Floodplain ecohydrology: Climatic, local, and anthropogenic controls on water availability to riparian trees

Résumé :
Seasonal and annual partitioning of water within river floodplains has great implications for ecohydrologic links between the water cycle and tree growth. These changes in how water shifts between various floodplain storage reservoirs (e.g., vadose v. phreatic zones) affect water availability to the root zone of different tree species. There is a further dependency on the physical conditions that control tree rooting depth (e.g., gravel layers that impede root growth), as well as the sources of contributing water, the rate of water drainage, and water residence times within particular storage reservoirs. We employ instrumental climate records alongside data from isotopes within tree ring cellulose, topographic data, and information on soil depth, to assess water sources used by two co-occurring tree species within a riparian floodplain along the Rhône River in France. We find that the impact of fluctuations in climate (e.g., wet v. dry years) on water availability to riparian trees depends strongly on the local (tree-level) relationship between floodplain surface elevation and gravel layer elevation. The latter represents the upper limit of the phreatic zone and therefore controls access to shallow groundwater and their difference represents the thickness of the vadose zone, which controls total soil moisture retention capacity. These factors thus modulate the climatic influence on tree ring isotopes. Additionally, we identified within tree ring isotopes and growth the signature of the restoration of minimum streamflows in the Rhône, which made new phreatic water sources available in otherwise dry years.

Objectifs du projet et mise en contexte

Using a multipronged dataset, we investigate the variability in isotopic signatures within two co-occurring riparian tree species rooted at a range of floodplain elevations and with varying soil depths at one site. We address several research questions: 1) How do trees in riparian zones access and use water for growth through fluctuations in hydrology? 2) What role do relative floodplain elevation and soil depth play in controlling the partitioning of water in floodplain storage reservoirs? 3) How is tree water use and growth affected by climatic and/or anthropogenic changes in water availability?

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This source switching by high gravel poplars allows them to maintain their growth in high spring rainfall years and more steady annual growth overall, compared to their low gravel elevation cohort. Fifth, the restoration has certainly had an important impact on these riparian trees, especially poplar. Both species exhibit a shift to more depleted water in dry years, suggesting there is a new source of water available to these trees in the form of an elevated water table. However, this water is undoubtedly more available to *Populus*, and it is not entirely clear why there should be such a shift in isotopic signatures for *Fraxinus*. In terms of poplars, the effect of the restoration is evident for high v. low trees, but even more so for high v. low gravel elevations. These isotopic signals diverge as low gravel elevations access increasingly depleted water from the shallow phreatic zone, allowing much more elevated and consistent growth for this species in dry years.

Perspectives :

A grand challenge in ecohydrology is identifying the direct controls exerted by water or its absence on vegetation. It is particularly important to separate the influences of climatically driven water availability from local, site-based factors and anthropogenic impacts to the water cycle. This is especially possible within trees that record hydrologic signatures in their annual growth rings. Such knowledge would improve efforts to characterize past climate over large areas, to model catchment hydrology, and to predict growth responses to changing climate within individual trees, across forest stands, or even over broad regions of the globe. It could also be used to better understand the recent history of partitioning between water storage reservoirs (e.g., vadose v. phreatic zones), knowledge which would support drainage basin water management, as well as restoration of river flows and of forest resources.

Plus-value pour les praticiens :

This work demonstrates the direct impacts of flow restoration at Pierre-Benite on riparian floodplain trees.

It shows in what conditions and positions in the floodplain we should expect benefits to riparian trees from flow restoration in the Rhône corridor.

Références :

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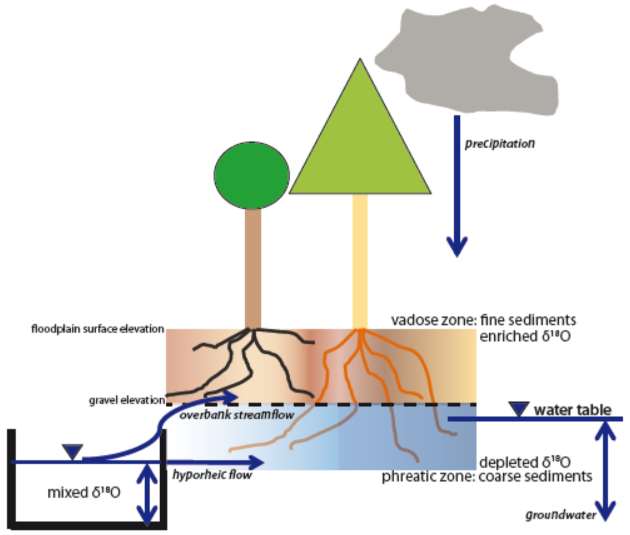
Dawson, T. E., and J. R. Ehleringer (1991), Streamside trees that do not use stream water, Nature, 350(6316), 335-337.

