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Potential shifts in the phenological development of representative spring plant species in Slovenia until the end of the 21st century

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Plant phenology is among the most sensitive biological indicators of climate change, reflecting how shifts in temperature and precipitation regimes alter the timing of key plant life-cycle events such as leaf emergence and flowering. Because these plant phenology developmental stages are tightly coupled to environmental cues, even subtle climatic changes can produce advances or delays in phenological phases, making them powerful measurable integrators of ecosystem responses to ongoing global warming. To investigate future changes in spring phenology, with particular emphasis on elevation-dependent responses, a climate-driven phenological model based on the Spring Indices methodology was developed. The study included both historical and projected flowering onset shifts for common hazel (*Corylus avellana*), dandelion (*Taraxacum officinale*), and common lilac (*Syringa vulgaris*). Phenological observations from 46 stations of the Slovenian National Phenological were combined with high-resolution climate data, and future phenological responses were simulated using 21st-century climate projections under two emission scenarios. Specifically, the study examined whether the agreement between model predictions and observed records varied with elevation during the reference period and whether this relationship changes in the future climate. The results indicated a systematic advancement of spring phenophases throughout Slovenia, driven by rising air temperatures. Moreover, the magnitude of this advancement increases with elevation, suggesting an enhanced sensitivity of high-altitude ecosystems to climate warming. These findings highlighted the growing role of topography in shaping future plant phenological patterns and have important implications for ecosystem functioning and climate-impact assessments in mountainous ecosystems.