Wandoo crown decline – the possible influence of environmental stress on tree physiology and condition

Final report of research carried out at the School of Plant Biology in collaboration with the Department of Environment and Conservation WA, and the Wandoo Recovery Group

Funding:
Linkage grant LP0347692 from the Australian Research Council
Department of Environment and Conservation
Wandoo Recovery Group
University of Western Australia

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Wandoo and its decline

Wandoo (*Eucalyptus wandoo* Blakely, white gum) is a widespread and ecologically valuable tree species of southwestern Australia. Wandoo occurs in valley floors of the jarrah forest belt, and in woodlands to the east of the jarrah forest, in what now constitutes the wheat belt of Western Australia. Mean annual rainfall in this region is generally 400-800 mm but can be as low as 300 and as high as 1100 mm. Wandoo grows, for Western Australian standards, on relatively fertile loamy to clayey soils, most commonly on valley slopes and floors. It usually grows in pure stands but may occur in association with several other eucalypts like jarrah (*E. marginata*), marri (*Corymbia calophylla*), powderbark wandoo (*E. acceden*s), York gum (*E. loxophleba*), brown mallet (*E. astringens*) and salmon gum (*E. salmonophloia*).

Wandoo is under threat from the phenomenon of ‘Wandoo Crown Decline’ (Veneklaas & Manning 2007). In its earliest stage there is foliage death on terminal branches (‘flagging’), which is often progressive, leading to tree death. Usually, affected trees produce epicormic branches, which may help to rebuild the crown, but if the condition of the tree is poor, these will also die. Wandoo crown decline was first observed in the 1980s, spread rapidly in the 1990s, and was found throughout the species’ distribution range in the first decade of the new millenium, when UWA scientists started to do research into the phenomenon. The current report summarises research performed at the School of Plant Biology, mainly funded through an ARC Linkage project, with a strong focus on tree water relations.

Over the past decades, rainfall in the Southwest of Western Australia has decreased significantly compared to long-term averages (Bates et al. 2007). The hydrology of the region, and certainly that of the catchments that contain wandoo, is such that groundwater recharge and runoff represent very small proportions of annual rainfall. As a consequence, relatively small reductions in rainfall can have much larger implications for groundwater and streamflow. In the Southwest of WA, a 10-15% decrease in rainfall since 1975 has already resulted in a >50% reduction of runoff (CSIRO South-West Western Australia Sustainable Yields Project; http://www.clw.csiro.au/publications/waterforahealthycountry/swsy/). Groundwater levels have decreased very significantly (Batini 2004; Kinal & Stoneman 2011). Forest and woodland trees of the region depend on stored soil water during the long dry summers, and a long-term decrease in rainfall is therefore likely to reduce the availability of water, and may affect tree condition and growth. In 2001, Researchers of the Department of Conservation and Land Management recommended that investigations into the water use physiology of wandoo should be a priority to enhance our understanding of wandoo crown decline (Wills *et al.* 2001).

Observations of borers and cankers in wandoo branches (Hooper & Sivasithamparan 2005) indicate that pests and diseases play a role in the phenomenon of Wandoo Crown Decline. The tree physiological research reported here was based on the premise that pests and diseases often take hold when trees are weakened by environmental stress. It was hypothesised that the most likely primary factor with a negative effect on tree condition would be the drying trend in the climate. Hooper (2009) provides a comprehensive report on biotic aspects of Wandoo Crown Decline.

Research background and aims

In May 2002, a project proposal was submitted to the Australian Research Council, by Chief Investigator Dr Erik Veneklaas (UWA Plant Biology) and Partner Investigators Dr John McGrath (CALM) and Dr Kingsley Dixon (Kings Park and Botanic Gardens). Funding was (partially) approved late 2002. Mid 2003, Dr Pieter Poot started as a postdoctoral research fellow on the project on a part-time basis. Ms Eleftheria Dalmaris started a PhD project with a scholarship provided by CALM and supplemented by the Cooperative Research Centre for Plant-based Management of Dryland Salinity.

The objective of the project was to identify ecophysiological mechanisms underlying Wandoo Crown Decline. It was proposed to carry out ecophysiological measurements to analyse the response of trees to environmental conditions, particularly drought stress, and identify site and tree factors that may predispose wandoo stands to crown decline.

Survey of populations

A large number of wandoo populations throughout the species’ distribution range were visited, with the aims of:

1. Correlating tree condition with a number of plant physiological indicators and soil indicators;
2. Assessing if there were any geographical patterns in Wandoo Crown Decline;
3. Collection of seed for experiments.

Locations were selected to represent the geographical and ecological range of the species. All populations were from sites with minimal disturbance, and small populations were avoided. Tree condition was assessed based on a method adapted from Landsberg & Wylie (1983) which scores individual trees on the basis of (1) previous canopy damage, (2) recent canopy damage, (3) recent canopy growth, (4) crown size, (5) crown density and (6) epicormic growth. At each site 12 randomly chosen adult wandoo trees, and 2 trees from co-occuring eucalypt species (where possible) were assessed. Seeds were collected from a minimum of five healthy wandoo trees at each location.

Wandoo condition varied from quite poor to quite good. There was no obvious spatial trend across the distribution (Figure 1), and no association with landscape position or management. At one location, where tree condition was worst, salinity was the obvious cause, which was confirmed by high levels of NaCl in the foliage (see below). Where other eucalypts co-occurred with wandoo, their condition was not correlated with that of wandoo. Poor health of wandoo sometimes coincided with good health of other eucalypts, and good health of wandoo sometimes coincided with poor health of other eucalypts (Figure 2). This indicates that the environmental factors affecting tree condition differ between species. There was no correlation between site health and annual rainfall. Annual rainfall, however, is not necessarily a good measure of the severity of drought during the critical summer period, when trees survive on stored soil moisture, which is influenced by factors like soil depth, soil texture, run-off and run-on.

