Response of *Eucalyptus largiflorens* to floodplain salinisation

M.D. Akeroyd*, G.R. Walker** and M.B. Kendall*

* Murray-Darling Basin Commission, 15 Moore Street, Canberra ACT 2601, Australia
** Primary Industries and Resources South Australia

Abstract An analysis of the stable isotopes from the tree rings of *Eucalyptus largiflorens* on the Chowilla Floodplain was undertaken. This chronology of tree water use responses was compared to the known hydrological changes that have occurred due to the effects of river regulation. The isotope chronology indicates that *E. largiflorens* has always oscillated between groundwater and rain-derived soil water and river regulation has apparently had little effect on tree water sources over time. This result is surprising, but no doubt reflects the complexity of floodplain processes and interactions between trees, water and the landscape.

Keywords *Eucalyptus largiflorens*; Murray-Darling Basin; plant water use; salinity; stable isotopes; tree rings

Introduction

Significant changes have occurred to the natural flow regime, hydrology and land-use of floodplains and adjacent riverine areas along the length of the Murray River since European settlement. As a consequence, mobilisation of natural salt stores has occurred and resulted in salinisation of landscapes. In 1990 it was estimated that approximately 18,000 ha of riparian vegetation along the Murray River was currently exhibiting signs of degradation caused by salinity, waterlogging, vegetation clearance, water stress and grazing (Margules and Partners *et al.*, 1990).

More recently, predictions based on the Salinity Audit of the Murray-Darling Basin (MDBMC, 1999) indicate that about 3.4 million hectares of land in the Murray-Darling Basin will be salt affected within 50 years due to the mobilisation of salt stored in the landscape. Another important finding was that much of the mobilised salt does not get exported to the ocean, but stays in the landscape or is diverted into irrigation areas and floodplains (Jolly *et al.*, 1997). This finding emphasises the importance of understanding the impacts of increasing salinity with respect to floodplain processes, in particular the change in water movement related to salinity impacts on vegetation water use.

There have been significant hydrologic changes to the Chowilla Anabranch (Figure 1) due to river regulation and construction of a nearby weir (CWG, 1995). As a consequence, salinisation has occurred in many areas of the floodplain with severe impacts on the health of the native riparian forests, in particular the water use of native *Eucalyptus largiflorens* forests (Eldridge *et al.*, 1993; Jolly *et al.*, 1993; Jolly *et al.*, 1996). In effect, the vegetation is suffering from water stress due to decreased water availability arising from increased soil salinity. The environmental importance of the Chowilla Anabranch was recognised under the Ramsar Convention in 1987 because it is the largest remaining area of natural riverine forest in the lower Murray valley.

Like tree health, water use of *E. largiflorens* varies depending on the salinity of the underlying groundwater, where transpiration rates vary between 0.3 and 0.4 mm d$^{-1}$ for individual trees overlying relatively non-saline groundwater (<30 dS/m) and between
The variations in transpiration are related to differences in water availability, where trees with access to relatively fresh groundwater utilise both groundwater and soil water (rainfall derived), whereas trees with access to saline groundwater almost exclusively rely on soil water for survival.

The dynamic hydrological environment at Chowilla has undergone significant change in the last 60–70 years. Since tree water use responses differ due to localised characteristics of water and salt, it is not unrealistic to consider that the stands have responded differently to these changes. An understanding of past plant water use responses would provide a better understanding of tree responses to better predict the future responses of the vegetation to either increasing salinity or the impacts of management actions.

Past plant water use chronologies have been constructed from tree rings in the Northern Hemisphere (White et al., 1985; Dawson, 1993; White et al., 1994). This technique is suited for ecological and hydrological reconstructions because the stable isotope composition of tree-ring cellulose is often a function of the local environment, where tree-ring characteristics differ annually in response to variations in the local environment. More specifically, the stable isotopes of water form part of the structure of cellulose that is one component of tree ring wood. Water sources of trees have been inferred from tree-ring cellulose (White et al., 1985; Dawson, 1993; White et al., 1994), hence yearly reconstructions of tree water sources can be established for the life-span of the tree or the length of the tree-ring chronology.

