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Drought-related tree mortality in drought-resistant semi-arid Aleppo pine forest

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The frequency and intensity of drought events are expected to increase as part of global climate change. In fact, drought related tree mortality had become a widespread phenomenon in forests around the globe in the past decades. This study was conducted at the Yatir FLUXNET site, located in a 45 years old *Pinus halepensis* dominated forest that successfully sustained low mean annual precipitation (276mm) and extended seasonal droughts (up to 340 days between rain events). However, five recent non-consecutive drought years led to enhanced tree mortality in 2010 (5-10% of the forest population, which was not observed hitherto). The Tree mortality was characterized by patchiness, showing forest zones with either $>80\%$ mortality or no mortality at all. Areas of healthy trees were associated with deeper root distribution and increased stoniness (soil pockets & cracks). To help identify possible causes of the increased mortality and its patterns, four tree stress levels were identified based on visual appearance, and studied in more detail. This included examining from spring 2011 to summer 2013 the local trees density, root distribution, annual growth rings, needle length and chlorophyll content, rates of leaf gas exchange, and branch predawn water potential. Tree phenotypic stress level correlated with the leaf predawn water potential (-1.8 and -3.0 in healthy and stressed trees, respectively), which likely reflected tree-scale water availability. These below ground characteristics were also associated, in turn, with higher rate of assimilation (3.5 and 0.8 μmol CO_2 $m^{-2}s^{1}$ in healthy and stress trees, respectively), longer needles (8.2cm and 3.4 cm in healthy and stressed trees, respectively). Annual ring widths showed differences between stress classes, with stressed trees showing 30% narrower rings on average than unstressed trees. Notably, decline in annual ring widths could be identified in currently dead or severely stressed trees 15-20 years prior to mortality or tree degradation. These results indicate, together with earlier results that showed a virtually close hydrological cycle (ET$\sim$P) for this forest, that mortality was dominated by conditions at the level of the single-tree or small group of trees. The dependency on belowground water availability of individual trees emphasizes the difficulties in drawing process-based conclusions from the mean response at the forest stand level and, alternatively, the need to investigate drought stress and survival processes at the patch scale. The capabilities of early identification, and of grading the stress level with simple tools, such as tree-rings and pre-dawn water potential, can facilitate partitioning forest stands into zones more relevant to the study and management of drought related mortality. Ultimately, an integrated approach considering both the stand and patch scales and which utilizes methodologies such as used in this study will be essential to reliably predict ecosystem response to changes in precipitation regimes and climate.