DOI 10.18699/SBB-2022-341

Changes in the phenology of perennial plants in Western Siberia against the background of global warming

Fomin E.[1]*, Fomina T.[2]

[1] *Institute of Cytology and Genetics, SB RAS, Novosibirsk, Russia*

[2] *Central Siberian Botanical Garden, SB RAS, Novosibirsk, Russia*

** fomin@bionet.nsc.ru*

Key words: climate change, meteorological trends, phenological trends, species of natural flora

Motivation and Aim: Global warming in recent decades is considered by most researchers to be the dominant factor affecting biodiversity indices and a shift in time of the occurrence of phenological events [1]. Changes in plant phenology affect productivity, interspecific competition, seasonal activity of pollinators, pollen release [2] and also has consequences for the spread of plant pests and diseases [3]. It is expected that the effect of warming on the growth and development of plants, especially in combination with other abiotic and biological stressors--drought and increased pressure of pathogens--will increase the problems for both wild and cultivated species [4]. The aim of the study was to identify deviations of local meteorological trends from the global one and to estimate the variability of the dates of phenological development of perennial plants due to a local trend of climate change in Novosibirsk.

Methods and Algorithms: This study was carried out in the Central Siberian Botanical Garden, Siberian Branch, Russian Academy of Sciences (55°2′29.4″ N, 82°56′4.6″ E). Seventy-eight species of perennial plants from the collection of decorative species of natural flora, for which phenological observations were performed at the time interval from 1996 to 2015, served as test subjects. Data on the Ogurtsovo weather station (no. 29638) were used to characterize the climatic indices for the period of study. Data on phenological and meteorological observations were processed with standard statistical methods using R and MS Excel packages, as well as our own programs written in C++. During the study period, we calculated intraseasonal trends of air temperature T and rainfall R (from April 1 to October 31) by the construction many individual (for each date of the year) linear trends with the subsequent calculation of a simple moving average in a window with a width of 30 days to smooth out short-term fluctuations and to detect the main changes. To obtain phenological trends and assess their confidence, a bootstrapping method was used [5] suitable for any probability distributions and sample sizes.

Results: During the study period, an average change in air temperature in the warm season of the year in Novosibirsk was +0.16 °C; total precipitation from April to October did not change (–0.01 mm). The construction of linear temperature and precipitation trends revealed intraseasonal periods with considerable changes in the main meteorological indices (Fig. 1). Although the beginning of the season became noticeably warmer (ΔT_{av} = +0.83), the late spring period became colder and wetter (ΔT_{av} = –1.87, ΔR_{av} = +0.47). At the same time, the probability of hot and dry weather increased both in the first half of summer (ΔT_{av} = +0.89, ΔR_{av} = –1.12) and in early autumn (ΔT_{av} = = +0.80, ΔR_{av} = –0, 37). As a result, the duration of the prefloral and floral periods characterizing the intensity of seasonal development decrease significantly in all species.

In the species flowering in the first half of the season, the decrease was 5–8 days; in summer ones, it was 10 days, while late-summer ones begin to bloom up to 24 days earlier. The effect of increased summer temperatures and dryness accompanying the climatic trend is obvious. The flowering periods are characterized by a very high variability for all groups with the trends of different direction and different value.

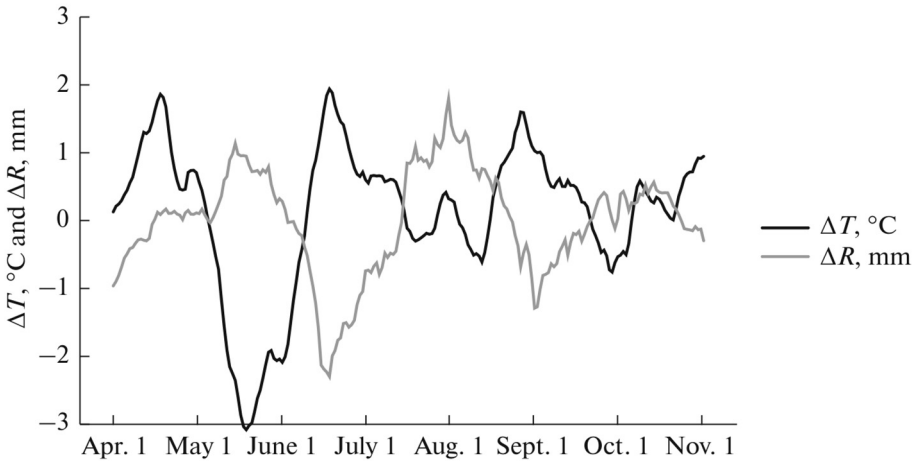

Fig. 1. Change in meteorological indices in Novosibirsk for 1996–2015. *X* axis, calendar dates; *Y* axis, difference between values of moving averages for the trends of average daily air temperature $\Delta T = T_{2015} - T_{1996}$ and precipitations $\Delta R = R_{2015} - R_{1996}$

Conclusion: Meteorological local trends of the warm season in Novosibirsk for 1996–2015 noticeably higher than the global trend: spring has become longer, colder and wetter, while early summer and early autumn have become warmer and drier. As a result, the prefloral period became much shorter, which indicates an acceleration in the development of perennials. At the same time, the trends in the duration of flowering vary greatly in magnitude and are multidirectional. Phenological trends are consistent with trends in climatic indicators and describe up to 16 % of the variability in the dates of phenophases and the duration of phenological periods. Otherwise, their variability is due to inter-annual and intra-seasonal fluctuations in weather factors, as well as the high inertia of seasonal development processes in perennial plants.

Acknowledgements: The study is supported by Central Siberian Botanical Garden, SB RAS (AAAA-A21-121011290025-2) and the Institute of Cytology and Genetics, SB RAS (0259-2021-0009).

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