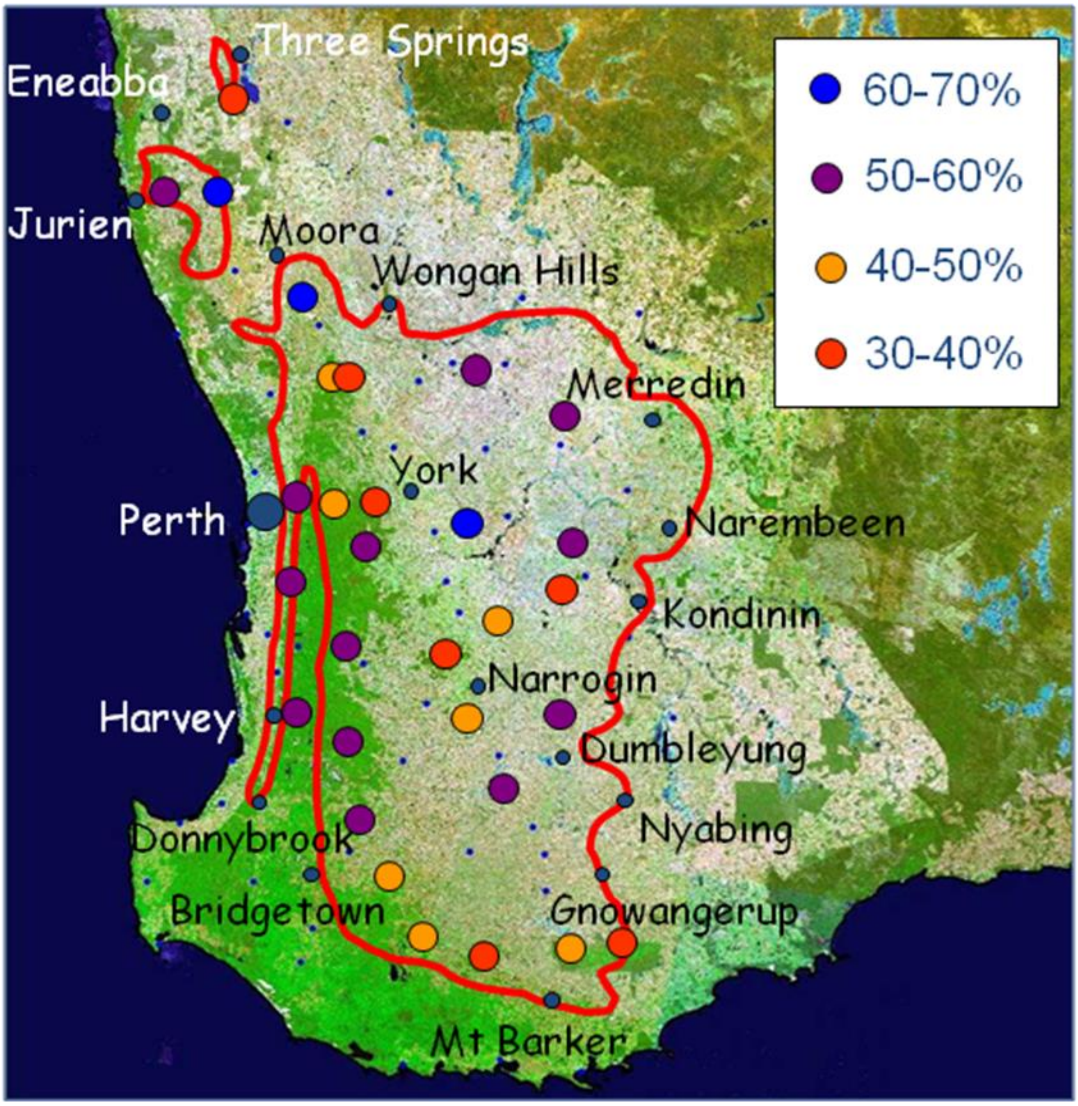

***Figure 1.** Distribution of* Eucalyptus wandoo *(red border) and the average condition of trees in selected woodland sites. Condition expressed as a percentage, where 100% indicates a dense, healthy crown.*

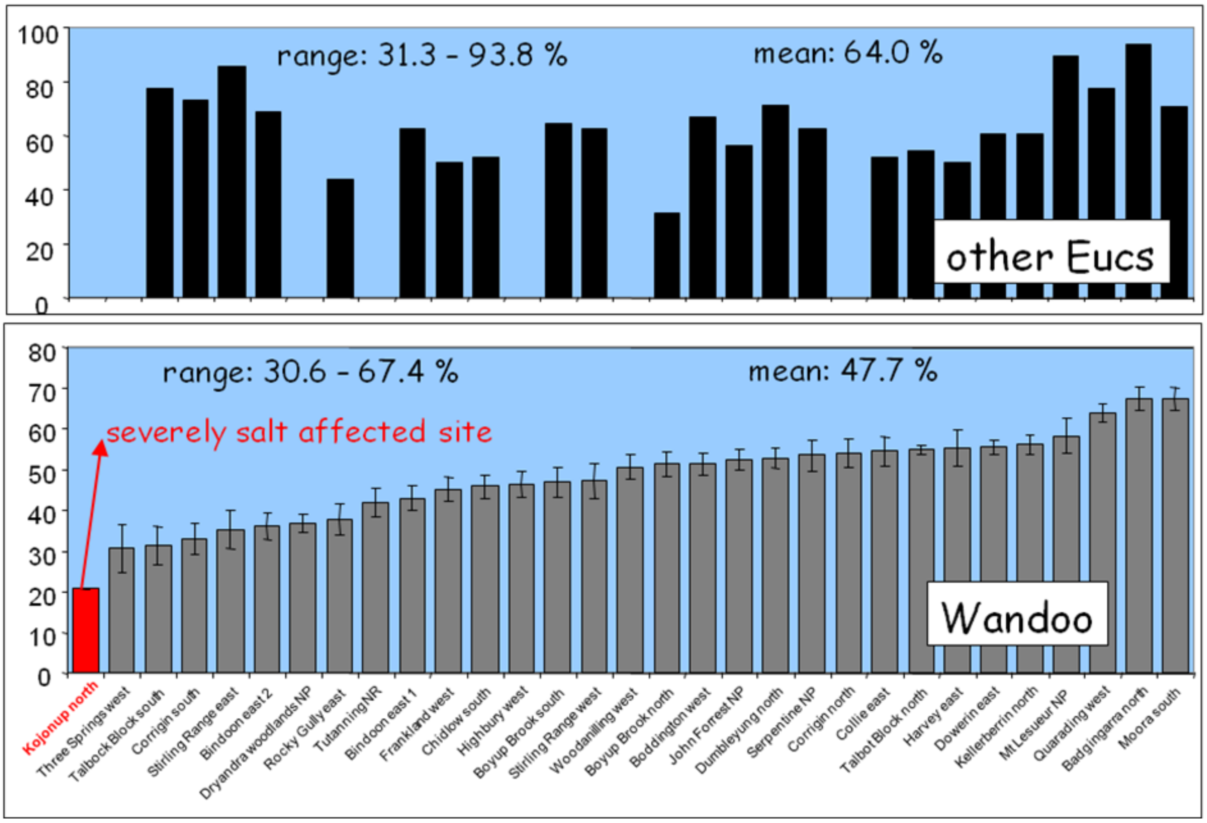

Figure 2. *Wandoo populations ranked by their health condition score (lower panel, health on vertical axis, in %), and comparative scores for other eucalypts co-occurring at these locations (upper panel). The co-occurring species varied between locations and included jarrah* (Eucalyptus marginata)*, marri* (Corymbia calophylla)*, powderbark wandoo* (E. accedens)*, York gum* (E. loxophleba)*, brown mallet* (E. astringens) *and salmon gum* (E. salmonophloia)*.*

