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The penalty of spring frost damages from earliest to latest possible leaf-out timings in temperate forest trees

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The timing of a tree's leaf emergence represents a trade-off between maximising competition for resources (e.g. light, nutrients) and avoiding freezing damage. Global warming has significantly advanced the date of the last frost events in temperate zones, but in parallel has also shifted the onset of vegetation in spring over the last decades. Thus, the risk of frost damage to plants has not necessarily decreased, depending on geographical location and species. In this study we aim to assess the overall impact of frost damage for saplings vitality. We used saplings of 4 temperate, deciduous tree species (*Prunus avium*, *Carpinus betulus*, *Quercus petraea* and *Fagus sylvatica*) and artificially altered the leaf-out date by applying a warming or cooling treatment before the natural leaf-out to reflect the whole range of possible leaf-out dates. Once leaves emerged, we simulated a natural frost event, damaging all or half of the new leaves. We then analyzed how fast the different species recovered depending on leaf-out timing in terms of recovery time (time until second flush), growth (biomass and height) and non-structural carbohydrate reserves (NSC) in relation to non-frozen control plants. By quantifying the penalty of frost damages in late spring this experiment aims to specify the risk of a species' strategy to time spring phenology.