CARBON AND WATER FLUXES OF TREES

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INTRODUCTION

Trees are important components of landscapes, whether that is in an urban, rural or wilderness landscapes. Their importance includes their economic, biodiversity, conservation, ecological, aesthetic and spiritual value. Although their economic value as sources of timber is well understood, their broader economic value through provision of ecosystem services remains poorly recognized (Eamus et al. 2005). Examples of ecosystem services that are provided by trees, woodlands and forests include stabilization of soil through their root system, absorption of carbon dioxide in the mitigation of climate change, transpiration of water to offset flooding and salinity risks and the cooling effects of canopies of trees in urban landscapes.

Carbon uptake is required for tree growth, and even mature, non-growing trees absorb carbon dioxide each day. The process of carbon uptake during photosynthesis is always associated with transpirational water loss from leaves and an understanding of how these two processes respond to changes in the environment is central to understanding how trees may respond to climate change.

The aim of this presentation is to present daily and seasonal patterns of carbon and water fluxes of some native woodland trees and then to discuss how climate change may impact on these processes.

METHODS

Two methods of measuring tree water use and canopy water and carbon fluxes were used. In the first, sapflow sensors (Fig. 1a) were used to measure the rate of flow of water up the stem of individual trees. In the second, eddy covariance methods were used (Fig. 1b). Descriptions of these methods can be found in Eamus et al. (2006). The data presented in this talk are derived from studies undertaken in the Northern Territory of Australia.

Figure 1 (a) Sapflow sensors measure the velocity of a heat pulse moving up the stem of trees. Eddy covariance towers have equipment to measure wind speed, wind direction, water vapour concentration and CO_2 concentration above canopies. From these measurements the flux of C to the canopy and water from the canopy can be calculated.

RESULTS AND DISCUSSION

Rainfall in the NT is highly seasonal, with a pronounced wet season (November to March inclusive) when 90% of annual rainfall occurs (Fig. 2). In contrast, the daily potential rate of evaporation is relatively constant, varying between about 5 and 7.5 mm per day (Fig. 2). Because of the seasonality of rainfall, soil moisture content in the upper soil profile remains high in the wet season but declines in the dry season (Fig. 3). The cause of this decline is uptake of water by tree roots, surface evaporation and deep drainage which occurs early in the dry season.

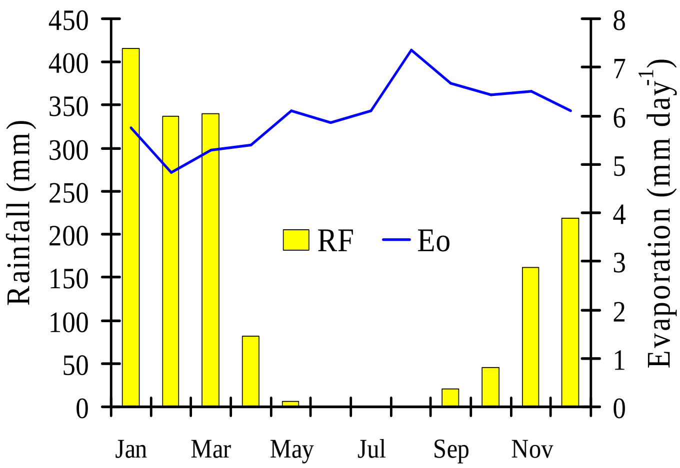

Figure 2 Rainfall is highly seasonal in the NT but evaporation rates are comparatively more stable. Data from Hutley et al. (2000).

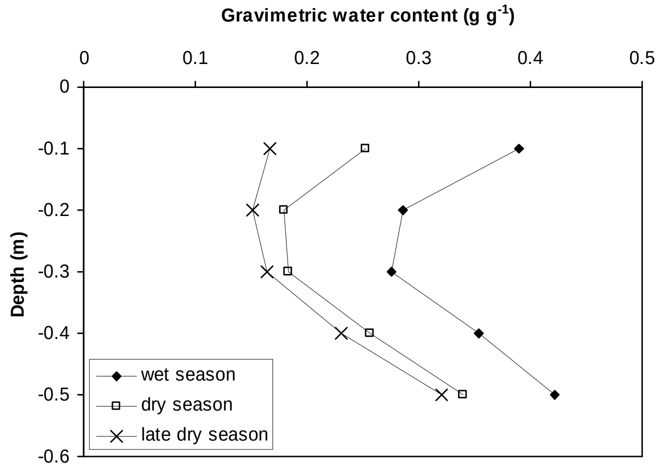

Figure 3 Soil moisture in the top 50 cm is high during the wet season but declines during the dry season because of uptake by trees, and also because of evaporation from the upper soil profile and also because of a percolation of water downwards due to gravity. Data from Kelly (2005).