Foliage sampled at all locations was analysed for the main mineral elements (N, P, K, Mg, Ca, Fe, Mn, Cu, Zn, S, B, Na). There were no strong correlations between tree condition and mineral concentrations, however there were significant relationships between health and Na (poorer health at high leaf Na concentrations), Fe and Zn (better health at high Fe and Zn concentrations) (Figure 3). However, good health was observed in some populations with Fe and Zn concentrations that were not particularly high. Moreover, the concentrations of Fe and Zn are similar to the typical concentration range found in forest eucalypts (Judd et al. 1996), and there were no symptoms of Fe or Zn deficiency (Dell 1996). There was no relationship between subsoil salinity (electrical conductivity 0.5-1 m depth) and foliage Na concentration. Foliage Na was high at one location affected by surface salinity, and low at two sites with annual rainfall exceeding 1000 mm.

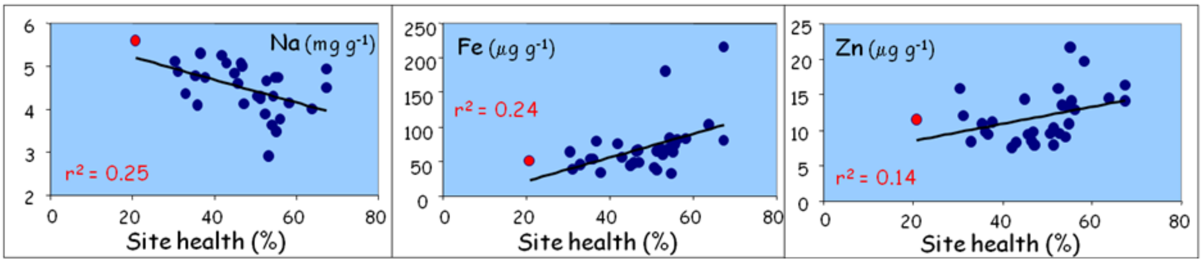

Figure 3. *Foliar concentrations of sodium, iron and zinc in wandoo sampled across its distribution range, plotted against the site health condition score. The red dot represents a site that was severely affected by surface salinity (see also Figure 2).*

Stable (non-radioactive) isotopes of carbon atoms are widely used as indicators of water use relative to photosynthetic carbon uptake. This assay was also carried out on the foliage samples of wandoo provenances. The relative amounts of the “normal” carbon isotope (atom mass 12) compared to the heavier isotope (atom mass 13) is usually expressed as $\delta^{13}C$. This value correlates with the mean concentration of CO_2 in the leaf while photosynthesis takes place, and is closely associated with stomatal opening. As has been observed for other species, including eucalypts (Schulze et al. 2006), $\delta^{13}C$ was less negative at locations experiencing lower annual rainfall (Figure 4a). This is explained by a lower average stomatal conductance, presumably due to poorer water availability and greater evaporative demand, requiring frequent stomatal closure. As site health was not correlated with annual rainfall, it was not surprising to find that there was no relationship between $\delta^{13}C$ and site health (Figure 4b). It is important to note that $\delta^{13}C$ is largely determined by conditions during foliage growth, which do not necessarily reflect the drier periods of the year.

Figure 4. *Carbon isotope discrimination ($\delta^{13}C$, in ‰) in leaves of wandoo sampled across its distribution range, plotted against the site annual rainfall (A) and site health condition score (B). The red dot represents a site that was severely affected by surface salinity (see also Figure 2).*

Genetics

Wandoo is a widespread species, with populations occurring over many hundreds of kilometers in the north-south and east-west direction, and covering a range of landscapes with different topography, soils and climate. Two subspecies, *E. wandoo* subsp. *wandoo* and *E. wandoo* subsp. *pulverea*, have been recognised, the latter representing the northern end of the distribution range, with a limited number of populations (Brooker & Hopper 1991). While large areas of wandoo woodlands (still) occur east of the jarrah forest and west of the wheatbelt, many other populations are spread around and have limited connectivity, even before large-scale clearing for agricultural land. Current DNA techniques are able to reveal genetic relationships between populations. This was attempted with the populations of wandoo sampled for the UWA project. The analysis is based on the DNA of chloroplasts in the leaves of wandoo. Chloroplast DNA inheritance is assumed to be maternal only, and is therefore not affected by pollen dispersal. Due to mutations that occur over long time spans, the DNA of a given population changes slowly. Thus, a population develops a “fingerprint” that is specific for that population, unless there is cross-breeding (mixing) with other populations. Similarity of the chloroplast DNA of two populations suggests that the two populations are genetically more related. While analysis of the chloroplast DNA does not provide information on levels of adaptation, it does give valuable insights in the history of the species and its genetic diversity. Such insights can support conservation and rehabilitation efforts, and help select populations to explore adaptive variation.

Chloroplast DNA analysis was conducted in order to identify the intra-specific variation of 26 wandoo provenances and the relationship between this genetic variation and the geographical distribution. Results indicate a geographically structured pattern of diversity. Among the 26 provenances there were 20 genetically separable “haplotypes”, which were separated into two main clades (Figure 5a). The first clade consists of 9 haplotypes representing 10 populations of the western margin of the distribution (Figure 5b), which includes the high rainfall area of the species, and appears to be the ancestral habitat. The second clade, which represents the other 17 populations, contains 13 haplotypes. The total haplotype diversity in the species, HT, was 0.918, which is higher than other south-western Australian species (e.g. *Eucalyptus loxophleba*, *E. marginata*; Hines and Byrne 2001; Wheeler *et al.* 2003). The haplotype diversity within populations, HS, was low, 0.222, and thus the majority of the haplotype diversity was found between populations (GST = 76%; the proportion of haplotype diversity between populations).

