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Long-term effects of drought on tree-ring growth and carbon isotope variability of Scots pine in a dry environment

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Drought frequency and intensity are increasing in many parts of the globe, enhancing tree decline and mortality. However, the underlying physiological mechanisms are still poorly understood, particularly regarding the chronic effects of long-term drought. Here, we combined analyses of radial growth and stable carbon isotopes in tree rings (δ^{13}C) in a mature Scots pine (*Pinus sylvestris* L.) forest over the 20^{th} century to elucidate causes of observed tree mortality in one of the driest parts of the European Alps (Pfynwald, Valais, Switzerland). Additionally, we investigated the effects of a 10-year irrigation experiment in the same forest stand, where annual precipitation was doubled. We found a sustained growth increase and immediate decrease of δ^{13}C values for irrigated trees, indicating higher stomatal conductance and thus showing that water is a key limiting factor indeed. Growth of now-dead trees started declining in the mid-1980s, when both mean temperature and vapor-pressure deficit (VPD) strongly increased. Growth of these trees was reduced to some extent already several decades earlier, while intrinsic water-use efficiency derived from δ^{13}C values was higher, indicating a very conservative water-use strategy, possibly at the cost of insufficient carbon uptake. The climate correlation analysis further showed that radial growth of the now-dead trees was highly sensitive to spring and summer mean temperatures as well as VPD. We conclude that the recent increase in atmospheric moisture demand in combination with insufficient soil water supply was the main trigger for tree decline and mortality of already weakened trees in Pfynwald.