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The use of the stable oxygen isotope (^{18}O) to trace the distribution and uptake of water in riparian woodlands

Luc Lambs,
Jean-Pierre Loudes,
Marie Berthelot

Abstract Streamside vegetation forming narrow "corridors" in temperate regions, is typically dominated by deciduous tree species reflecting strong influences by human activities. Riparian woodlands depend on hydrological resources and have to adapt to rapid changes in water levels and soil moisture conditions. Three main water sources are typically present in the riparian zone: river water originating in the mountains, ground water and rainfall. Stable isotopes, such as oxygen-18, are useful tools which allow for water movement to be traced within the riparian zone and which help to identify water sources utilised by the trees growing in these areas.

Keywords oxygen isotope • riparian forest • water origin • xylem sap

L. Lambs[✉], J.-P. Loudes, M. Berthelot
Centre d'Ecologie des Systèmes Aquatiques Continentaux (CESAC),
UMR Université-CNRS C5576,
29 rue Marvig, 31055 Toulouse Cedex 04, France,
Tel.: 00 33 5 62 269994, Fax: 00 33 5 62 269999,
e-mail: lambs@cesac.cemes.fr

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Introduction

Given the high biodiversity within riparian zones [3], there is much to learn about plant-water relationships, life stages and functional groups of these species, which are sensitive bio-indicators of surface and groundwater decline. There is, however, relatively little data available that can be used to predict the impact of hydrological changes on riparian biota [6]. Depth of groundwater sources and spatial correlates such as floodplain elevation and inundation frequency exert the largest influence on the composition of what are typically floristically rich plant assemblages [5].

Groundwater depletion and stream diversions have contributed to the loss and alteration of wetland and riparian ecosystems throughout the world. This is particularly true in areas with distinct dry seasons, since surface and groundwater sources are in high demand for human uses, including irrigation. The effects of agricultural expansion and water reduction have ranged from a total loss of riparian vegetation to more subtle impacts. In streams, flow rights are granted for fish and wildlife habitats in most developed countries, but often these rights are minor compared to others [5].

Study sites

The field sites were located in alluvial forests situated 50 km downstream of Toulouse, along the Garonne River, in southwestern France. Around Toulouse, the Garonne Valley has an asymmetric shape with high terraces on the left bank and low and numerous terraces on the right bank (Fig. 1). Bands of naturally regenerated riparian forest occur on the lower terraces close to the river. Often adjacent to the riparian forest, but further inland, poplar plantations are established in areas where annual floods prohibit other cultivations.

The riparian woodlands along the riverbank mainly comprise black poplars *(Populus nigra)* and white willows *(Salix alba)*. Because the river has been regulated in part, there has been vertical erosion (incision) of the river bed, with the result of a deepening of ground water table levels and drier conditions on riverbanks, especially during summer drought. While poplars seem to be adapting to these new moisture conditions, over the past 10 years, willows have been progressively disappearing.

Methods

Over a four year period (from July 1997 to May 2001), the stable isotope, oxygen-18 (^{18}O), was used to identify the water sources (i.e. river, ground or rain water). All the numerical isotopic values are given in per mil (‰) and relative to the Standard Mean Ocean Water (SMOW). The isotopic values given in Figure 1 are the mean values and corresponding standard error derived from the total number of samples collected at each measuring point. River samples were collected from the Garonne river itself (26 samples), from two small rivers running adjacent to the Garonne river on the right bank (i.e. 2 and 6 samples from the St Jean and Tauris Rivers, respectively), and on the left bank from a brook (4 samples) and the Save River (3 samples). Ground water samples were collected from agriculture wells established on the higher terraces (22 samples on the right bank and 4 samples from the left bank). On the lower terraces, piezometers were installed to allow for the monitoring of groundwater on a gravel bar and within both the poplar plantations and spontaneous regenerated riparian woodland (3 to 4 samples collected per piezometer). The conductivity, temperature and water level of all these different water sources were measured, but at more frequent intervals, usually once a week.

The second point was to look at the vertical profile of the water and study how it can be used and absorbed by the trees. Trees sampled were located in two contrasting situations: one black poplar situated on the right bank (tree 1), about 20 meters from the river near the piezometer p18, where the ground water level was shallow (about 1 meter), and another hybrid black poplar situated on the left bank (tree 2) close to piezometer p2, not far from high terrace, and thus there was a much deeper groundwater level (about 3 meters). On the feet of these trees, the soil water in the unsaturated part has been trapped by vacuum ceramic tensiometers (tensionics, SDEC France) installed at different depths. Xylem sap was collected from the base of tree trunks and from both deep and surface roots during the dry season by extraction from wood cores, with the help of a home made hydraulic press (Lambs and Berthelot, Plant and Soil, accepted).