Singer, M. B., J. C. Stella, S. Dufour, H. Piégay, R. J. S. Wilson, and L. Johnstone (2012), Contrasting water-uptake and growth responses to drought in co-occurring riparian tree species, Ecohydrology, In Press.

Méthodologies :

We obtained 5-mm tree cores via increment bore (two per tree) from *P. nigra* (poplar) and *F. excelsior* (ash) within a reasonably homogeneous floodplain. Visually healthy, mature (> 30 years and > 20 cm DBH) trees were selected in order to remove any potential ecological impacts to tree growth or water sources associated with the juvenile effect. For this study, we utilized 59 ash and 51 poplar trees that were all located < 200 m from the Old Rhône. We extracted α-cellulose from the raw wood of dated tree rings by the Brendel method and analyzed these samples in a Finnegan Delta plus XP gas source mass spectrometer, coupled to a High Temperature Conversion/Elemental Analyzer peripheral to obtain oxygen isotopes in dated annual tree rings. To assess soil depth, we used a cone penetrometer at the base of each tree (i.e. depth to gravel based on first refusal). We employed high resolution (need to quantify resolution here) LiDAR data to extract floodplain surface elevation and to compute the elevation of the gravel layer, by subtracting the soil depth from the surface elevation. We then analyzed tree ring growth chronologies, $\delta^{18}O$ in tree rings, rooting depth, alongside records of Q, P, and water table elevation from a local piezometer. We segregated our data such that we could compare growth and isotopic values for the two species, as well as to assess differences between trees rooted at high (>158 mASL) v. low (<157 mASL) elevations. We further subdivided our tree ring data by soil depth (< 1 m v. > 2 m), which allowed us to compute the gravel elevation below each tree (<155 mASL v. >156 mASL), indicative of the boundary between phreatic and vadose zones.

Figure 1 -Schematic showing how two species with contrasting rooting depths may record different annual values of $\delta^{18}O$ based on variability in hydrologic partitioning between floodplain storage reservoirs. There is a large dependence on the depth to gravel and the relative surface elevation of the floodplain above the water table.



Principaux résultats :

First, comparing isotopes in poplars and ash, $\delta^{18}O$ in Populus is more enriched that in Fraxinus for high floodplain surface elevations, shallow soils, and at high gravel elevations. This suggest that poplars rooted at locations where they may become easily stranded from phreatic water, access an isotopically enriched source of tightly bound soil water as a last-chance resource, compared with co-occurring ash trees. Second, ash trees have virtually no access to phreatic water table, apart from the lowest floodplain trees, while poplars have extremely variable access to shallow phreatic water across the study site. Third, the direct climatic signal on water availability to these two tree species reveals that the water uptake by *Populus* is relatively depleted in $\delta^{18}O$ for wet years at low floodplain elevations, in shallow soils, and at high gravel elevations, suggesting that in such years the phreatic water table rises into the zone where roots penetrate gravels. Yet this source of water is unavailable to *Fraxinus* trees within the same cohorts. After the minimum flow in dry years is raised to 100 m^3 s^{-1}, the strong $\delta^{18}O$ differences between wet and dry years in poplars for these cohorts (low, high gravel elevation, and shallow soils) disappear because the water table is supported in all years, which diminishes the wet v. dry isotopic differences in water available to this species. That is, *Populus* no longer switches to a very enriched vadose zone source of water during dry years. Conversely, *Fraxinus* expresses its strong sensitivity to precipitation and its seasonality both before and after the flow restoration. All ash trees in 2002 seem to utilize a very enriched source of water from late spring rains that creates a strong difference between $\delta^{18}O$ values for the wet and dry years. However, this is irrelevant to the flow restoration. Fourth, the differences in isotopic signatures between the snowmelt and rainfall years suggests that trees with low gravel elevations gain access in high snowmelt years (e.g., 1995) to phreatic water containing a high proportion of relatively enriched river water via hyporheic flow (compared with the more depleted groundwater of more typical flow years). In contrast, there is likely not enough hyporheic flow in such years to elevate the water table to the elevations of the higher gravels, so these poplars must subsist on deeper and more depleted sources of shallow groundwater (farther from the river's edge), whereas their low gravel counterparts access this an enriched source of water, suggesting that their gravel substrates have been infiltrated with mostly hyporheic water.

