed, well replicated tree-ring datasets, for which the age-related trends, climatic variations, and other parallel anthropogenic signals,

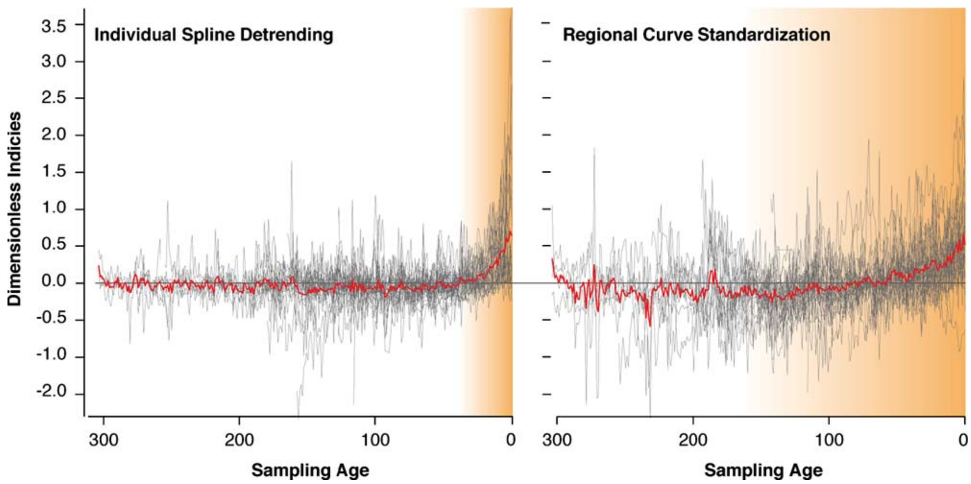


**Fig. 3.** End-effect problems in a high-elevation conifer network from the Pyrenees expressed as difference series (ratio minus PTres chronologies) of 28 TRW site chronologies (grey) and their arithmetic mean (red) using either ratios or PTres for index calculation. Time-series are aligned by the outermost calendar date after (A) individual 300 years spline detrending and (B) composite RCS detrending.

have been considered, is necessary before any magnitude and extent of $CO_2$ fertilization effects in natural forests can be quantified.

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