It is a common practice to choose germplasm within a population for revegetation purposes in order to enhance local adaptation. However, the criteria for defining local provenances are vague and increasingly questionable given climate change predictions. Phylogeographical studies identify patterns of variation reflecting evolutionary history and facilitate understanding of biotic responses to past climate change. This study has identified two lineages in wandoo, with the basal lineage in the western more mesic area indicating that this was the ancestral habitat. The inland lineage appears to have colonized, or re-colonized the area in more recent geological times. Contraction and expansion of species ranges is often related to climate change. The observed phylogeographic patterns may indicate that wandoo, due to its ecology and the characteristics of the habitat that it is adapted to, may have experienced fluctuations in its presence across the region. The current period of crown decline may represent the species' response to marginal conditions that, when they persist or get worse, could lead to a contraction of the species.

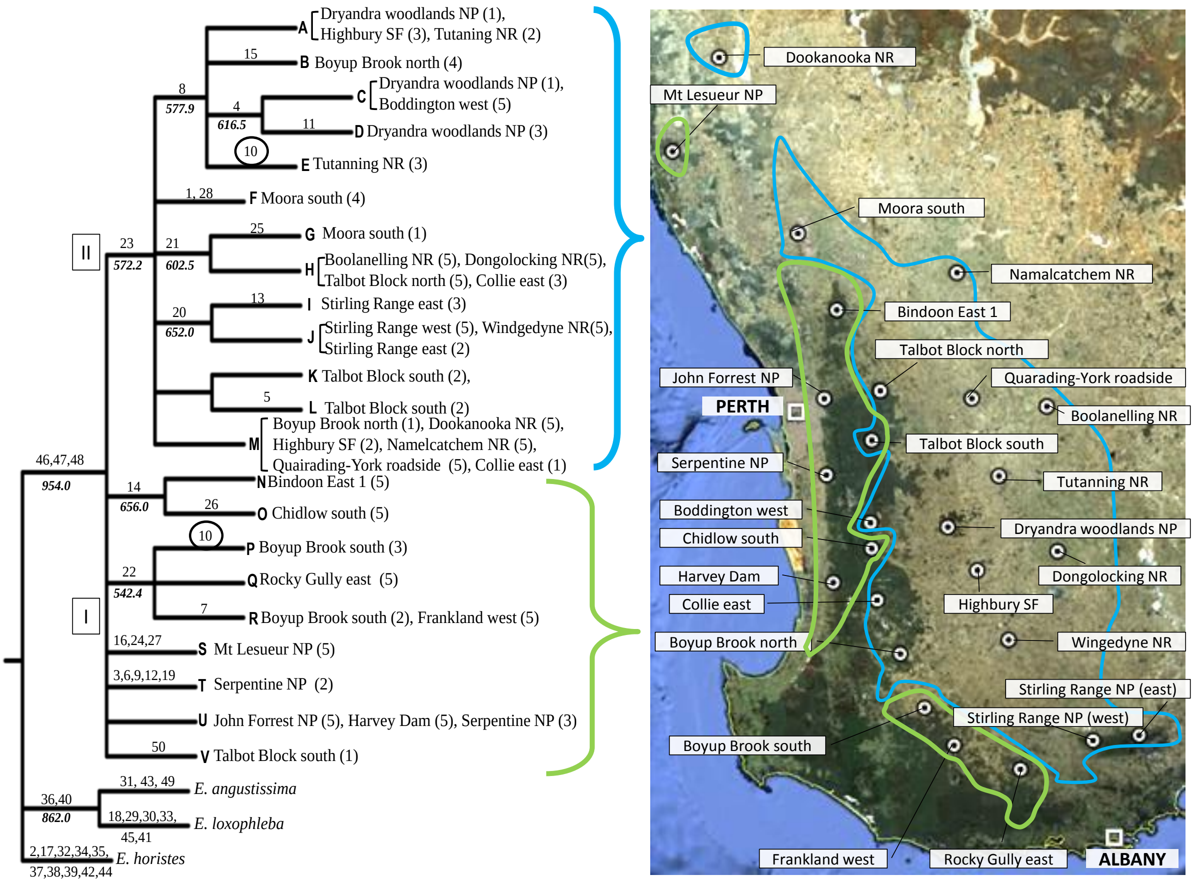

Figure 5. *Dendrogram indicating genetic relationships between wandoo populations as determined by markers in the chloroplast DNA. The two main groups (clades) are indicated with blue and green brackets, and their distribution on the map with lines of the same colours.*

Drought and salinity tolerance of populations

Genetic variation across the wandoo distribution range was further explored by exposing seedlings from all populations to two environmental stress factors, drought and salinity, which are common in the landscape where wandoo occurs. Seeds were germinated and seedlings grown in pots for several months in controlled environments (UWA greenhouses). In the drought experiment, in which plants were grown in a loamy sand, plants were allocated to a drought treatment (soil water content rewatered every second day to 45% of soil field capacity) or continued to be well-watered (rewatered to 90% field capacity). Growth and several physiological traits were measured. The same approach was followed for the salinity experiment, where one treatment was saline (200 mM NaCl, moderately saline, approx. 40% of seawater) and one was non-saline. The strength of the experimental approach is that all populations are compared in identical conditions. This is only feasible at the seedling stage, however most of the physiological mechanisms underlying tolerance to drought or salinity are expected to be similarly expressed in seedlings as in adult trees.

Drought reduced growth and led to the expected change in physiology in all plants. There was limited variation among populations in the response to drought, i.e. there were hardly any statistically significant differences in the measured traits between populations. The lack of statistical sigificance was partly due to unexpectedly large variation in the size of the plants, which also affected the intensity of the drought treatment. As the main ecological gradient across the wandoo distribution is related to water availability, and tolerance to drought was a focus in these experiments, populations were partitioned into groups for the purpose of analysis and presentation, based on an index of aridity. This index, AI, is defined as ratio of site annual rainfall and site annual potential evapotranspiration (UNEP 1992). AI was estimated based on interpolated climate data that were obtained from the Australian National Land and Water Resources Audit (http://www.environment.gov.au/land/nlwra/index.html).

In the drought experiment, plants from populations of greater AI (least arid sites) tended to be somewhat bigger than those of populations from drier sites. Water potential and stomatal conductance, however, did not show any trend (Figure 6). In the salinity experiment, water potential and stomatal conductance tended to decrease somewhat with AI (Figure 6). The responses to drought and salinity, as assessed by comparing the stressed plants and the controls, did not correlate with AI. This suggests that adaptation to drought and salinity, at least in juvenile trees, does not vary much between populations that originate from locations that are geographically far apart and ecologically quite distinct.

