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A LANDSCAPE APPROACH TO UNDERSTANDING WATER USE BY TREES IN THE PILBARA REGION OF NW AUSTRALIA

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ABSTRACT

The natural abundance of deuterium (^2H) within soil water, groundwater and plant sap has been useful in determining sources of water used by a range of plants species growing in deserts, savannas and riparian systems. This, combined with "heat pulse" methods for measuring amount and direction of sap flow, can estimate of the volume of water used by trees within the landscape with different water availability. Increasing extraction of groundwater by government agencies, the mining industry and pastoralists in the Pilbara has focused attention on the health and survival of riparian vegetation. However, there has been no quantitative analysis of the sources and availability of water to any species in the Pilbara.

Despite increasing industrial use, the role of groundwater in maintaining/supporting ecosystems is poorly understood throughout semi-arid Australia and limited to assumptions based on descriptions of plant communities. This paper summaries numerous detailed studies of the physiology of *Eucalyptus* and *Acacia* spp. at Hamersley and Marillana Stations in the Pilbara. We used a landscape approach to assess plant responses to a gradient of water availability, where depth to groundwater increased with distance from creek-lines. Species growing in creek-lines used both soil and groundwater, but the source was dependent on season. The implications of these finding are discussed in terms of possible changes in plant communities, in response to changes in water availability resulting from a disturbance.

INTRODUCTION

Both the short- and long-term availability of water affect the physiology and hence distribution of arid and semi-arid plants. The large variation in life-form, anatomy, morphology and physiology among these communities can be traced to variation among species in their dependence on groundwater or soil water (e.g. Dodd *et al.* 1998). In semi-arid rangelands the water content of surface soil fluctuates due to evapotranspiration while deeper soil layers are buffered by recharge.

Increasing extraction of groundwater by government agencies, the mining industry and pastoralists in the Pilbara has forced attention on the health and survival of riparian vegetation. There are also concerns that interruption of sheet flow (e.g. roads and railways) has contributed to the decline of some species owing to a perceived dependence on soil water. However, there are no quantitative analyses of the sources of water used by these species or, in fact, of the availability of water to any species in the Pilbara. Despite increasing use of groundwater, its role in maintaining and supporting ecosystems is poorly understood throughout semi-arid Australia (Hatton and Evans 1998) and limited to assumptions based on descriptions of plant communities in relation to where they grow in the landscape (e.g. Masini 1988).

Understanding the effects of changes in hydrology on species composition will only be improved if we can establish where different species access water and to what extent they depend on soil water and or groundwater. Clearly, alteration of these sources following disturbance can affect survival and hence species composition and possibly impact local biodiversity.

METHODS

We compared drought stress and the sources of water used by different species growing at Hamersley Station in the Pilbara region of north-western Australia. Species were examined among seasons between 1996 and 1999 at sites within a creekline (*E. victrix, E. camaldulensis, A. citrinoviridis*), a floodplain (*A. xiphophylla, A. aneura*) and hill-slope (*E. leucophloia, A. xiphophylla, A. aneura*). The dependence of riparian species (*E. camaldulensis, M. argentea*) on groundwater was inferred from additional studies of tree water use at Marillana Station in 2000. Sites were selected that differed in depth to groundwater that in turn depended on the distance to dewatering bores used to pump water from nearby mining pits.

Estimates of the availability of water to trees, such as shoot water potential and stomatal conductance (Turner 1981) and isotopic signals of water ($\delta\,^2H$), which depend on ratio of ^2H to ^1H, were used to determine the sources of water available to trees (Flanagan and Ehleringer 1991). These techniques, in conjunction with a recently modified heat pulse method (Burgess *et al.* 1998) that allowed estimation of the volume of water transpired by riparian species, helped to evaluate species dependence on groundwater.

Potential water sources in trees were identified by comparing the isotopic signature ($\delta\,^2H$) of rainfall, soil water and groundwater with the water collected from within roots and branches of trees. Soil samples (50 g) were collected at depth intervals of 25 cm to a maximum of 3 m and sealed in zip-lock plastic bags and stored in a freezer. In the laboratory, the water in frozen soil was cryogenically extracted (e.g. Dawson and Ehleringer 1998). Root systems of trees were exposed using a backhoe and hand tools. Branches selected from the canopy in full sun and leaves were removed immediately. Xylem water was extracted in the field by applying a mild vacuum to a container, using a hand pump, surrounding the cut end of a shoot or root.