The decline in soil moisture content of the upper 50 cm of soil, where most of the roots are located, is reflected in the change in pre-dawn leaf water potential (Fig. 4). Declines in pre-dawn water potential (moving away from zero to a more negative value) are indicative of declining soil water availability and reveal the development of increasing levels of water stress in the leaves as the dry season progresses.

It is interesting to compare the behaviour of two contrasting ecosystems, a eucalypt open forest (EOF) and a monsoon forest (MSF) in their response to the cessation of rains that occurs at the end of the wet season (Fig. 4). The decline in water potential of the eucalypt forest is much larger than that of the MSF because the MSF is found at low points in the landscape where surface and sub-surface run-on of water keeps the soil wet all year. This difference in behaviour is also reflected in the difference in response of the leaf area index of the two ecosystems (Fig. 5). Leaf area index is a measure of how much leaf is present in the canopy and it varies seasonally. As soil moisture content declines for long periods (weeks and months) leaf fall occurs and the leaf index of the canopy falls significantly in the eucalypt canopy.

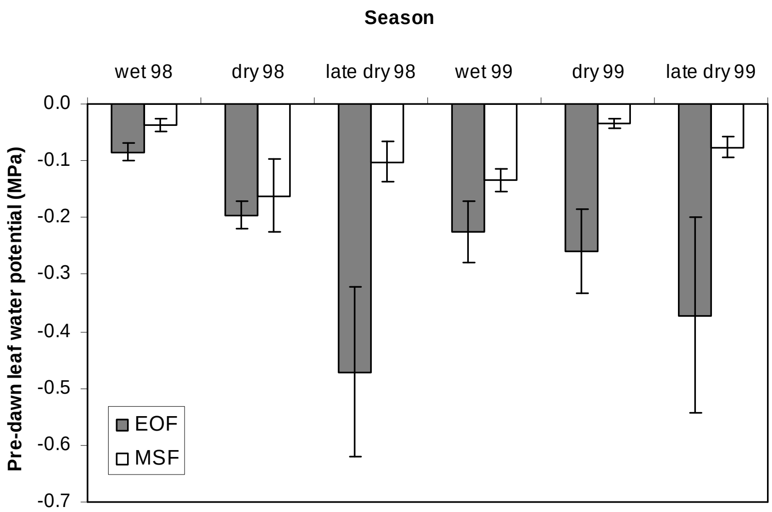

Figure 4 As the soil moisture content of the upper soil profile declines, pre-dawn leaf water potential declines from a maximum value observed in the wet season to a minimum value observed at the end of the dry season. Two ecosystems, a eucalypt open forest (EOF) and a monsoon forest (MSF) are compared in this figure. The decline in the eucalypt forest is much larger than that of the MSF because the MSF is found at low points in the landscape where surface run-on of water keeps the soil wet all year. Data from Kelley et al. (2007).

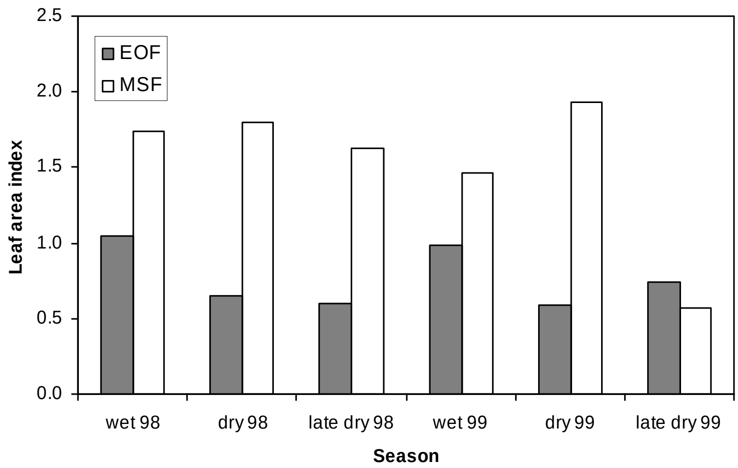

Figure 5 Seasonal changes (wet season to late dry season) in leaf area index of the tree canopy are very large for the eucalypt open forest, where changes in soil moisture content are also highly seasonal. In contrast, the change in LAI observed for the monsoonal forest (MSF) are much smaller because changes in soil moisture are much smaller. The large decline in the MSF in the late-dry of 1999 is because of a fire that passed across the site. Data from Kelley et al. (2007).

