

A standardized resilience index to ecological droughts (RED50) reveals local adaptation of tree species and their populations *

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Abstract

Climate change adaptation in forestry requires metrics that identify species and populations with the capacity to tolerate and recover from drought. Yet, empirical comparisons of drought resilience are challenging due to inconsistent drought definitions and confounding effects of species composition, regional population adaptation and local site factors. To address this, we develop a standardized Resilience to Ecological Drought index (RED50), which quantifies the ability of trees to recover from a modeled drought event that causes a 50% growth reduction. Applied to 718 tree-ring sites globally, including detailed analyses of 20 North American species, RED50 enables consistent, cross-species assessments of recovery potential. First, we found a moderate negative correlation between drought resistance and recovery ($r = -0.24$, $p < 0.0001$), indicating a trade-off: species that suppress growth during drought tend to recover more fully afterward. Second, recovery potential varied within species across their ranges, with trailing-edge and interior populations generally showing the highest RED50 values. Third, within-region comparisons revealed that drought-adapted species occupying more xeric sites consistently outperformed mesic-site species in post-drought recovery. These patterns suggest that both species- and population-level adaptations to water limitation enhance resilience. Two complementary, low-risk assisted migration strategies emerge for climate-informed forest management from this analysis: seed sourcing from resilient populations within the species range (e.g., from dry-edge provenances), and RED50-informed species selection within regions when water limitations are expected (i.e. a short-distance version of assisted migration among local sites). Together, these approaches offer practical pathways for reforestation, restoration, and gene conservation planning under climate change.

Keywords: Dendroclimatology, drought resistance, drought resilience, drought adaptation, forest ecosystems.

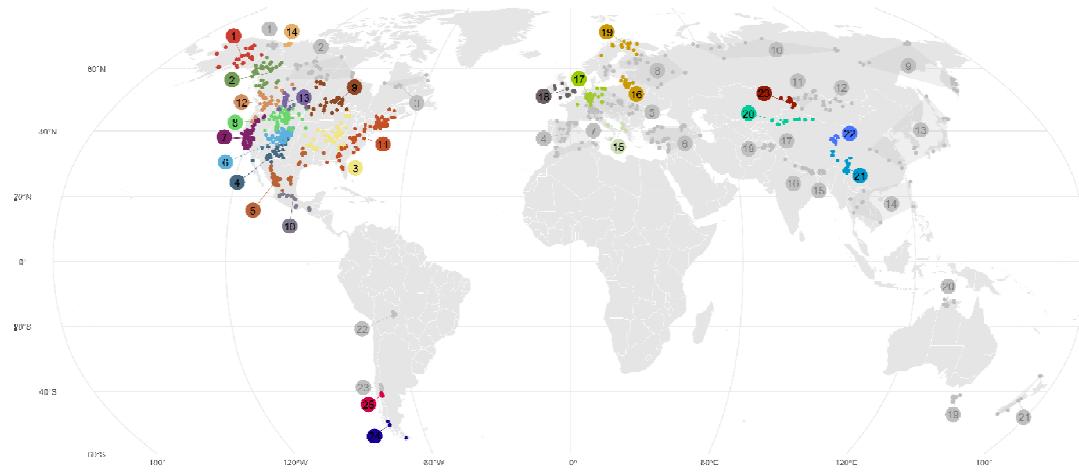


Figure 1. Chronology sites and clusters of sites with similar climatologies and growth response. Approximately 40% of chronology sites were removed to satisfy filtering criteria that ensured that drought metrics could be estimated, and reliable inferences could be drawn for clusters with regards to their drought vulnerability.

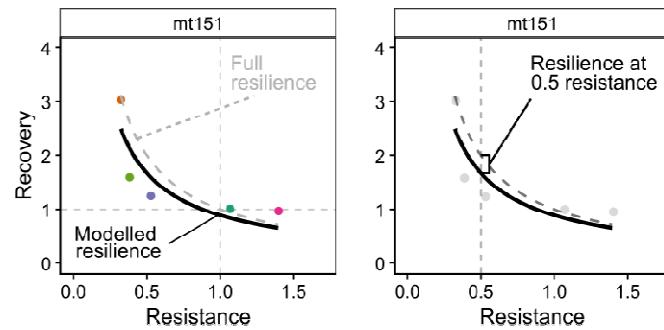


Figure 2 Estimation of a recovery capacity metric by fitting a curve to resistance and recovery values. The deviation of the fitted lines (solid) to full recovery (dashed lines) for a hypothetical drought event that causes 50% growth reduction (Resistance = 0.5) is interpreted as a recovery capacity metric that is independent of the severity of the observed individual drought events (colored dots).