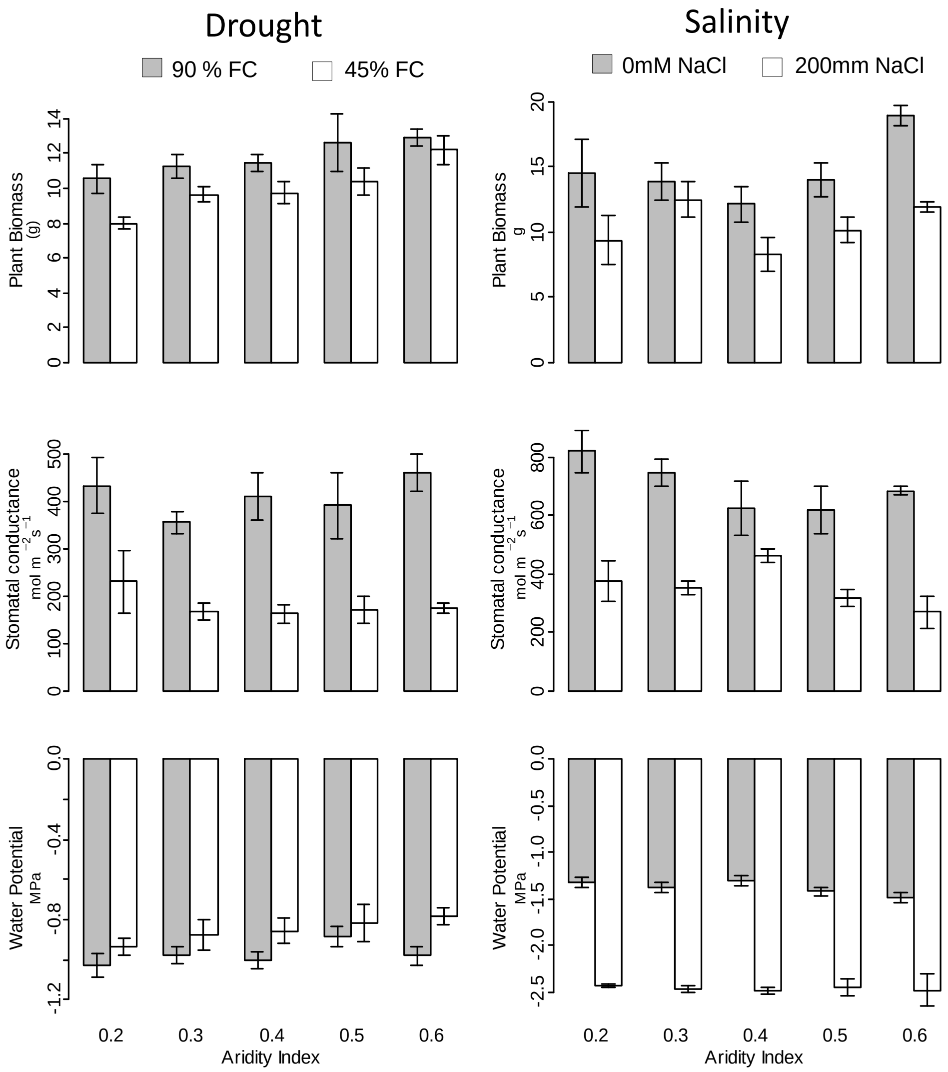

Figure 6. *Selected plant parameters for the experiments testing the tolerance of 24 wandoo populations to drought (left panels) and salinity (right panels). Effects on plant mass are relatively small as the treatment period comprised a short part of the growth period.*

Field-based tree water relations research

The project addressed the broad question if wandoo crown decline could be related to a drying trend of the climate. In the absence of long-term historical data, a comparison of current tree physiological indicators with the same indicators 1-3 decades earlier was not possible. It was also felt that a comparison of physiological indicators between healthy and unhealthy trees or locations would be fundamentally flawed. Local conditions are bound to differ in more aspects than water availability only. Moreover, trees adapt to changes in water availability, and most potential physiological indicators would not reflect impacts on the tree as a whole. Exploratory findings early in the project indicated that the remaining foliage on trees that had lost a considerable part of their crown had similar water status and water use compared to foliage of healthy trees. This observation may be interpreted as an adaptive loss of foliage, enabling better functionality of the remaining foliage.

The research strategy chosen was to quantify in detail how wandoo trees adjust their water relations to seasonal changes in water availability and diurnal variations in tree water requirement. An essential aspect of the strategy was the comparative approach: since all other eucalypt trees in the region are subject to the same changes in climate, but not all species are currently displaying crown decline, the key question is if there is any indication that wandoo might be more vulnerable to these changes.

The research required a core site where wandoo co-occurred with other eucalypts, and which was not affected by wandoo crown decline. A location was found in Julimar State Forest, where a gradient from sandy lateritic soil to clayey valley floors created a situation where wandoo, powderbark wandoo (*E. accedens*), jarrah (*E. marginata*) and marri (*Corymbia calophylla*) all occurred side-by-side. Three additional sites were selected to represent the optimal environment for each of these species; these sites were within a few kilometers of the core site and were pure wandoo woodland, powderbark wandoo woodland, and jarrah/marri mixed woodland.

Continuously recorded sap flow (upwards movement of water in the stem of the tree to replenish transpired water) shows different seasonal patterns for wandoo and powderbark compared to jarrah and marri at the mixed woodland site, but similar patterns for all species at sites where they are presumed to grow in their preferred habitat (Figure 7). Water use by all species is greater in summer than in winter, due to the greater evaporative demand (warmer and drier air) and radiation load. In the mixed woodland, however, jarrah and marri could not sustain the high rates from mid-summer to late autumn, as soils dried out in the absence of rain. These observations suggest that wandoo and powderbark had better access to soil moisture, either because of a larger or deeper root system, or because of a better ability to extract water at a given level of soil moisture.

