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CORRESPONDENCE

Reply to communications by Fu et al. international journal of biometeorology

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Abstract Temperature sensitivity of plant phenology (S_T) is a determining factor of as to what degree climate change impacts on plant species. Fu et al . (Int J Biometeorol 60:1611–1613, 2016) claimed that long long-term linear trends mask phenological shifts. However, the decreased and increased S_T was both found in warming scenarios. The conceptual scheme telling the nonlinear relationship between spring temperature and leaf unfolding date proposed by Fu et al . (Int J Biometeorol 60:1611–1613, 2016) cannot be supported by observation data across Europe. Therefore, linking declined S_T to climate warming is misleading, and future S_T changes are more uncertain than they suggested.

Keywords Phenology · Temperature sensitivity · Spring leaf unfolding

Temperature sensitivity of plant phenology is a determining factor of to what degree climate change impact on plant species. We appreciate that Fu and co-authors studied our work (Wang et al. 2016) very thoroughly. In their *Correspondence* (Fu et al. 2016), the authors discuss changes of the temperature sensitivity of leaf unfolding date (S_T) in Europe over nearly past 60 years in Wang et al. (2016) and claim that long term linear trends mask phenological shifts. They also claim, as in their past work (Fu et al. 2015), that the advancement of spring leaf unfolding will likely slow down under future climate warming since temperature sensitivity is reduced.

Fu and colleagues argue that "the long-term linear trends may mask short-term phenological shifts" (Fu et al .2016). We understand that increasing the length of a study period may mask shorter-term changes in phenological temperature sensitivity. However, we disagree that confining the study period to 1980–2013 with any defined subperiod supports the conclusions drawn by Fu et al. (2015). Fu et al. (2016) states that "according to the IPCC AR5, the period since the 1980s was very likely the warmest 30-year period of the last 800 years in the Northern Hemisphere (IPCC 2013); we therefore investigated the phenological changes during this warmest period (Fu et al. 2015)". Assessing the same database, we suggest that data availability might also have been a strong argument to define the study period in Fu et al. (2015). Furthermore, we reproduced the results from Fu et al. (2015) with a reduced number of time series in order to extend the data availability further into the past. This approach of "subsampling" leads to similar results. Referring to centennial-scale analyses of temperature sensitivity back to 1753 rather weakens the arguments by Fu et al. (2015) as the current S_T are still within the range of the past centuries. Citing IPCC (2013) at the Northern Hemisphere scale is strongly misleading as phenology responds to very local temperature changes and not to semi-global averages.

There are remaining arguments of the paragraph in Fu et al. (2016). We have not reproduced the analyses on the number of chilling days (yet). Neither do we agree with the rationale of Fu et al. (2015) that the 30-year-long time period is the only choice for studying changes of S_T in the study period defined by Fu et al. (2015); they apparently failed to notice the fact that the S_T

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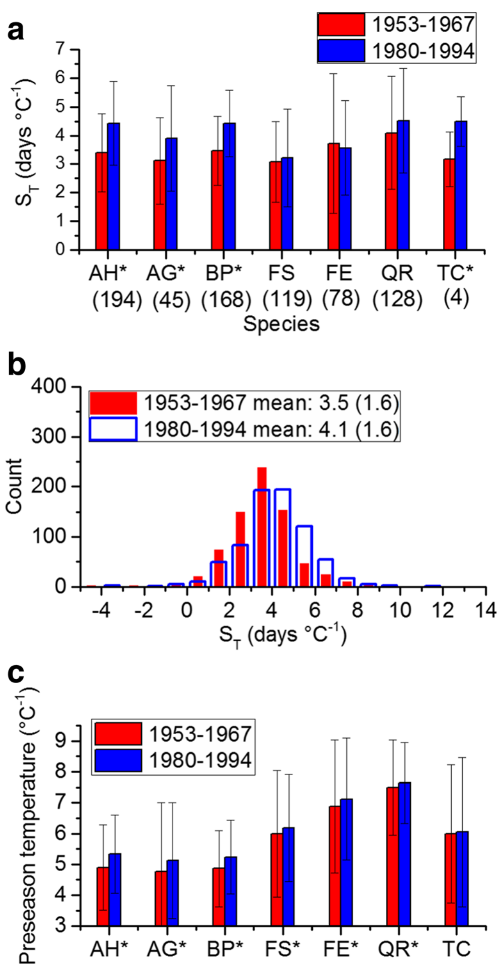

Fig. 1 Changes in temperature sensitivity of leaf unfolding (S_T) of seven major European tree species over different time scales. **a** Species-specific S_T and SD (shown by *error bar*) across all sites during 1953–1967 and 1980–1994. The number of sites for each species is given in *brackets* below the species name. The *asterisk* (*) marks significant difference between two periods. **b** The frequency distribution of S_T across all species and sites in two different periods and the mean S_T and SD (*in brackets*). **c** mean preseason temperature and SD (shown by *error bar*) across all sites during 1953–1967 and 1980–1994. The *asterisk* (*) marks significant difference between two periods. *AH* horse chestnut (*Aesculus hippocastanum*), *AG* alder (*Alnus glutinosa*), *BP* silver birch (*Betula pendula*), *FS* beech (*Fagus sylvatica*), *FE* ash (*Fraxinus excelsior*), *TC* lime (*Tilia cordata*), *QR* oak (*Quercus robur*)

increased from late 1970s to early 1990s is based on 15-year moving window (Wang et al. 2016). We have stated that the longer time period is better for the study of the S_T changes on longer time scales (Wang et al., 2016).

