

Using herbarium specimens to test for effects of climate change on the time of flowering

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Climate change has been a serious problem for many decades already. According to the Intergovernmental Panel on Climate Change (IPCC) human activities are estimated to have caused approximately 1.0 K rise in global mean temperature since the pre-industrial times and the process has intensified in the last decades (Masson-Delmotte et al. 2021). In the Baltic Sea region, the warming has been even more rapid than globally. Mean annual air temperature during the period 1951–2015 in Estonia has increased by 2.0–2.5 K (Jaagus et al. 2017). Considerable changes have taken place in the month of March where the mean temperature has risen 3–5 K (Jaagus 2006). Climate change has an influence on both individual organisms as well as on ecosystems. Especially sensitive to temperature change is flowering – other studies have found one degree of temperature rise can prompt flowering 2–10 days earlier. Temperature change in different seasons has various impacts on phenological events. In recent times herbarium material has become more relevant in studying ecological consequences of climate change. Digitalized historical herbarium provides useful material in addition to observational data. This study is the first to use Estonian herbarium material to test the usefulness of herbarium material for studying phenological changes due to climate change.

We hypothesized that during the last 120 years flowering time has shifted to earlier dates and that there is a difference in the rate of change in mainland and coastal areas.

The Ranunculaceae was selected as the study group because it is a species-rich family with a wide distribution over the whole of Estonia. The family contains both species flowering in spring and in summer. This allows to compare the impact of climate change on flowering in different seasons. Flowering herbarium specimens (Fig. 1), in total 3083, with correctly filled labels from the largest four Estonian herbaria (TAA, TAM, TALL, and TU), were included in the study, representing material that was collected from all over Estonia between 1901–2020 (Fig. 2). 22 species of Ranunculaceae were studied out of which half were spring and the other half summer flowering. Temperature data used in the study was acquired from the Estonian Environmental Board.

Linear regression and analysis of variance with programming language R were used for statistical analysis.

Results indicated that on average the flowering time has advanced 16 days (Fig. 3) since 1900. Similar trends in Estonia

Keywords

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Fig. 1. Herbarium specimen of *Ranunculus fallax* (Herbarium of Estonian University of Life Sciences, TAA).



Fig. 2. Location of herbarium specimen of Ranunculaceae in Estonia used to test for changes in flowering time between 1901–2020.

have been found before through direct phenological observations. In the course of the last 45 years the change has intensified (Fig. 4). The strongest correlation was found between the flowering time of spring flowering species and spring temperature. Within single species, the impact of climate change on phenology was not significant.

The strongest changes in the time of flowering for spring flowering species were found in central and south-eastern Estonia, where the time of flowering in 120 years has shifted earlier 21 and 13 days, respectively. Changes in flowering time in areas close to the sea in northern and western Estonia were statistically insignificant ($P > 0.05$).

To conclude, Estonian herbarium material is suitable for studying climate change effects on phenology and results based on herbarium material are comparable with results from other observations.

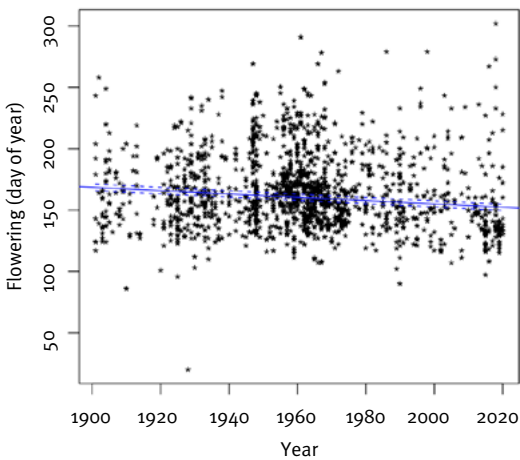


Fig. 3. Change of flowering time between 1901–2020 as shown by herbarium specimen of 22 species of Ranunculaceae. Linear trend -0.13 day/year ($P < 0.001$).

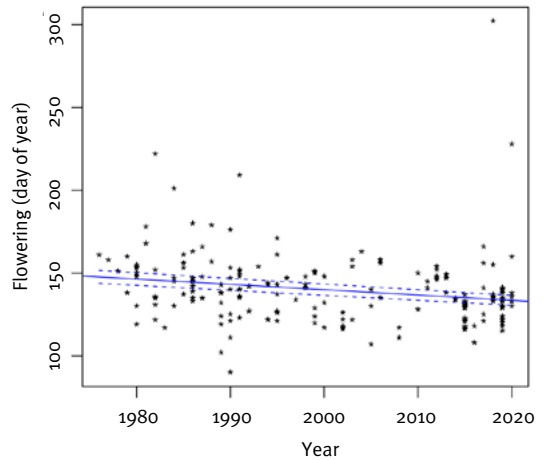


Fig. 4. Change of flowering time between 1976–2020 as shown by herbarium specimen of 22 species of Ranunculaceae. Linear trend -0.32 day/year ($P < 0.001$).

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