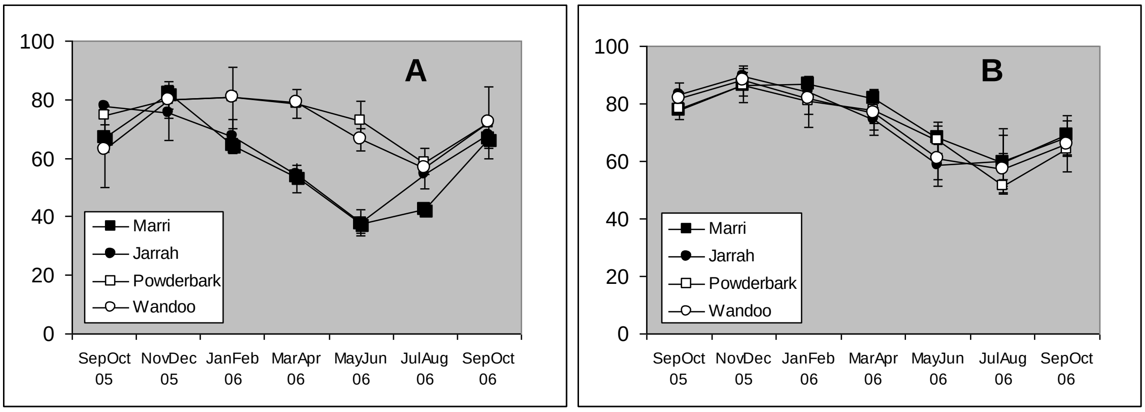

Figure 7. *Relative sapflow velocity of four eucalypt species on a site where they co-occurred (A) and on sites more typical for each individual species (B). Daily sapflow velocities of each tree between 9 am and 4 pm were averaged for 2-monthly periods and expressed as a percentage of the maximum 2-monthly average observed for that tree.*

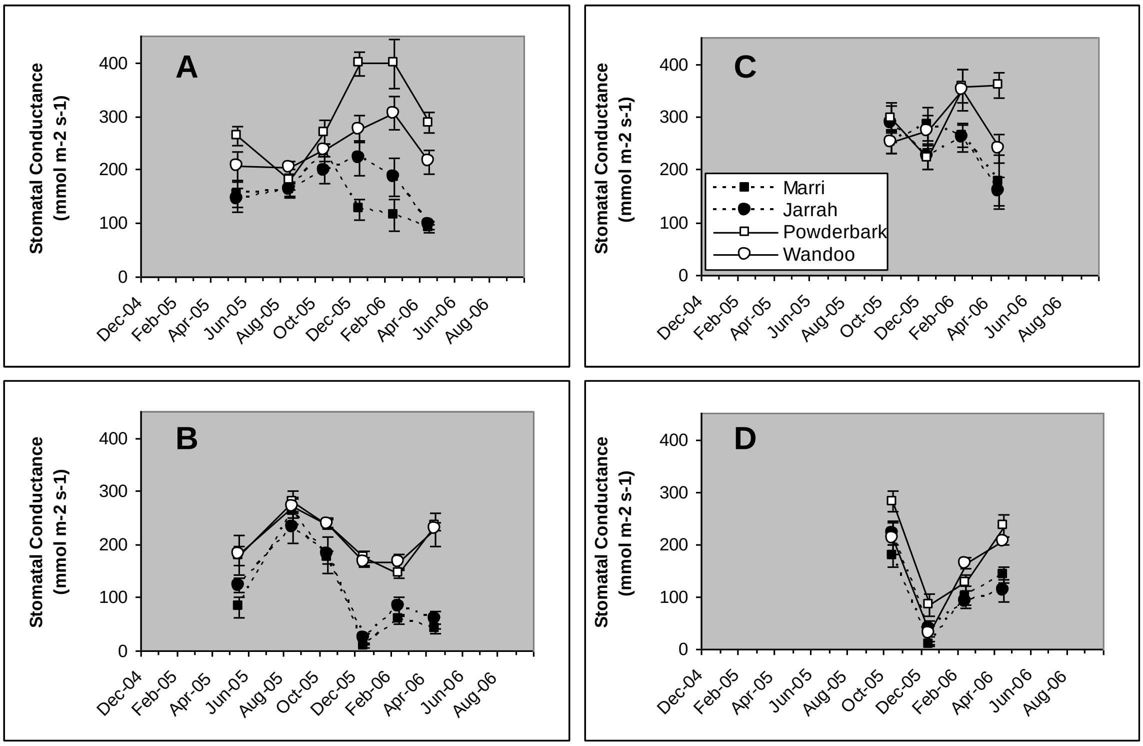

Figure 8. *Stomatal conductance in the morning (A, C) and the afternoon (B, D) for four eucalypt species on a site where they co-occurred (A, B) and on a site more typical for each individual species (C, D).*

Stomatal conductance (a measure of the degree of stomatal opening; Figure 8) of jarrah and marri was usually lower than that of wandoo and powderbark. Significant stomatal closure was observed in the summer and autumn months, particularly at the mixed site, consistent with the reduced rate of water uptake and transpiration. Presumably, jarrah and marri trees closed their stomata in order to avoid dehydration of the leaves, as they were unable to take up water from the soil at the required rate.

Observations of leaf water potential provide further insight into the availability of water to trees of the different species, and their respective water use strategies. Leaf water potential is a measure of the hydration (water content) of the leaf, and more specifically indicates the suction under which water is held in the leaf. It is this suction that drives the transport of water from roots to the foliage, and also from the soil to the roots. After several hours of darkness, when transpiration is negligible, leaf water potentials are assumed to be identical to root and soil water potential, i.e. they can be interpreted as a reflection of soil water content. Pre-dawn water potentials of wandoo and powderbark were strikingly different from those of jarrah and marri throughout the year (Figure 9), suggesting that the roots of wandoo and powderbark are located in soils that are drier or hold their water more tightly than soils of jarrah and marri. Values for wandoo were consistently lowest among the species. The data from the mixed woodland site are very similar to those of the single-species sites. As the trees at the mixed site are standing side-by-side, these contrasts indicate patchy distribution of water, patchy distribution of coarse and fine-textured soil, or different rooting depths. Belowground research is needed to elucidate these interesting species differences.

Contrasts in leaf water potentials were maintained during the day, resulting in much greater afternoon suctions (more negative water potentials) in wandoo and powderbark compared to jarrah and marri. Wandoo water potentials were lower than those of powderbark in mid-summer. These data clearly show that it was not a greater suction that caused the stomatal closure observed for jarrah and marri seen in Figure 8. Apparently, Jarrah and marri use water much more conservatively than wandoo and powderbark in this habitat. Wandoo and powderbark allow their leaf water content to decrease to much lower levels before they close their stomata. This pattern of water use and stomatal regulation is also evident during the diurnal cycle. On a warm and sunny day in December 2005, stomatal conductances were approximately twice as high for wandoo and powderbark than jarrah and marri, resulting in leaf water potentials that were twice as low (data not shown).

