Reduced hydraulic redistribution under future climate will affect root water uptake and ecosystem carbon balance across divergent forest ecosystems

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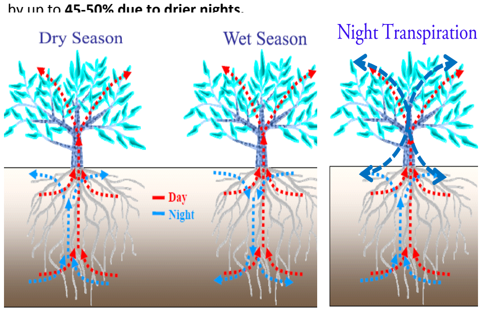
•Jean-Christophe Domec[1,2], Asko Noormets[1], John King[1], Steve McNulty[3], Ge Sun[3], Sari Palmroth[4], Jennifer Swenson[4], Ram Oren[4] – PIs.
•Andrew Radecki[1] – Graduate Student / Christopher Oishi[4] – Postdoctoral Researcher.
•Gaby Katul[4], Jeffrey M. Warren[5], Jérôme Ogée[6], Nate G. McDowell[7], William T. Pockman[8], Marcy E. Litvak[8] – Collaborators.
[1]North Carolina State University, NC; [2]Bordeaux Sciences Agro/INRA TCEM, France; [3] USDA FS-EFETAC, NC; [4]Duke University, NC; [5]Oak Ridge National Laboratory, TN; [6]INRA EPHYSE, France; [7]Los Alamos National Laboratory, NM; [8]University of New Mexico, NM.

Rationale and Objectives

Deep root water uptake and hydraulic redistribution (HR) play a major role in forest ecosystems during drought, but little is known about the impact of climate change on root-zone processes influencing HR and drought-induced root loss of functionality and their consequences on carbon fluxes. The first decade of the 21th century was the warmest on record, and by 2050 the global average surface temperature is predicted to increase by 2-4°C, with larger increases projected for the summer in most latitudes. Furthermore, in northern latitudes, nighttime temperatures are expected to increase more than daytime temperatures. Because the water-holding capacity of the atmosphere increases with temperature, and relative humidity is not projected to change markedly, this may lead to higher nighttime evaporative demand (vapor pressure deficit). However, nighttime water loss may interfere with the hydraulic distribution (HR) (**Figure 1**), potentially decreasing transpiration and photosynthesis. Using data from three old growth sites in the western USA, four mature sites in the eastern USA, two mature sites from the western USA, one site from southern Brazil **(Table 1**), and simulations with the process-based model MuSICA, our objectives were to show that HR can 1) mitigate the effects of soil drying on root functioning by reducing root hydraulic dysfunction and mortality, and 2) have important implications for carbon uptake and net ecosystem exchange (NEE).

Figure 1. Schematic description of hydraulic redistribution **(left panel)** and the negative effect of nighttime transpiration on HR **(right panel)**. Drier nights under future climate will increase water loss at night, which will act as a competing sink for hydraulically water pools. Across sites (Table 1) HR was predicted (MuSICA model) to be reduced by up to **45-50% due to drier nights.**



(Adapted from Amenu and Kumar 2007)

Sites

Table 1: Main characteristics of the sites studied. LAI (leaf area index) is projected, RAI (root area index) is all sided. Values in bold represent data that have been or are being collected for the project

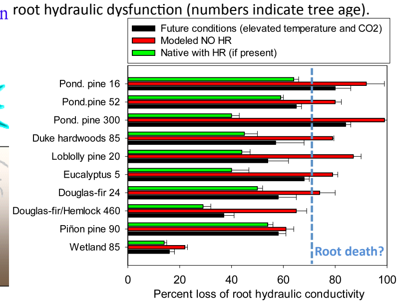
	Ameriflux site code	Age (years) Tree composition	LAI (m^2 m^{-2})	Rooting depth (m)	RAI (m^2 m^{-2})	HR measured or modeled (mm d^{-1})
Alligator river site (NC)	US-AR	65-150 wetland tupelo/baldcypress	**4.6**	**0.8**	**Being determined**	**Low <0.10**
Duke hardwood site (NC)	US-Duke2	80-100 mixed hardwood bottomland	**4-7**[1, 2]	**1.3**	**Being determined**	**Being determined**
Coastal Parker tract (NC)	US-NC2	20, loblolly pine plantation	2.9-4.2[3]	1.8[4]	**9.8**[4]	**High, >0.80**
Wind River old-growth (OR)	US-Wrc	>450, Mixed conifers	9[6]	1.4[7]	5.25[7]	Medium –low[8], 0.15-0.25
Wind River young (OR)		26, Douglas-fir natural stand	6[6]	1.0[7]	5.25[7]	Medium–low[8], 0.10-0.20
Metolius old site (OR)	US-Me4	>300, ponderosa pine savanna	2.9[8]	1.2[7,9]	4.5[7,9]	Medium-high[8], 0.25
Metolius young site (OR)	US-Me5	19, ponderosa pine savanna	1.0[8]	0.7[10]	1.7[10]	Low[9], <0.10
Sevilleta (NM)	Us-Sec	80-90, piñon-juniper woodland	1.1[11,12]	1.1[12]	**3.7**	**Low, <0.15**
Sandy Pine (NC)		25, pine natural regeneration	2.2-3.5[5]	2.5[5]	**4.2**	**Low, <0.20**
Itatinga (Brazil)		4, eucalyptus plantation	3.4-3.9[13]	15[13]	3.8[13]	**High, 0.85-1.10**

[1]Stoy et al. 2008, [2]Oishi et al. 2010, [3]Norrmets et al. 2009, [4]Domec et al. 2010, [5]Domec et al. 2012, [6]Phiilips et al. 2002, [7]Warren et al. 2005, [8]Irvine and Law 2002, [9]Warren et al. 2007, [10]Domec et al. 2004, [11]Anderson-Teixeira et al. 2010, [12]Plaut et al. 2012,[13]Nouvellon et al. 2012.

