

Spatial and temporal climate signals in reproductive traits of Scots pine across Poland

S. Bury¹*, J. Foest¹, J. Szymkowiak¹, S. Jastrzębowski², A. Guziejko², M.K. Dyderski³, M. Bogdziewicz¹

¹Forest Biology Center, Institute of Environmental Biology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland, *sebastian.bury@amu.edu.pl

²Department of Silviculture and Genetics, Forest Research Institute, Braci Leśnej 3, 05-090 Raszyn, Poland

³Department of Systematic and Environmental Botany, Institute of Environmental Biology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

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Understanding how climate drives tree reproduction requires disentangling the effect of spatial (across-site) climatic variation from temporal climate variability (within-site, weather). While spatial gradients often reflect long-term evolutionary adaptations, temporal variability captures immediate phenotypic plasticity in response to inter-annual weather anomalies. These two sources of climate variation may influence plant reproductive traits through different ecological mechanisms, yet they are rarely analyzed simultaneously. Understanding this distinction is crucial, as trees may respond differently to a warming climate than they do to geographic temperature gradients.

Here, we investigated spatial and temporal climate signals in reproductive traits for cones and seeds of Scots pine (*Pinus sylvestris* L.) across Poland. Scots pine is an ecologically and economically important forest-forming species in many European countries. We analyzed a dataset of reproductive traits (i.e., cone and seed mass) collected across 184 Forest Districts (State Forests) between 2010 and 2024. Using mixed-effects models, we evaluated the influence of within-site and among-site climate variation on reproductive traits. To reflect the phenology of Scots pine reproduction, the effects of climatic predictors were evaluated for periods corresponding to key stages of the reproductive cycle, including the summer preceding seed development, winter conditions, and the growing season of the year of reproduction.

We hypothesized that the reproductive traits of Scots pine react differently to spatial and temporal climate variation. Additionally, we assumed that the effects of specific climatic indicators are consistent across reproductive traits within the study periods. The results help us better predict forest reproductive responses to climate change and improve long-term management plans for Scots pine forests. The impact of climate change on the reproductive capacity of this widespread species is pivotal to the future species composition of European forests.