Results

The whole floodplain had fairly homogeneous isotopic water values (^{18}O around -6.7‰ to -7.0‰), reflecting the predominance of local rain inputs (-6.9‰). The Garonne River water originating at high altitudes was more depleted in ^{18}O (-8.8‰), as the low altitude tributaries have a poor contribution to the global flow. The two upper terrace rivers, the Save and Tauris Rivers, displayed middle values (-7.4‰ to -7.5‰) corresponding to rainfall in distant hill slopes. As riparian woodlands and poplar plantations are chiefly located in a transitional area where river and ground water mix, the water level in this area depends mainly on the river levels [2]. Willows are limited to areas with more constant soil moisture conditions, where there is a well--established link with groundwater sources.

Table 1 displays interesting differences in the isotopic readings of the water table with a greater dependency on water extracted from the saturated layers and water extracted from deep roots (respectively 9.08‰ and 8.85‰ for tree 1, and -6.7‰ and -6.6‰ for tree 2). As the water from the water table fractionated progressively as it evaporated through the soil, an isotopic gradient was evident in both cases from soil water collected in the unsaturated part. Note a reversal in the ion profile between the two soils,

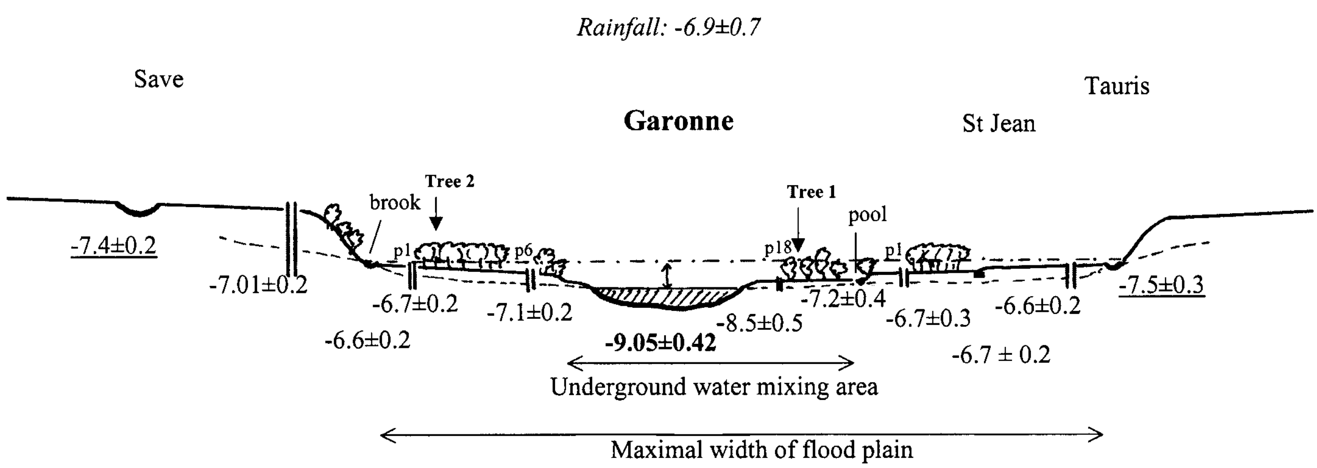

Fig. 1. Cross section of the Garonne valley downstream of Toulouse indicating ^{18}O isotopic values of different water sources given in ‰ relative to SMOW. The floodplain has an asymmetric profile with higher terraces on the left bank compared with right banks. The vertical lines indicate the locations of piezometers installed on each bank (p1 to p6 on left bank, and p1 to p18 on the right bank) and the locations of the two wells utilised. The dashed line represent an estimate of the groundwater level based on levels in the piezometers and wells. The alternative dash-dot line gives an idea of the 10 years flood level.

Table 1. Comparison of ^{18}O concentrations and conductivity of the sap of the both poplar trees relative to the water collected from the piezometer (water table) and the soil water collected from different depths from within the vacuum ceramic tensiometers (soil water). Ground water levels were shallow where tree 1 was located (0.98 m) with only 3 tensiometers installed here while around tree 2, the ground water level was at 3.06 m, with 5 tensiometers installed.