Results: Hydraulic Redistribution (HR) Keeps Roots Alive

At the dry old-growth ponderosa pine site and at the eucalyptus stand, both characterized by deep sandy soils, HR limited the decline in root hydraulic failure (Figure 2) and increased dry season tree transpiration (*T*) by up to 25% (Figure 3), which impacted NEE through major increases in gross primary productivity (GPP). The presence of deep-rooted trees did not necessarily imply high rates of HR unless soil texture allowed large water potential gradients to occur, as was the case in the wet old-growth Douglas-fir/mixed conifer stand (Table 1). At the Duke mixed hardwood forest and at the piñon/juniper site characterized by shallow soils, modeled HR was low but not negligible, representing annually up to 10% of *T* (Figure 3). At those sites, in the absence of HR, it was predicted that annual GPP would have been diminished by 7-19%. At the coastal loblolly pine plantation, characterized by deep organic soil, HR limited the decline in root conductivity by more than 50% (Figure 2), prevented tree root mortality and increased dry season *T* by up to 40%.

Figure 2. Effect of Hydraulic Redistribution on Root Functioning. Hydraulic redistribution (HR) prevents irreversible loss of root hydraulic capacity and limits root death. Drier nights likely to occur under future climatic conditions are predicted to reduce HR and thus increase root hydraulic dysfunction (numbers indicate tree age).



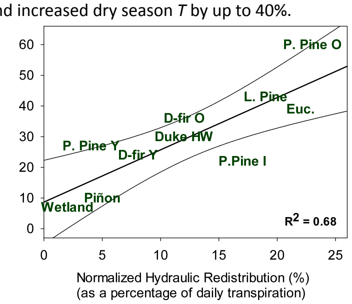
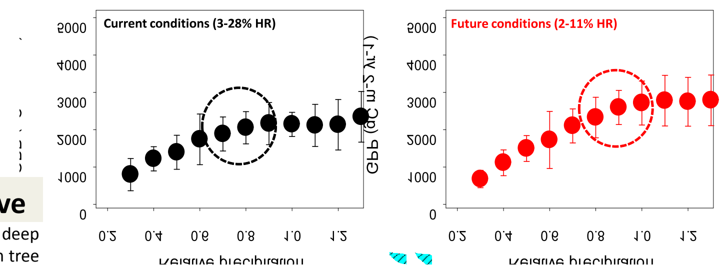


Figure 3. Hydraulic Redistribution keeps roots alive. Relationships between the amount of water lifted at night by deep roots and the maintenance of root hydraulic function across divergent forests ecosystems.

References: See attached flyer.

Results: Effect of Hydraulic Redistribution on C Fluxes

Figure 4: Simulations (MuSICA model) of gross primary productivity under current and future climatic conditions (elevated atmospheric [CO_2] and temperature). Shaded areas represent the site variability in GPP (eucalyptus being the maximum and piñon-juniper the minimum). Filled symbols represent the means of all sites (±SE). Large circles indicate severe droughts and reveal that under future conditions (red), GPP will be more sensitive to reduced precipitations because of a reduction in hydraulic redistribution (HR) due to drier nights (Figure 1). The range in %HR (Figure 3) is indicated in each panel.



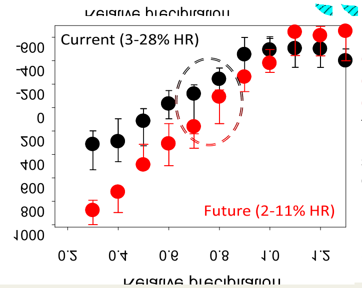


Figure 5: Precipitation effect on net ecosystem exchange (NEE) under current (**BLACK**) and future (**RED**) climatic conditions (elevated [CO_2] and temperature). The filled symbols represent the means (±SE) of all modeled sites (Table 1) The oval indicates the onset of severe droughts and reveals that under future conditions (red), NEE will be more sensitive to reduced precipitations, because of less hydraulic redistribution (HR) due to drier nights (Figure 1).

Perspectives - Conclusions

- Our work highlighted the interactive effects of root functioning and climate change on HR, and showed that the negative effect of drier nights on HR would be greater under future climate conditions (**Figures 2, 4, 5**).
- This work enhances our confidence in accurately predicting how HR impacts forest carbon balance by establishing a direct link between plant root functioning and carbon fluxes (Katul and Siqueira 2010, Domec et al. 2010).
- The predicted reductions in HR under future climate conditions are expected to play an important regulatory role in the land–atmosphere interaction by affecting the partitioning of net radiation between sensible and latent heat fluxes (Siqueira et al. 2009, Prieto et al. 2012). The next step is to implement HR and its interactions with rooting functioning in soil–vegetation–atmosphere transfer models (Lee et al. 2005).

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