Drought effects on plants can make them more vulnerable to insect and pathogen attack. Hanks *et al.* (1999) showed that in particular wood-boring insects are associated with drought-stressed eucalypts. Hooper (2009) showed that declining wandoo trees were often affected by a native woodborer (*Cisseis fascigera*, Buprestidae). Further research is needed to determine if there is a causal link between reduced water availability and the presence of and damage caused by this borer.

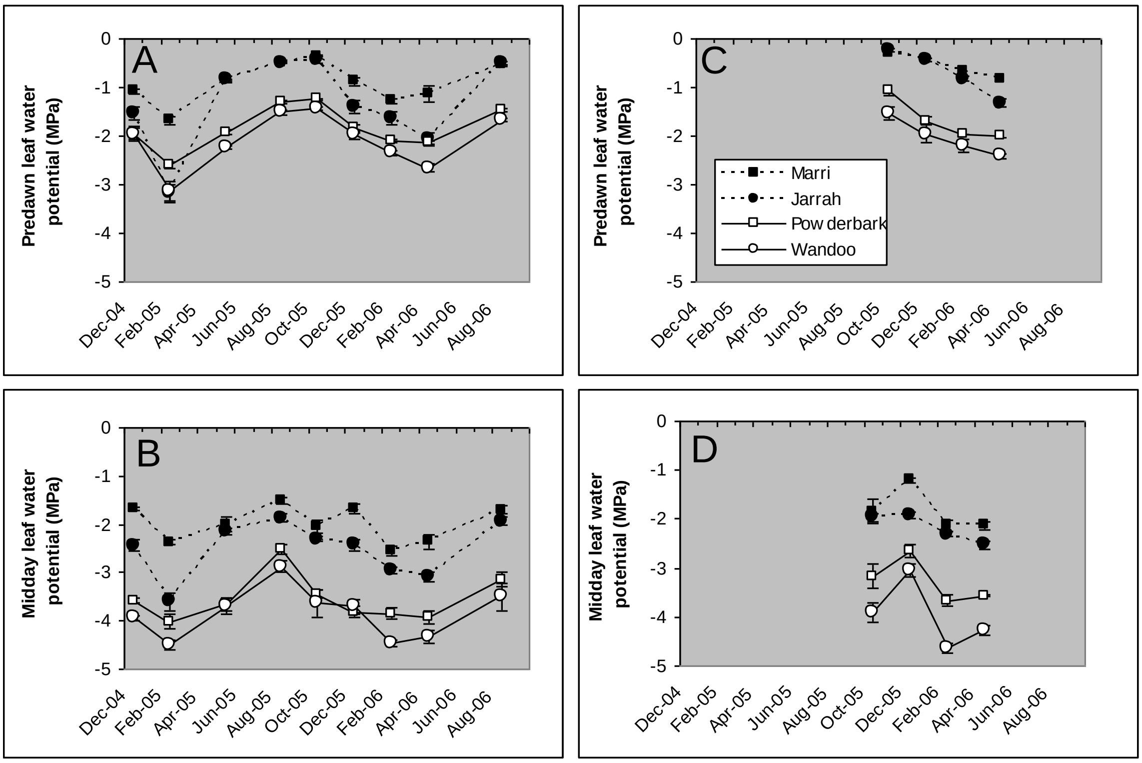

Figure 9. *Predawn (AC) and midday (BD) leaf water potentials for four eucalypt species on a site where they co-occurred (AB) and on sites more typical for each individual species (CD).*

In summary, field observations show that wandoo, but also powderbark, have a water use strategy that is quite distinct from two other important eucalypt species in the region. Wandoo and powderbark are able to extract water from soils that hold water more tightly. This ability is at least partly due to the tendency of wandoo and powderbark to keep their stomates open until they reach lower levels of hydration. A potential of this strategy is that hydration can reach values that are so low that leaf and stem function and hydraulic integrity are compromised. Laboratory analyses were carried out to determine the comparative vulnerability of the four species.

Vulnerability of leaves and stems to drought

Leaves have a characteristic relationship between their water content and their water potential, which is determined by characteristics like osmotic values and cell wall elasticity, and therefore influenced by physiological and anatomical factors. These relationships, which also determine turgor, were quantified for the four study species and are summarised in Figure 10. Turgor is the positive pressure that plant cells require for adequate functioning and for growth.

Due to a greater concentration of osmotically active solutes, wandoo and powderbark leaves have more negative water potentials when fully hydrated, and higher turgor values. Turgor declines as leaf water content declines, at rates that are roughly similar between the species, due to similar cell elasticity. An important consequence of the osmotic and elastic parameters of the species is that the critical leaf water content at which turgor is lost is significantly different among the species. Jarrah was found to lose turgor at 89% of full hydration, marri at 87%, wandoo at 85% and powderbark at 82%. Although these differences may seem small, they indicate that the most tolerant species can lose 40% more water than the least tolerant species before it loses turgor. These differences are correlated with the behaviour observed in the field. The species that allowed their leaves to reach more negative water potentials (stronger suctions, lower hydration) are clearly equipped to do so.

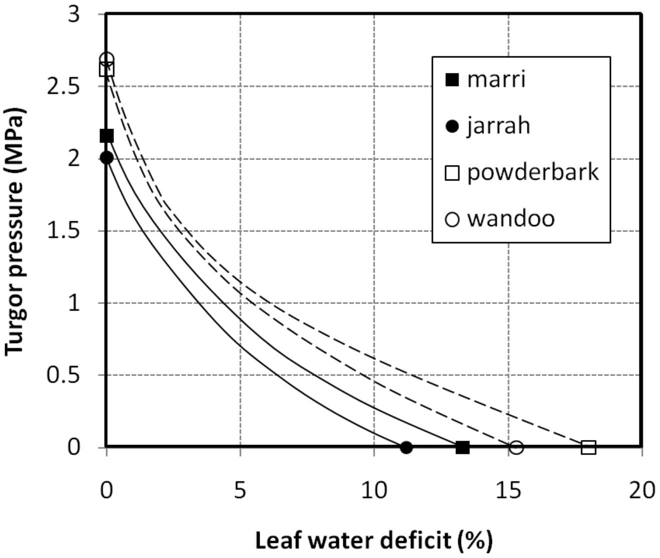

Figure 10. *Loss of turgor (positive cell pressure) in four co-occurring eucalypt species as leaves lose water.*