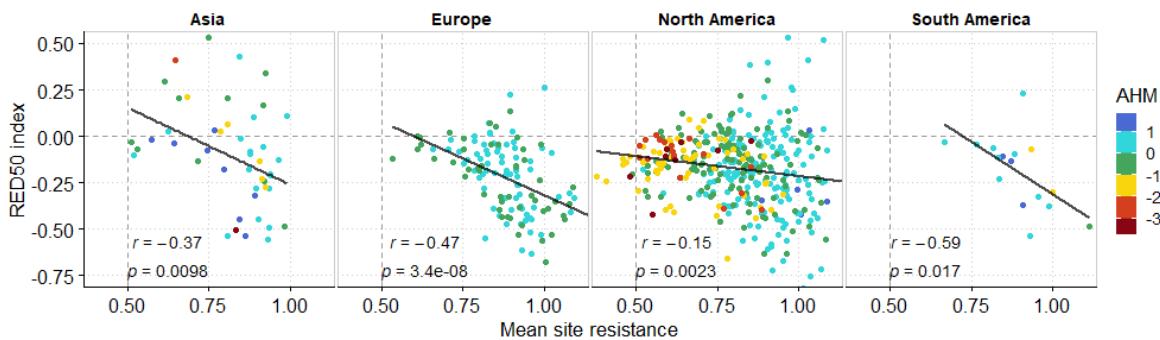


Figure 3 Resilience to ecological droughts (RED50) as a function of the ecological drought severity (resistance), and their relationships with a non-standardized annual heat-moisture index (AHM, log transformed values with smaller values indicate a drier climate normal values). Data points represent chronologies averaged by species and sites. A RED50 value of zero indicates complete recovery to pre-drought levels, a resistance value of 0.5 indicates a 50% growth reduction (indicated by dashed lines).