This method depends on sources of water having different isotopic compositions. Natural variations in isotopic composition arise because of isotopic fractionation caused principally by transport processes (Gat, 1981) and phase transitions through both the atmosphere and the lithosphere (Barnes and Allison, 1983). Evaporation enriches the source water in \( \delta^{18}O \), whereas snow-melt is depleted in \( \delta^{18}O \). Since the relative proportions of the fractionating processes are likely to be different for groundwater, stream water and soil water, different sources of plant water will often, but not always, have different isotope values. The difference in sources of water in Australian environments is much less than those from the Northern Hemisphere, where the sources of water have often been affected by snow-melt. These small differences in isotopic variability could complicate interpretation of the tree ring chronology in Australian environments. Analysis of \( \delta^{13}C \) of tree ring cellulose complements water source studies in that it can provide an insight into plant functioning and water status of the local environment, where a more positive \( \delta^{13}C \) indicates lower availability of water (Livingston and Spittlehouse, 1996; Saurer et al., 1997).

If *E. largiflorens* has become more reliant on groundwater since river regulation, then the isotope signal of the tree ring cellulose would become more negative over time, since the groundwater stores are naturally more negative than water stored in the upper soil profile. Further, as a result of the decrease in plant water availability due to river regulation, the \( \delta^{13}C \) of the trees will become more negative over time.

**Methods**

**Site description**

The study was conducted on the Chowilla Anabranch of the Murray River in eastern South Australia (140°52′E 33°59′S). The Chowilla Anabranch is an area of approximately 200 km² and is semi-arid with mean annual rainfall of approximately 260 mm and mean annual potential evaporation of 2,000 mm. The soil in the area is grey cracking clay, which typically extends to 2 m depth, overlying an alluvial sand aquifer which reaches a depth of approximately 30 m (Hollingsworth et al., 1990). The clay layer has a very low hydraulic conductivity as a result of its sodic and swelling nature (Jolly et al., 1994) and the saline 0.04 and 0.1 mm d⁻¹ for individual trees overlying saline groundwater (= 60 dS/m) (Thorburn, 1993; Streeter et al., 1996).
Groundwater (20,000–40,000 mg L⁻¹ total dissolved salts) generally resides within the sand aquifer with the water table found between 2–4 m below the soil surface.

Two field sites differing in salinity were selected for this study (Table 1). The δ¹⁸O composition of stream water is in the range of +6 to −5‰, groundwater is in the range of −2 to −6‰, and water stored in the soil profile ranges between 0 to −6‰.

Sample preparation
Radial slices were cut from two *E. largiflorens* trees, one from the saline site and the other the fresh site. One tree was investigated per site given the exploratory nature of this research, the cost of analysis and the need to collect whole stem sections. The central heartwood of the Saline tree was missing due to termite attack and this tree also only had live cambium and active sapwood present around half of the stem circumference. Flood and non-flood years were identified for both tree ring chronologies based on river flow records. The number of rings per sample varied from one to five, depending on the sequence of flood and non-flood rings. Alpha-cellulose was extracted from these samples following the methods described by Leavitt and Danzer (1992). This process involved a series of solvent extractions followed by acid washes.