Advancing the discussions, we show that S_T increased with increasing temperatures from 1953 to 1967, 1980–1994 (Fig. 1c), and similar trends in changes of chilling temperatures. When comparing the S_T between 1953 and 1967 and 1980–1994, six out of seven species showed increased S_T (Fig. 1a). The difference of S_T between these two periods was significant for four species through pair-sample *t* test ($P < 0.05$). On average, S_T significantly increased by 17.1% from 3.5 days °C^{-1} during 1953–1967 to 4.1 days °C^{-1} during 1980–1994 (Fig. 1b). Meanwhile, the preseason temperature of six species became significantly warmer during 1980–1994 than that during 1953–1967. This example reflected climate warming would also lead to an increase of S_T. Therefore, from the viewpoint of longer time scales, there is no basis for alleging that the advancement of spring leaf unfolding will likely slow down in the future.

Fu et al. (2016) proposed a conceptual scheme telling the nonlinear relationship between spring temperature and leaf unfolding date (LUD). Even if this nonlinear relationship exists independently of the length of the time periods (15, 20, 30, or 100 years), reduced S_T would be found in warmer periods. However, when we compared S_T over two 30-year periods, this result could not be reproduced (Wang et al. 2016). In fact, the "conceptual" scheme is not realistic and cannot be verified by observational data.

The true relationship between spring temperature and LUD can be best illustrated with the example of LUD of *A. hippocastanum* observed at Juebek, Germany (Fig. 2). According to the scatterplot, we can find that there is no obvious nonlinear relationship between spring temperature and

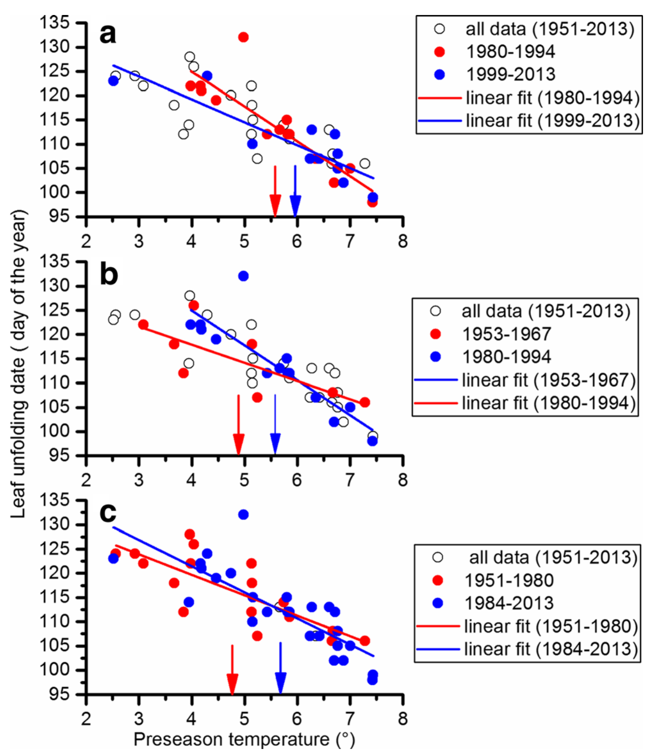

Fig. 2 An example of relationship between leaf unfolding date (LUD) and preseason temperature among different periods and climate. Data was LUD of *A. hippocastanum* observed at Juebek, Germany (PEP725 ID: 238). **a** comparisons between 1980 and 1994 and 1999–2013, **b** comparisons between 1953 and 1967 and 1980–1994, **c** comparisons between 1951 and 1980 and 1984–2013. The *arrows* show the mean preseason temperature of different periods.

LUD as shown in their figure. The S_T increases from a cold period (1953–1967) to a warm period (1980–1994) (Fig. 2b), and then decreased in a warmer period (1999–2013) (Fig. 2a), further confirming our result above. It seems that one point with extreme low temperature would cause the S_T to decline during 1999–2013 (Fig. 2a), because 15-year time period (minimum 7-year records) is relatively short and is easily impacted by extreme values. If comparing S_T between two 30-year windows, the S_T is relatively stable even the temperatures of two periods have significant difference (Fig. 2c).

In conclusion, decreased and increased S_T was both found in warming scenarios. Linking declined S_T to climate warming is misleading and future S_T changes are still more uncertain than suggested here. We must consider combined effects of biotic and abiotic factors impacting S_T, such as reduced chilling, photoperiod limitation, uncertainties of linear regression methods, changes in tree age, non-linear responses of plant development to temperature, and microclimate (Wang et al. 2016). Future interactions between climate and vegetation will remain complicated, influencing regional vegetation on one way or the other, and abundant work need to be done for the ecological protection under background of global change. We disagree with the statement that additional analyses performed in Fu et al. (2016) with an enlarged data set only strengthen the findings that the S_T of leaf unfolding is declining. As a final point, we keep awaiting the analyses from Fu et al. for a 30-year period before 1981 with similar temperature increase as the 1980 to 2013 period. Restricted data availability does not allow to draw the same conclusions as IPCC (2013) did for temperature increase with respect to the past 800 years.

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