Impacts of climatic variability and anthropogenic impacts on riparian hydrology and forest dynamics: Evidence from isotopes and tree rings in the Rhône corridor

Résumé:

Seasonal and annual partitioning of water within river floodplains has important implications for ecohydrologic links between the water cycle and tree growth. Climatic and hydrologic shifts alter water distribution between floodplain storage reservoirs (e.g., vadose, phreatic), affecting water availability to tree roots. Water partitioning is also dependent on the physical conditions that control tree rooting depth (e.g., gravel layers that impede root growth), the sources of contributing water, the rate of water drainage, and water residence times within particular storage reservoirs. We employ instrumental climate records alongside oxygen isotopes within tree rings and regional source waters, as well as topographic data and soil depth measurements, to infer the water sources used over several decades by two co-occurring tree species within a riparian floodplain along the Rhône River in France. We find that water partitioning to riparian trees is influenced by annual (wet versus dry years) and seasonal (spring snowmelt versus spring rainfall) fluctuations in climate. This influence depends strongly on local (tree level) conditions including floodplain surface elevation and subsurface gravel layer elevation. The latter represents the upper limit of the phreatic zone and therefore controls access to shallow groundwater. The difference between them, the thickness of the vadose zone, controls total soil moisture retention capacity. These factors thus modulate the climatic influence on tree ring isotopes. Additionally, we identified growth signatures and tree ring isotope changes associated with recent restoration of minimum streamflows in the Rhône, which made new phreatic water sources available to some trees in otherwise dry years.

Objectifs du projet et mise en contexte

Using a multiparameter data set (tree ring and local water oxygen isotopes, tree ring width, instrumental climate data, high-resolution topography, and soil depth measurements), we investigate the variability in isotopic signatures within two co-occurring riparian tree species rooted at a range of floodplain elevations and with varying overbank fine sediment thickness at one site. We address several research questions: (1) how do trees in riparian zones access and use various water sources 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 source partitioning?

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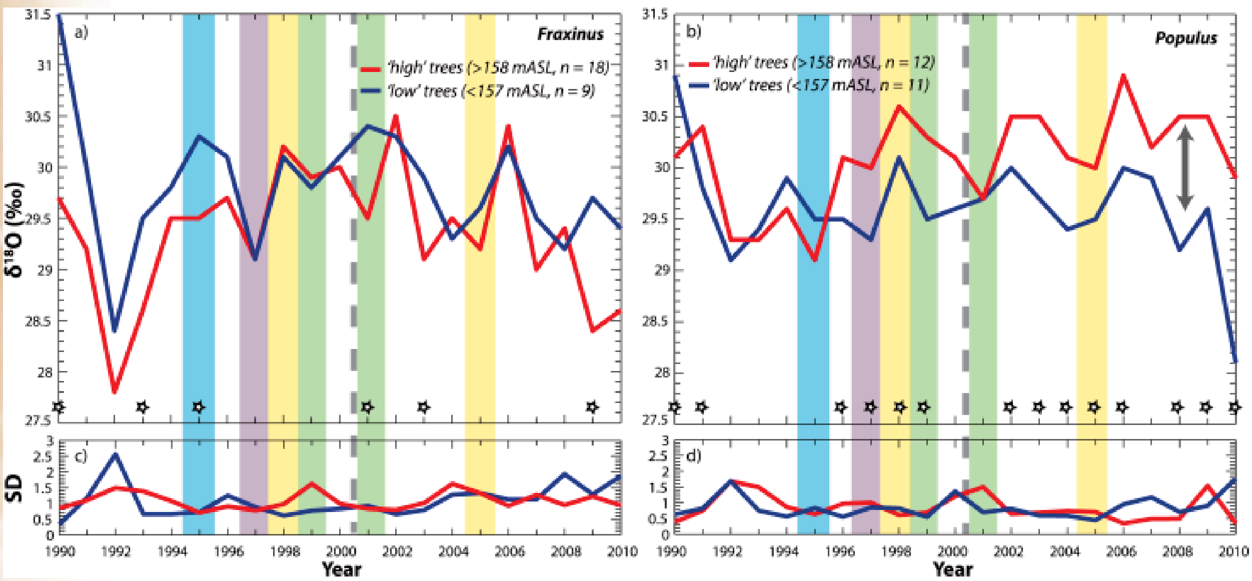
Méthodologies :

