Eco-hydrological consequences of drought-induced forest mortality: an observational case study in piñon -juniper woodlands in the southwestern US

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Tree die-off events have rapidly increased across the globe in the last decade as a result of warmer temperatures and more severe droughts. In the southwestern US, where piñon-juniper (PJ) woodlands occupy 24 million ha, the turn of the century drought (1999-2002) triggered 40-95% mortality of piñon pine (*Pinus edulis*) in one of the most extensive mortality events recorded in the last century. To determine the consequences of this disturbance on the main components of the surface water balance, we conducted a girdling experiment in September 2009 where all adult piñon trees were girdled in an area of 200 m^2 reducing the piñon basal area of the site by 66%. We compared water fluxes measured in this girdled site (PJG) to fluxes measured simultaneously in an intact PJ woodland less than 3 km away (PJC). In addition to evapotranspiration (ET) measurements from open-path eddy covariance, canopy transpiration (ETc) was measured using sap flow probes (Granier thermal dissipation method) installed on five juniper and five piñon trees at each site. Below canopy evapotranspiration (ETbc) was derived from ET and ETc measurements. Soil volumetric water content (VWC) was monitored using TDR probes (CS610, Campbell Scientific) under the three main cover types (bare soil, under juniper and under piñon) at three depths (5, 10 and 30 cm depths) at both sites for comparison.

Total ET at the girdled site decreased slowly, but progressively, relative to the intact PJ woodland following the girdling, with annual ET 3%, 9% and 20% lower in 2010, 2011 and 2012, respectively, in the girdled site. This decrease in ET was largely due to a significant reduction in canopy transpiration following girdling (annual ETc at PJG decreased by 47%, 59% and 75% from 2010 to 2012 compared to the PJC site). Daily ET was substantially higher (44%, 14% and 18% for years 2010 to 2012) at PJG than at PJC only during the winter, especially during the very snowy winter of 2009/2010 (likely due to higher sublimation in the girdled site). Soil water content decreased following girdling, particularly under dead piñon trees (VWC_{0-30} at PJG were on average 20%, 16% and 18% lower than at PJC for post-girdling years 2010 to 2012). In addition, surface temperatures inferred from longwave radiation measurements made at the site, and infrared canopy temperature sensors indicate that the girdled site surface temperature progressively increased from 2010-2012. Our results suggest piñon mortality leaves PJ woodlands both hotter, and drier than intact PJ woodlands. Given the extent of mortality observed in these woodlands and the predicted increase in mortality expected over the next century, these results have important surface energy balance consequences for the Southwestern US.