Table 1 Site characteristics of the field sites investigated. The salinity of seawater is approximately 60 dSm⁻¹

<table>
<thead>
<tr>
<th>Site</th>
<th>Groundwater salinity (dSm⁻¹)</th>
<th>Soil saturation (weeks per year)</th>
<th>Leaf area index (m²m⁻²)</th>
<th>Site elevation (m above AHD)</th>
<th>River flow required for inundation (Gl day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline</td>
<td>55</td>
<td>&lt;1</td>
<td>0.6</td>
<td>20.6</td>
<td>77–82</td>
</tr>
<tr>
<td>Fresh</td>
<td>18</td>
<td>6</td>
<td>0.9</td>
<td>19.4</td>
<td>62–77</td>
</tr>
</tbody>
</table>

*Source* Eldridge *et al.* (1993)
Stable isotope analysis

The carbon and oxygen stable isotope ratios were determined from the alpha-cellulose samples, following the online methods described by Farquhar et al. (1997). The isotope results are presented as delta values (δ\(^{13}\)C and δ\(^{18}\)O) in parts per thousand (‰) where:

\[
delta(\%e) = \left(\frac{R_{\text{cellulose}}}{R_{\text{standard}}} - 1\right) \times 1,000
\]

R is the ratio of the heavy to light isotope. The defined international standard for δ\(^{13}\)C is V-PDB (Pee Dee Belemnite), and the defined international standard for δ\(^{18}\)O is V-SMOW (Standard Mean Ocean Water). Precision of the analyses is estimated to be ±0.5‰ for δ\(^{18}\)O and ±0.1‰ for δ\(^{13}\)C.

Results and discussion

In order to produce an isotopic chronology from tree rings, it is necessary to determine the periodicity of ring growth. Babourina et al. (in prep.) undertook an investigation of the periodicity of tree ring production for both the Saline and Fresh tree at Chowilla. The findings of this study indicated that tree ring production was annual.

Figure 2 depicts the trend in δ\(^{18}\)O for the Saline and Fresh trees, along with the expected ranges if the trees utilised soil water or groundwater and the year Lock 6 became operational. Some interesting trends were observed that relate to development of the root system and the utilisation of different water sources.

Within the first 15–20 years of growth for the Fresh tree, the δ\(^{18}\)O signal progressively becomes more negative and then oscillates between the soil water and groundwater ranges. The gradual downward trend during the first 15–20 years is possibly reflecting the development of the root system and the establishment of deep roots that can access groundwater. This pattern is not observed in the Saline tree although, as mentioned in the methods section, the centre of the tree was decayed and therefore the first 15–20 years of growth are likely to be missing in this chronology.

![Figure 2](https://iwaponline.com/wst/article-pdf/48/7/113/423570/113.pdf)

**Figure 2** Trends over time for the δ\(^{18}\)O of tree ring cellulose for the Saline and Fresh trees. The line on the chart indicates the construction of Lock 6 (a flow control weir located upstream of the study sites). The x-error bars indicate the span of years included in each sample. Hume Dam, an upstream storage of 1,520 GL, was completed in 1936 and enlarged to 3,040 GL in 1961.
The tree ring isotope chronology of the Saline tree becomes depleted in $\delta^{18}$O over time. This trend indicates increasing groundwater use, since the groundwater is more negative than rain-derived water stored in the upper soil profile. It would seem that this chronology conflicts with current knowledge of water use strategies that are employed by Saline trees during the 1990s, where Saline trees were not utilising groundwater at any of the sampling times. However, during 1992–1993, the average $\delta^{18}$O for the Fresh tree was approximately 1–2‰ more positive than that of the Saline tree (Thorburn, 1993; Streeter et al., 1996). When average values are compared, these data are consistent with the tree ring isotope data. It is important to remember that the tree ring isotope chronology is an average value over one or several years and may not reflect the extent of seasonal variability.

The isotopic chronology of the Fresh tree is slightly more positive since construction of Lock 6. This suggests that the Fresh tree has not altered its water use strategies. The positive shift could reflect changes to the isotopic composition of river water due to regulation and the fact that the Fresh tree is in a zone of freshening where the groundwater is being recharged by the fresher stream water. River regulation is likely to have caused enrichment of river water due to mixing of water from different seasons and years in dams and other water holding structures.