We combined several methods to achieve the goals of this research. These included: 1) Isotopic Characterization of Source Waters; 2) Tree Ring Growth and Isotopic Characterization; 3) Analysis of the Impact of Climate Variables on $\delta^{18}O$; and 4) Ancillary Variables and Hydrologic Characterization. We used existing datasets on isotopies in precipitation along with our own measurements in stream water to interpret the range of expectable endmember. We analyzed dendrochronology for two co-occurring tree species and developed corresponding chronologies for stable isotopes (oxygen). We back-calculated the isotopic signatures of source waters used by trees via a mechanistic model. Finally, we interpreted the results in the context of ancillary information on regional climate and hydrology.

Principaux résultats :

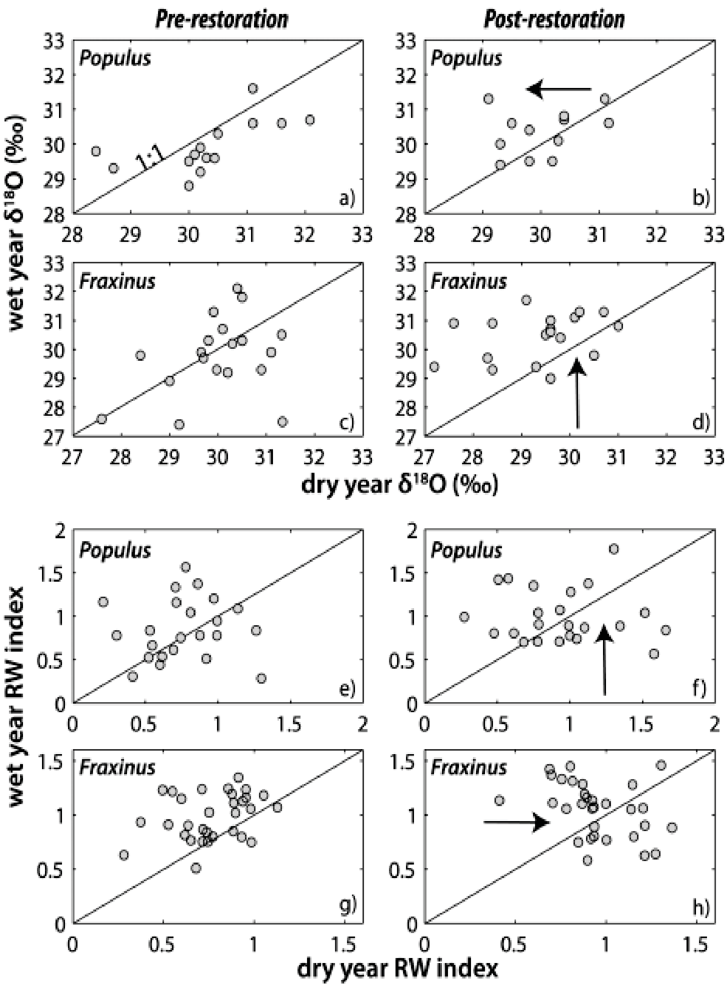
This study investigated ecohydrology within a forested riparian corridor designed to assess the influence of various physical controls on water partitioning between different floodplain water reservoirs over a range of hydrologic years. Our detailed approach used trees as annual integrators of the hydrologic cycle, particularly in terms of water availability at the root zone, and its uptake and incorporation into tree ring cellulose. We compared normalized annual tree ring widths and $\delta^{18}O$ against various local parameters (soil depth, floodplain surface elevation, gravel elevation, and local water $\delta^{18}O$) that differ for groups of trees. We further assessed these physical controls in the context of characteristic hydrologic years over several decades, which might be expected to produce strong differences in water partitioning, especially before and after major human modification of the local water balance.