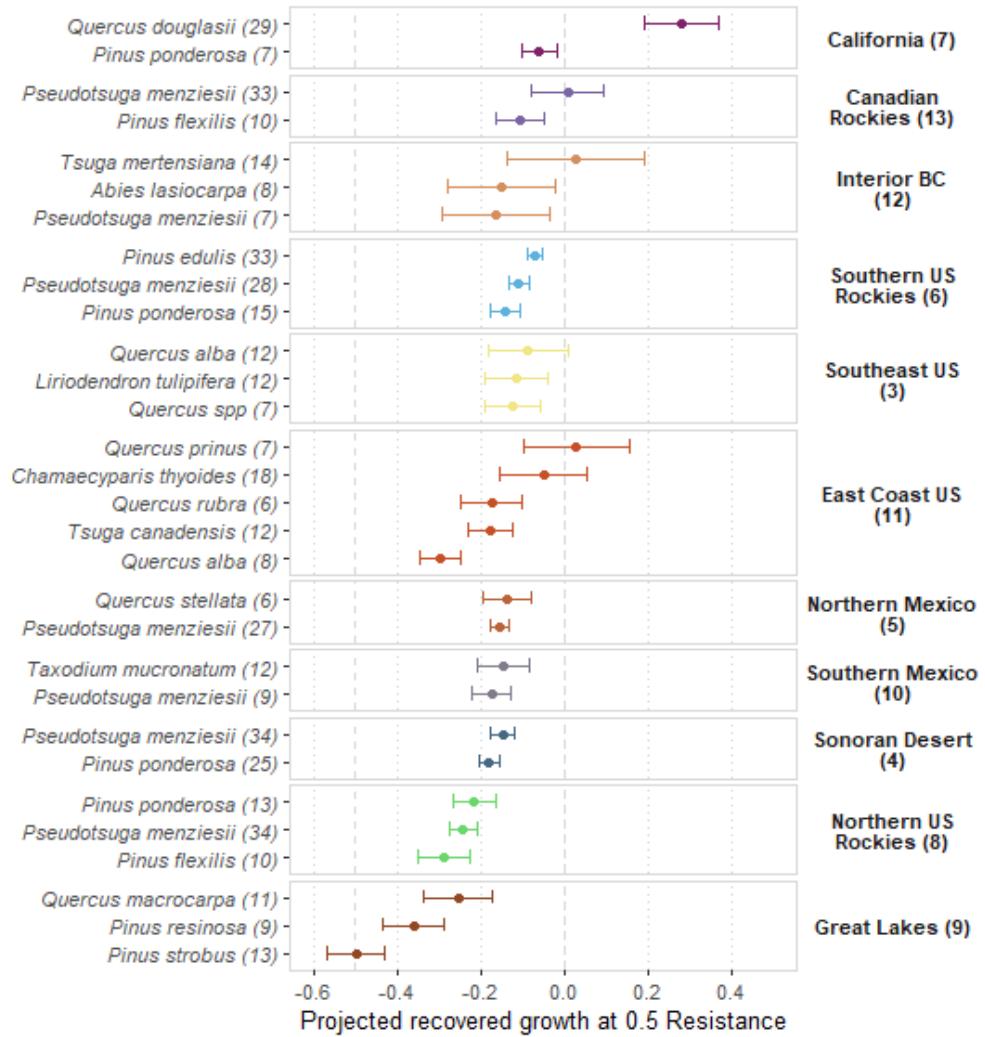


Figure 4. Average RED50 across clusters and species. Points represent average RED50 species recovery for a given cluster in a given region. Horizontal bars show one standard error. Only species with more than six sites are shown ($N = 718$). A RED50 value of zero indicates complete recovery to pre-drought levels, while -0.5 represents no recovery at all (dashed lines). Points to the left of -0.5 indicate that growth during the recovery period was lower than during drought. Positions to the right of zero indicate growth rates exceeding pre-drought levels.

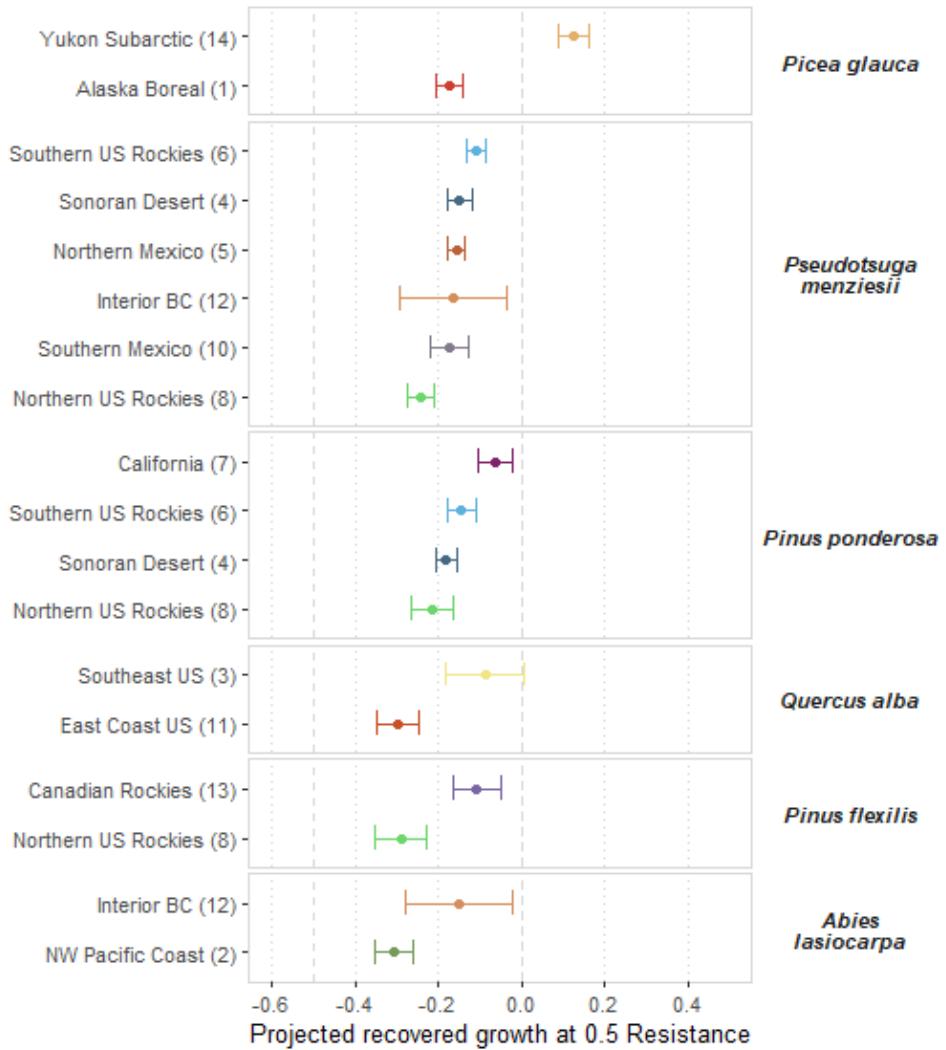


Figure 5. Same as Fig. 4 but RED50 averages are grouped by species for population comparisons.