There is no discernable difference between flood and non-flood samples. Modelling of tree characteristics by Slavich et al. (1999) suggests that tree responses to flooding can continue over many years. Given this scenario, it is perhaps not surprising that short-term responses were not observed in the sampled tree ring sequences.

Analysis of $\delta^{13}$C of tree ring cellulose complements water source studies in that it can provide an insight into plant functioning and water status of the local environment, where a more positive $\delta^{13}$C indicates lower availability of water (Livingston and Spittlehouse, 1996; Saurer et al., 1997). It was anticipated that $\delta^{13}$C from the tree ring chronologies at Chowilla would become more positive since river regulation. Recent studies at the Saline and Fresh locations at Chowilla have identified differences in the water status of the soil and trees due to salinity and availability of water (Eldridge et al., 1993; Akeroyd et al., 1998). The analysis of $\delta^{13}$C from the tree ring chronologies of the Fresh and Saline trees also indicates differences in water status between the trees, consistent with the theory that increasing water availability will result in a more negative $\delta^{13}$C signal (Figure 3). Interestingly, there is no obvious change in $\delta^{13}$C due to river regulation.

The $\delta^{13}$C trend for the Fresh tree initially mimics the $\delta^{18}$O signal, where there is a gradual decrease within the first 15–20 years. Again, this is consistent with the expectation that the groundwater, if fresh enough, is a reliable source of water that creates a high water

![Figure 3](https://iwaponline.com/wst/article-pdf/48/7/113/423570/113.pdf)
availability environment for plant growth. Since there are no historic records of measured water availability at Chowilla that match the tree ring chronology, modelled simulations of water availability from the WAVES model (refer Slavich et al., 1999, for a full description), were used to determine the correlation between $\delta^{13}C$ and tree water availability (excluding groundwater). Surprisingly, the relationship between $\delta^{13}C$ and water availability was weak ($R^2 = 0.56$, Figure 4). Despite the weak relationship between water availability and $\delta^{13}C$, Figure 4 quite clearly demonstrates that the Fresh site has a much higher water availability than the Saline site.

**Conclusions**

The analysis of stable isotopes from tree ring cellulose of *E. largiflorens* has provided an insight into the water use response of these trees over a time period where significant hydrological changes have occurred. The findings of this research highlight some interesting growth responses of *E. largiflorens*, for example, it takes 15–20 years before the root system is able to access the groundwater. Further, once the root system is able to access relatively fresh groundwater, the tree predominantly relies on the water stored in the upper soil profile for growth and survival.

There were some subtle changes in water use in relation to altered flow regimes and floodplain hydrology resulting from regulation. The $\delta^{18}O$ chronology indicated that the Saline tree was utilising water deeper in the soil profile after regulation, possibly even groundwater in some instances. There was a slight positive shift in $\delta^{18}O$ with respect to the Fresh tree, however, this did not reflect a change in water use strategies. It is important to remember that the tree ring data is an average over one or several years, in contrast to present day studies of water use that look at seasonal changes in water use and possibly much greater fluctuations between utilisation of different water sources.

The $\delta^{13}C$ chronology further reinforces the difference in water availability between the Saline and Fresh site, however, there were no real trends observed with respect to river regulation. This is surprising given the enormous changes to water movement resulting in decreased availability of water to trees in saline areas of the floodplain.

In conclusion, no definitive responses to the hydrological changes resulting from river regulation were observed. While on the one hand this is somewhat of a surprise, it is well acknowledged that floodplains are complex environments which is why research is being undertaken to understand floodplain processes and responses of the landscape.

![Figure 4](https://iwaponline.com/wst/article-pdf/48/7/113/423570/113.pdf)

**Figure 4** Relationship between $\delta^{13}C$ of tree ring cellulose and modelled water availability from WAVES (Water-Atmosphere-Vegetation-Energy-Solutes) described by Slavich et al. (1999). Water availability increases from 0 to 1
findings of this study have reinforced our awareness of the complexity that exists in floodplain environments, particularly between trees, soil, water and climate.

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