Our work demonstrated significant differences in isotopic signatures of tree-ring cellulose between the two co-occurring tree species, as well as between cohorts of the same species that were rooted in contrasting settings (e.g., high v. low relative floodplain elevations, Fig 1). These results suggest that the physical conditions in the floodplain (e.g., thickness of vadose zone, floodplain elevation, etc) may be equally important to interpret tree ring cellulose isotopic signatures as understanding the variability in isotopes in precipitation. We further found by back-calculating the isotopic signatures of source waters available to riparian trees that there are significant annual differences in isotopes of available water associated with the particular combination of hydrologic partitioning in the floodplain (e.g., high snowmelt years v. high rainfall years). These results also indicate water source switching by many trees, depending on their rooting position.



We also found that the flow restoration in 2000 has certainly had an important impact on some riparian trees at this site, especially Populus. The effect of the restoration is evident for high versus low trees of this species (Fig. 1), but even more so for high versus low gravel elevations. These isotopic signals diverge as trees at low floodplain and gravel elevations accessed increasingly depleted water from the shallow phreatic zone, allowing much more elevated and consistent growth for this species in dry years (Fig. 2). Annual differences in mean growth and $\delta^{18}O$ between Populus cohorts at high versus low elevations and high versus low gravel elevations support our conclusions about the effect of the flow restoration. Increases in yearly differences in $\delta^{18}O$ for high versus low Populus after the restoration yielded fewer differences in annual growth. Overall, the flow restoration appears to have had an impact on source water availability to riparian trees at Pierre-Bénite, especially Populus.

The availability of water to riparian trees is often discussed in terms of end-member sources of phreatic water versus vadose zone water. However, in riparian environments in particular, modest variations in driving hydrology based on climatic fluctuations may notably influence the partitioning of water between these sources, especially in floodplains with heterogeneous structure (i.e., in terms of sedimentary architecture and elevation). Thus, the isotopic signature of water preserved in vegetation is likely to fluctuate annually based on water availability alone and will vary across individual stands of forest. These variations in tree ring $\delta^{18}O$ are ultimately reflective of complex interactions between driving hydrology, which varies by annually and seasonally by magnitude, timing, and phase of precipitation, and the local conditions of topography and soil texture that influence the movement of water between the various saturated and unsaturated floodplain storage reservoirs. Such annual differences may be expected to undergo substantial and unpredictable changes, as climatic shifts are expressed in particular regions. For example, the warming and drying of basins such as the Rhône will affect precipitation regimes, evaporation rates, and thus antecedent moisture in floodplain forests.



Anthropogenic influence on river-floodplain corridors may also dramatically impact the partitioning of water between these storage reservoirs. The influence of hydrologic modifications on streamflow regimes are well documented throughout the world and their influence may propagate or dissipate through the fluvial network. In addition, impacts to flow regimes due to water extraction or even large-scale rehabilitation scenarios aimed at improving river-floodplain interaction and functioning are likely to change streamflow regimes, hyporheic flow, and regional shallow groundwater tables. As these changes influence the annual availability of water in floodplain storage reservoirs, we should expect impacts to riparian forests. However, the prediction of such ecohydrologic responses requires detailed study into the imprint of human alteration of hydrology on top of inherent (or even shifting) climatic variability and local topographic and sedimentary controls that influence partitioning of water in floodplains.

Perspectives:

An important 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 physical factors and anthropogenic impacts to the water cycle. This is possible using 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 versus phreatic zones). This would support drainage basin water management, as well as restoration of river flows and of forest resources. In this paper, we endeavor to disentangle the primary controls on water availability to trees rooted in floodplains of the Rhône River in France. We use historical time series of tree ring oxygen isotopes, ring width chronologies, instrumental climate data, high-resolution topography, and soil depth measurements to identify climatic, anthropogenic, and physical controls on spatial and temporal variability of water sources used by streamside trees and their influence on annual tree growth within this major river floodplain.

Plus-value pour les praticiens:

Water shifts due to climatic fluctuations between floodplain storage reservoirs.
Anthropogenic changes to hydrology directly impact water available to trees.
Ecohydrologic approaches to integration of hydrology afford new possibilities.

Références:

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