Similar to the leaves, stem functionality can also be compromised by great suctions. Water transport depends on continuous capillaries in the vessels of the sapwood. When suctions exceed certain critical values, air can enter in the vessels (embolisms), rendering them ineffective. Anatomical specialisations make some vessels more tolerant to strong suctions than others. Stems of the four species were tested in the laboratory to assess their vulnerability. Similar to what was found for leaves, species that in the field demonstrated conservative behaviour, and reduced water loss through stomatal closure to avoid dehydration, were those most vulnerable to hydraulic failure (Figure 11). Wandoo and powderbark, which seemingly took greater risks by allowing the development of much lower water potential, are in fact much less vulnerable to those lower water potentials. Loss of

50% conductivity, was reached at -1.3 MPa for jarrah, -1.5 MPa for marri, -3.2 MPa for powderbark and -3.4 MPa for wandoo. Comparison with measured water potentials in the field suggest that wandoo and powderbark, despite their lower water potentials, maintained higher proportions of functional vessels than jarrah and marri.

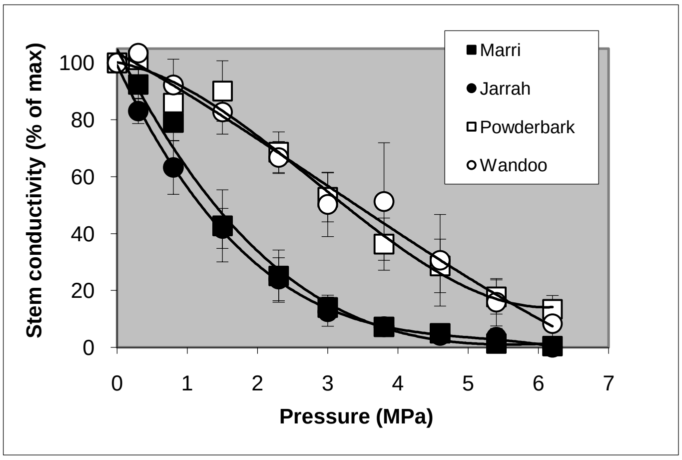

Figure 11. *Relative loss of stem conductivity of small diameter branches (4-9 mm) of four co-occurring eucalypt species. The positive pressure plotted on the horizontal axis corresponds with a water potential of the same magnitude but opposite in sign.*

In summary, wandoo and powderbark are less vulnerable to dehydration of stems and leaves than jarrah and marri. This is consistent with the generally drier habitats in which they are normally found, but also matches the different water use strategies observed for these species when growing at the same location.

Conclusions

Observations in the field and in the laboratory show that wandoo has clearly different patterns of water use and tolerance to dehydration compared to two other common eucalypts, jarrah and marri. Differences with powderbark are very small. Wandoo's tendency to keep stomata open for much longer while leaves and other tissues lose water is probably related to the need to develop great suctions in order to extract water from fine-textured soils. Fine-textured soil can hold much water, but this water is held very tightly. Wandoo appears to have evolved with a reliance on this source of water, and its regulation of water use as well as tissue tolerance to water deficits allow it to function well in these conditions. There may be a risk to this strategy if soil water storage is reduced, as wandoo would tend to deplete it too far. Reduced soil water storage, or reduced access for trees to this water, can be due to several factors, or combinations of factors. Long-term below-average soil recharge (due to climate change), rising saline groundwater (due to secondary salinity), excessive water use by the vegetation (e.g. due to changes in ecosystem processes or community composition), or biotic/chemical/physical factors impacting on root growth and function are examples of factors that can reduce water availability to wandoo trees. Research reported here was not aimed at demonstrating that locations experiencing wandoo decline have been exposed to greater reductions in water availability than healthy sites. Such a study would require large scale monitoring and is challenging due to the absence of historic data and the complexity of belowground soil-plant interactions.

Wandoo's strategy has allowed it to become a dominant tree in a large region, but the genetic analysis suggests that this has not always been the case. It is possible that the species' distribution was limited to the moister south-west in the past, possibly due to arid periods in geological times. Screening of wandoo provenances provided very limited evidence of ecophysiological differentiation across the distribution range. This may indicate that wandoo habitats may not be as different as the wide ranges in annual rainfall and aridity index suggest. Water availability to a tree is not only determined by rainfall and potential evaporation, but also by local hydrology (run-on, run-off, subsurface flow, groundwater levels, salinity), the capacity of the soil to store moisture for the long dry summer, and the density of vegetation claiming a share of the available water. Despite this complexity, a reduction in annual rainfall will reduce water availability in any situation. The significance for a tree of a reduction of annual rainfall from 1000 to 900 mm or from 300 to 270 mm depends on several factors, the quantification of which requires dedicated long-term research.

In the South-west of WA, tree water relations are central to understanding species distributions and likely impacts of climate change. The present study highlights differences between common eucalypts and identifies an element of risk in the water use pattern of wandoo. In cases of severe drought, hydraulic failure in branches or leaves can cause branch deaths. In Wandoo Crown Decline, however, branch deaths are often associated with biotic factors as well (Hooper 2009). Therefore, understanding the effect of drought on the ability of trees to withstand pest and disease should be an important element of future research.

Research on wandoo and other eucalypts will be continued in the Centre of Excellence for Climate Change, Forest and Woodland Health.

Acknowledgements

We are grateful to many people who have contributed to the UWA project. Foremost, members of the Wandoo Recovery Group are thanked for their interest, support and encouragement. DEC (formerly CALM) made significant cash and in-kind contributions to the ARC Linkage project and provided an ad-hoc PhD scholarship (2003-2007) and supplementary funding (2008). The CRC for Plant-based Management of Dryland Salinity also supported the scholarship. Bob Huston provided a weather station for the duration of the field campaign. Margaret Byrne supervised the genetic work of Eleftheria Dalmaris and made available her lab. Hans Lambers, Kingsley Dixon, John McGrath and Siegy Krauss contributed in the early phase of the project. Koen Antonise, Lotte Westerhof, Werther Guidi, Fabiano Scarpa and Perry Swanborough helped with field work, and Pachi Baquedano, Athena Kiapekou and Leida Williams helped with greenhouse and lab work. Fabiano Scarpa and Mike Oatham carried out part of the lab tests of branch and leaf vulnerability. Steve Burgess and Tim Bleby provided advice on the sap flow measurement technique.

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