	Tree 1		Tree 2	
	^{18}O (‰)	Conductivity (µS)	^{18}O (‰)	Conductivity (µS)
Trunk sap	**-8.00**	2072	**-6.8**	2116
Surface root sap	**-8.02**	2047	-5.1	4489
Deep root sap	-8.85	2336	**-6.6**	5380
Soil water at 30 cm	-8.43	614	*dry*	*dry*
Soil water at 60 cm	-8.44	550	-6.3	604
Soil water at 90 cm	-8.55	529	-7.6	554
Soil water at 120 cm			-7.7	666
Soil water at 170 cm			-7.0	770
Water table	-9.08	392	**-6.7**	883

which leads to similar ion contents in the available water closer to the surface (respectively 614 µS at 30 cm for tree 1 and 604 µS at 60 cm for tree 2), compared with very different values in water collected from the piezometers (392 and 883 µS, respectively). For tree 2, during almost the entire dry season, the upper tensiometers, at 30 and 60 cm, were dry. In these areas the ground water level could drop up to 1.50 m in relation to the mean winter level. For tree 1, the active roots are clearly the surface roots as isotopic values (-8.02‰) are very similar to those of the sap trunk (-8.00‰). For tree 2, the active roots are the deep roots (-6.6‰) with similar isotopic values to those found in the trunk sap (-6.8‰). The sap in the trunks of both trees displayed similar ion contents (2072 and 2116 µS) although the sap in the roots of tree 2 had a higher charge (4489 and 5380 µS).

Discussion

The natural concentration of oxygen isotope often varies between the different "pools" of water in the environment. The ^{18}O isotopic composition of rainfall also varies in relation to variations in temperatures and at different altitudes and latitudes. The isotopic composition of groundwater if recharged by rain, will be the annual average of local rain. River water is much depleted in heavy isotopes if the rain or snow have been more fractionated by the altitude elevation. Provided water is not fractionated when absorbed by roots, the isotopic composition of xylem sap reflects that of the "pool" from which the water originated [7].

Poplars and willow have long been recognized as indicators of shallow groundwater levels, just as changes in water table depth are know to have the potential to alter the structure of riparian forest assemblages. The distributions of poplars and willows are also different; the former species is typically closely associated with active channels, while the latter is less commonly linked to perennial streams [1]. The construction of river embankments along the Garonne River (even if only on one side of river) has reduced the number of river arms and active channels where willow might otherwise flourish in damp areas with substantial fine sediment deposits. Suitable areas available for willow regeneration is progressively taken over by *Acer negundo*, a species that demonstrates greater tolerance of deep groundwater levels during the summer months. In many American riparian zones [1], tamarix is another species which has undergone rapid expansion following a decline in willow and poplar numbers. In studies investigating seasonal soil moisture depletion, *Tamaris* and *Salix* show little evidence of water acquisition from unsaturated zones, whereas *Populus* uses soil moisture even when groundwater is available [1]. This might explain why poplars, as for tree 1, can adapt to new moisture conditions, whereas willow cannot. The high adaptability of poplar allows it also to survive in localities where ground water level are deep during the dry season and with a dry soil surfaces due to its active deep roots as for tree 2. Willow only survives where shallow and stable ground water levels exist.

Seasonal variations in water availability throughout the soil profile can change faster than roots can be redistributed. Root distribution is not only dependent on water availability, but also on other factors such as morphology, available nutrients, soil texture and competition between plants. The maximum uptake of nutrients and water from a horizon do not necessarily coincide [4]. This was seen in tree 1 (Table 1) where the poplar was observed to extract limited water supplies, highly charged in ions from the upper layers of the sediment, even though there was more water available in deeper layers, but less charged in ions. Measurements undertaken on other poplars near tree 1, demonstrate that there is a high capacity to concentrate the uptake water to maintain a high ion content compared with willows.

In conclusion, this study highlights the complex water linkages within the alluvial forest zone. The results of the isotopic study reported here is just the qualitative work of a wider study on quantitative water absorption by poplar and willow in alluvial forest. More work is needed to better understand how this unique and useful landscape is modified by changes in water usage. There is equally the need to explore reasons for the gradual disappearance of willow from the riparian landscape. We should be aware of the consequences of water management on these dynamic sites dominated by woody sites as important zones influencing water quality and as active buffer to floods and wildlife habitat.

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