RESULTS

Seasonal water availability was more variable for species growing on the floodplain and hill-slope than species in the creekline and, overall, less water was available to species on the floodplain and hill-slope compared to species growing in the creekline. The difference was most extreme in summer before cyclonic rains. However, following winter rains, water availability was greatest for all species regardless of where they grew. In the driest month of the study, the availability of water to *A. aneura* and *A. xiphophylla* on the floodplain was greater than the same species growing on the hill-slope. In contrast, the seasonal variation in the availability of water to creekline species was far less than the other species growing elsewhere in the landscape.

The sources of water used by the trees identified from isotopic analyses confirmed the extent and seasonality of water stress. Species on the floodplain and hill-slope did not have access to groundwater. Creekline species had access to groundwater since the δ^2H of water within branches and tap roots of *E. victrix* and *A. citrinoviridis* was similar to that of groundwater. The similarity was greatest before summer rains, and suggests these riparian species had access to water 21 m below the soil surface; however, after rain, water within 2 m of the soil surface was used. Generally, the δ^2H of water in shoots of *A. xiphophylla* and *A. aneura* on the hill-slope and floodplain were similar.

Widely distributed creekline species such as *E. camaldulensis* typically used around 80 L/day with little seasonal variation during wet years when the soil profile is saturated. It was difficult to determine if this water was mainly taken up by the tap root. *Melaleuca argentea* that is only found where water is permanent and close to the surface (< 2m) uses more water, typically greater than 120 L/day. It seems that diurnal cavitation within the xylem of roots reduces the actual volume of water transpired compared to the potential water use typically calculated at these sites, given the very dry conditions and permanent water that is available (Graham 2001).

DISCUSSION

Riparian species at both sites are probably similar to other riparian vegetation in that following rain they use moisture from surface layers of the soil profile (e.g. Sala and Lauenroth 1982, Ehleringer *et al.* 1991, Lin *et al.* 1996), switching to deeper sources as soil water is depleted (e.g. Thorburn *et al.* 1993). In contrast the floodplain species are dependent on the soil water and therefore strongly influenced by rainfall. This suggests that riparian species may be susceptible to dewatering, On the other hand floodplain species that rely on sheet flow (e.g. mulga within groves) may also die if roads and railway lines alter drainage patterns, though it is likely that this may be restricted to one grove.

Woody species extract water from deeper in the soil profile than grasses (Knoop and Walker 1985, Walker and Brunel 1990, Le Roux *et al.* 1995, Sala *et al.* 1997). As a result of this "two-layer system" it is perhaps not surprising that woody species may actually be less tolerant of drought than grasses (e.g. Soriano and Sala 1983). Modelling over long-time scales suggest that increasing summer rainfall will favour grasses while winter rainfall will favour shrubs/trees (Weltzin and McPherson 1997). A "two-layer system" thus helps explain the co-dominance of *Acacia* spp. and grasses in semi-arid regions of Australia.

A. xiphophylla survive on soil water stored within the massive clay profile of cracking clays (perhaps greater than 2 m depth) while groves of mulga (*A. aneura*) access water deep within the grove. The dry surface soils and deeper wetter soil may generate hydraulic lift where water is brought from deeper parts of the profile to soil closer to the surface, which may assist shallower rooted species. This water that is additional to rainfall may help explain the importance of these plants to the overall function of systems that possibly support other vegetation.

The ability to switch from groundwater to soil water, when available, has been noted for other phreatophytic species. Phreatophytes in semi-arid regions, like all shrubs and trees in dry environments, probably take up most nutrients through fine lateral roots, following pulses in the availability of nutrients that follow rains. The switch between groundwater and soil water is also important for nutrient availability, though this is often overlooked in hydrological studies (e.g. Dawson and Ehleringer 1991).

Long term dewatering in an area has the potential to alter the species composition of riparian systems and may favour shallow-rooted grasses and shrubs not dependent on groundwater. The coarse nature of these soils, however require a high degree of drought tolerance. These species are likely to be transient as they will be flushed from the creeklines following heavy rains and flooding.

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