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Climate change hampers endangered species through intensified moisture-related plant stresses

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With recent climate change, extremes in meteorological conditions are forecast and observed to increase globally, and to affect vegetation composition. More prolonged dry periods will alternate with more intensive rainfall events, both within and between years, which will change soil moisture dynamics. 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.

The consequences of climate change for our natural environment are among the most pressing issues of our time. The international research community is beginning to realise that climate extremes may be more powerful drivers of vegetation change and species extinctions than slow-and-steady climatic changes, but the causal mechanisms of such changes are presently unknown. The roles of amplitudes in water availability as drivers of vegetation change have been particularly elusive owing to the lack of integration of the key variables involved. Here we show that the combined effect of increased rainfall variability, temperature and atmospheric CO2-concentration will lead to an increased variability in both wet and dry extremes in stresses faced by plants (oxygen and water stress, respectively). We simulated these plant stresses with a novel, process-based approach, incorporating in detail the interacting processes in the soil-plant-atmosphere interface.

In order to quantify oxygen and water stress with causal measures, we focused on interacting meteorological, soil physical, microbial, and plant physiological processes in the soil-plant-atmosphere system. The first physiological process inhibited at high soil moisture contents is plant root respiration, i.e. oxygen consumption in the roots, which responds to increased temperatures. High soil moisture contents hamper oxygen transport from the atmosphere, through the soil - where part of the oxygen additionally disappears by soil microbial oxygen consumption - and to the root cells. Reduced respiration negatively affects the energy supply to plant metabolism. Plant transpiration, which responds to increased temperatures and atmospheric CO2-concentrations, is the first physiological process that will be inhibited by low soil moisture contents, negatively affecting both photosynthesis and cooling. As both the supply and demand of oxygen and water depend strongly on the prevailing meteorological conditions, both oxygen and water stress were calculated dynamically in time to capture climate change effects.

We demonstrate that increased rainfall variability in interaction with predicted changes in temperature and CO2, affects soil moisture conditions and plant oxygen and water demands such, that both oxygen stress and water stress will intensify due to climate change. Moreover, these stresses will increasingly coincide, causing variable stress conditions. These variable stress conditions were found to decrease future habitat suitability, especially for plant species that are presently endangered. The future existence of such species is thus at risk by climate change, which has direct implications for policies to maintain endangered species, as applied by international nature management organisations (e.g. IUCN). Our integrated mechanistic analysis of two stresses combined, which has never been done so far, reveals large impacts of climate change on species extinctions and thereby on biodiversity.