The two dominant species growing in the northern savannas around Darwin in the NT are *Eucalyptus tetrodonta* and *E. miniata*. These two species are evergreen and transpire all year. In some years, such as 1998, transpiration rates may be reduced in the dry season, but most often, there is no decline in transpiration observed between the wet season and dry season, as observed in 1999 (Fig. 6). This lack of seasonality in water use in the dry season has been observed across many years and is counter-intuitive. It occurs because of the ability of these evergreen trees to extract water from deep stores in the soil. These species extract water from up to 8 m depth. Despite the evergreen trees showing a reasonably constant rate of transpiration between the wet and dry seasons, (averaged over many years) there is a highly consistent and large decline in the rate of carbon uptake by savannas in the dry season (Fig. 7). This is the result of three factors. First, the annual C4 grasses that have a very high leaf area index in the wet season, die in the first month of the dry season and stop fixing carbon. Second, the deciduous trees lose their leaves in the first month of the dry season. Consequently, the amount of green leaf that is fixing carbon in the dry season is much less than that seen in the wet season. Finally, as the dry season progresses, the soil moisture content declines and there is some closure of stomata even in the evergreen trees. This further reduces the ability of the savanna ecosystem to fix carbon, as shown in Fig. 7.

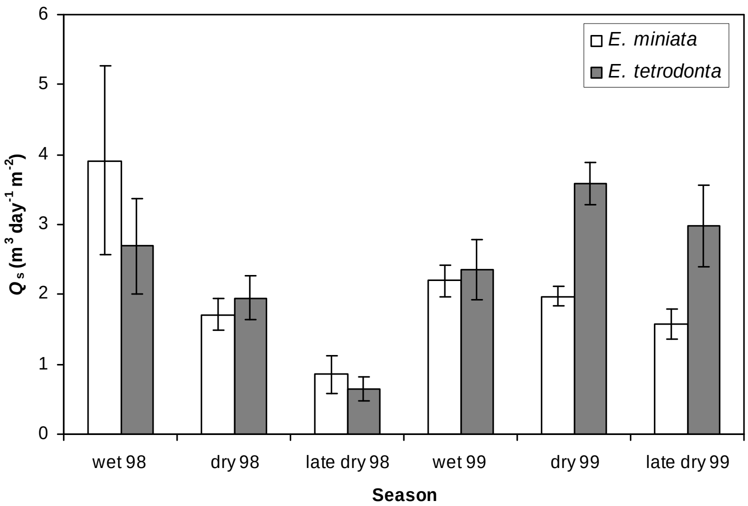

Figure 6 The dominant evergreens in the northern savannas of the NT of Australia are *E. miniata* and *E. tetrodonta*. In some years (for example 1998) they may show a reduced rate of transpiration in the dry season, but in most years they do not show such a decline (for example 1999).

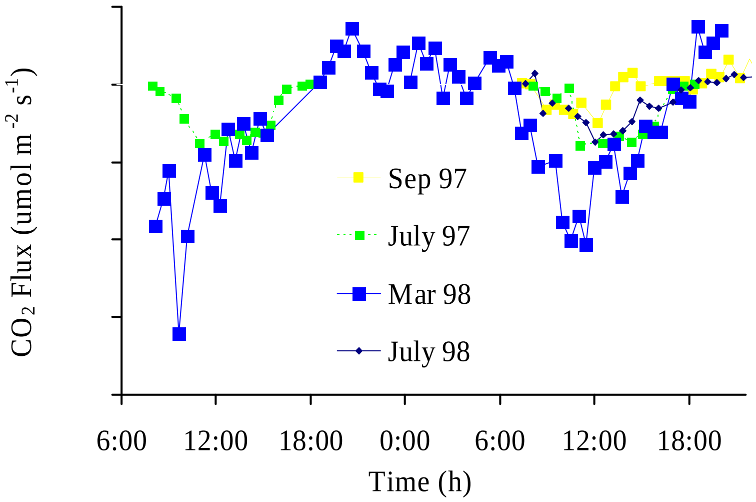

Figure 7 Canopy-scale fluxes of carbon to savannas shows a strong diurnal and seasonal pattern. Photosynthesis is largest in the morning when temperatures are not too high and evaporative demands not too large. They are also largest in the wet season (March) and smallest in the dry season (July and September) when soil moisture is low and the annual grasses have died and the deciduous trees have lost their leaves. Data from Eamus et al (2001).