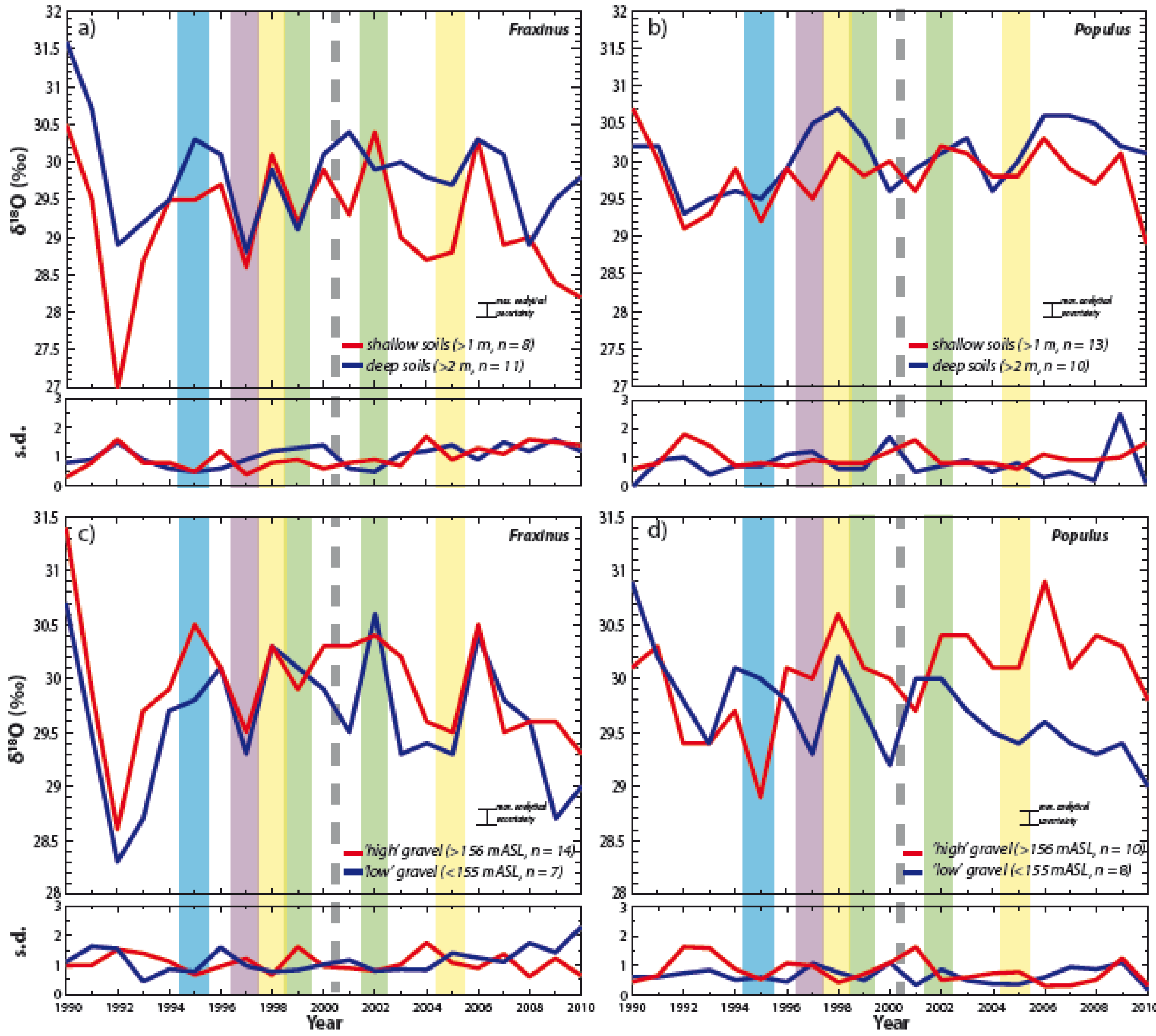


Figure 2 - Mean oxygen isotope ratios, $\delta^{18}O$, for *F. excelsior* (a) and *P. nigra* (b) rooted deep v. shallow soils (measured by penetrometer to first refusal). (c) and (d) show mean $\delta^{18}O$ for 'high' v. 'low' gravel elevations determined by subtracting penetration depths from floodplain surface elevation from determined from LiDAR. Standard deviations in $\delta^{18}O$ are shown for the two species in the corresponding subpanels.