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Contrasting extremes in water-related stresses determine species survival

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In temperate climates, soil moisture, in concert with nutrient availability and soil acidity, is the most important environmental filter in determining local plant species composition, as it determines the availability of both oxygen and water to plant roots. These resources are indispensable for meeting the physiological demands of plants. Especially the occurrence of both excessive dry and wet moisture conditions at a particular site has strong implications for the survival of species, because plants need traits that allow them to respond to such counteracting conditions. However, adapting to one stress may go at the cost of the other, i.e. there exists a trade-off in the tolerance for wet conditions and the tolerance for dry conditions.

Until now, both large-scale (global) and plot-scale effects of soil moisture conditions on plant species composition have mostly been investigated through indirect environmental measures, which do not include the key soil physical and plant physiological processes in the soil-plant-atmosphere system. Moreover, researchers only determined effects of one of the water-related stresses, i.e. either oxygen or drought stress. In order to quantify both oxygen and drought stress with causal measures, we focused on interacting meteorological, soil physical, microbial, and plant physiological processes in the soil-plant-atmosphere system. We simulated these plant stresses with a novel, process-based approach, incorporating in detail the interacting processes in the soil-plant-atmosphere interface.

High variability and extremes in resource availability can be highly detrimental to plant species ('you can only die once'). We show that co-occurrence of oxygen and drought stress reduces the percentage of specialists within a vegetation plot. The percentage of non-specialists within a vegetation plot, however, decreases significantly with increasing stress as long as only one of the stresses prevails, but increases significantly with an increased co-occurrence of oxygen and drought stress. These results confirm earlier suggestions that species that are simultaneously tolerant to multiple stresses, lack full adaptation to each potential stress. Specific adaptations to either oxygen or drought stress thus reduce the adaptive ability to the other stress and increase the impact of the other stress.

We further show that the combination of stresses is detrimental particularly to endangered species, while the number of common species within a vegetation plot does not decline with increasing co-occurrence and intensification of oxygen and drought stress. Additionally, our results show significantly smaller tolerance ranges for oxygen and drought stress for endangered species than for common species. Variability in the availability of resources is thus especially detrimental to species with narrow physiological tolerance ranges.

Finally, we found that increased rainfall variability in interaction with predicted changes in temperature and CO_2, may affect soil moisture conditions and plant oxygen and water demands such, that both oxygen stress and drought stress will intensify due to climate change. Moreover, these stresses will increasingly coincide, causing variable stress conditions. Consequently, more variable and extreme meteorological conditions may decrease the future habitat suitability, especially for specialists and plant species that are presently endangered, which has direct implications for policies to maintain species.