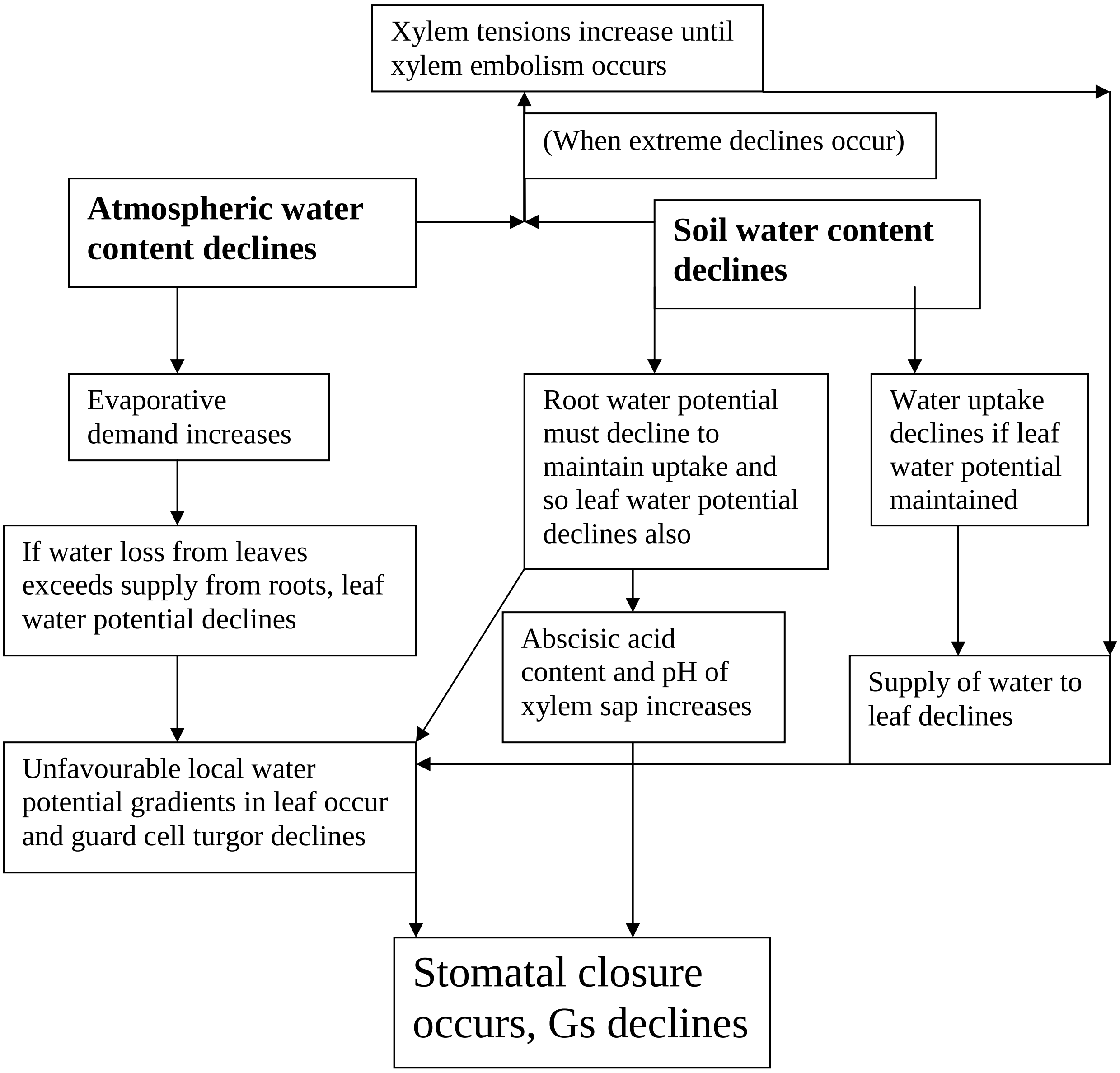

Figure 8 A schematic of the mechanisms linking reduced soil or atmospheric water content with reduced stomatal aperture and conductance (Gs).

The importance of soil moisture and atmospheric water content (RH) to the behaviour of leaf physiology is highlighted in Figure 8. This figure shows how these two factors combine to reduce stomatal conductance and hence water loss and carbon uptake. This pattern of responses is observed almost universally across all trees of Australia, whether they are growing in urban, rural or wilderness landscapes.

Predicting the effect of climate change on water and carbon fluxes presents many challenges. A large experiment being conducted in NSW by a consortium of UWS, UTS, UNSW and NSW Primary Industries is growing 12 trees from seedling to 6 y age under CO_2 enriched conditions with two levels of water supply. The aim of this work is to validate a process based model of tree growth and function under future climate scenarios. At the moment it is likely that the increase in carbon dioxide concentration within the atmosphere is already having an impact on the amount of carbon being taken up by Australian landscapes into vegetation. The reduction in stomatal conductance that invariably arises in response to an increase in atmospheric CO_2 concentration in broadleaved species increases water-use-efficiency and this, coupled to the increased C uptake, may be causing significant increases in tree cover in native woodlands of Australia. The biggest unknown at the moment is the impact of climate change on the fire regime of Australia. Changes in fire frequency, fire intensity and the timing of fires, is likely to have a major impact on the native vegetation of Australia.

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