COMPARATIVE ECOPHYSIOLOGY OF *EUCALYPTUS* WOODLANDS ALONG A DEPTH-TO-GROUNDWATER GRADIENT

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September 2013

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy in The School of Environment at the University of Technology, Sydney

CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Acknowledgements

It would not have been possible to write this PhD thesis without the help of the kind people around me. First and foremost, I would like to express my sincere gratitude to my supervisor Prof. Derek Eamus who has supported me continuously during my PhD study and research whilst allowing me the room to work in my own way. His guidance and immense knowledge helped me throughout my research and writing of this thesis.

I would like to thank Dr. Melanie Zeppel, my co-supervisor for her encouragement, insightful comments, and kindness. My sincere thanks also goes to Dr. James Cleverly who helped me to improve my thesis by feedback while I was writing the thesis.

A friend has been involved in this research who was not officially my supervisor but helped me with all my field work, laboratory work. I could not imagine conducting such a project without the help of Dr Randol Villalobos-Vega. I have learned much from him and thank him greatly. I could not think of a better friend-colleague to do this project with.

I thank other TERG laboratory members Dr. Nicole Grant, Ralph Faux, Dr. Nicolas Bulian, Stephen Fujiwara, Dr. Zheng Li, Dr. Cate Macinnis-NG and Dr. Restrepo-Coup who helped me during my field work, data analysis and thesis writing.

I also am grateful to those who helped me in field work and sample collections and specially to Lea Richards who became a close friend and great asset when times were tough; she gave me the confidence and supported me.

Last but not the least, I would like to thank my parents and my sisters who were not here with me but supported me spiritually throughout my PhD. Specially I thank my beloved husband, Shahin who has been extremely kind, patient, supportive, understanding and honestly I could not ask for a better support while I was doing such a difficult job.

I would like to acknowledge the financial, academic and technical support of the University of Technology Sydney (UTS) and the National Center for Groundwater Research and Training (NCGRT).

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List of abbreviations, acronyms and symbols

AGB	Above-ground biomass (Mg C ha^{-1})
ANOVA	Analysis of variance
ANPP	Above-ground net primary productivity (Mg C ha^{-1})
BA	Basal area (m^2 ha^{-1})
BNPP	Below-ground net primary productivity (Mg C ha^{-1})
CCA	Canonical correlation analysis
C_{FT}*	Absolute capacitance (g m^{-2} MPa^{-1})
C_{FT}	Capacitance at full turgor (MPa^{-1})
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
C_{TLP}	Capacitance at turgor loss point (MPa^{-1})
DBH	Diameter at breast height (cm)
DGW	Depth-to-groundwater (m)
EWR	Environmental water requirement
ET	Evapotranspiration (mm day^{-1})
ET_0	Reference evapotranspiration (mm day^{-1})
ET_{act}	Actual evapotranspiration (mm day^{-1})
ET_{eq}	Equilibrium evapotranspiration (mm day^{-1})
ET_P	Potential evapotranspiration (mm day^{-1})
GDEs	Groundwater dependent ecosystems
GPP	Gross primary productivity (Mg C ha^{-1})
H_V	Huber value (mm^2 mm^{-2})
K_L	Leaf specific conductivity (Kg m s^{-1} MPa^{-1} m^{-2})
K_S	Branch sapwood specific conductivity (Kg m s^{-1} MPa^{-1} m^{-2})

LAI	Leaf area index (m^2 m^{-2})
MANOVA	Multivariate analysis of variance
Non-GDEs	Non groundwater dependent ecosystems
NPP	Net primary productivity (Mg C ha^{-1})
NSW	New South Wales
P	Precipitation (mm)
PLC_{50}	Water potential associated with 50% loss in hydraulic conductance (MPa)
PLC_{88}	Water potential associated with 88% loss in hydraulic conductance (MPa)
P-V curve	Pressure- volume curve
RO	Run-off
RWC_{TLP}	Relative water content at turgor loss point
SCA	Sydney catchment authority
SLA	Specific leaf area (cm^{-2} g^{-1})
SWC	Saturated water content (g cm^{-3})
T	Transpiration
VIC	Victoria
VOC	Volatile organic compounds
VPD	Vapour pressure deficient (kPa)
WA	Western Australia
Ψ_{min}	Minimum leaf water potential (MPa)
Ψ_{pd}	Pre-dawn leaf water potential (MPa)
Ψ_{TLP}	Leaf water potential at turgor loss point (MPa)
ε	Bulk modulus of elasticity (MPa)
π_{100}	Osmotic potential at full turgor (MPa)

Abstract

A major challenge for groundwater research is to consider the complex relationships amongst groundwater resources, vegetation (function and structure) and climate. Transpiration from vegetation (especially trees when present) is the principal pathway for discharge of water from vegetated landscapes. Whilst it is known that the ability to access groundwater can help plants survive drought conditions and in particular the importance of groundwater in arid and semi-arid areas is well documented, there have been few studies that compare ecophysiological (e.g. leaf water relations), structural (e.g. basal area, leaf area index) and functional (e.g. rates of tree water-use, above-ground net primary productivity; water-use-efficiency) attributes of trees along a naturally occurring gradient in depth-to-groundwater, especially in mesic environments.

The aim of this research was to establish whether differences in groundwater depth along a transect influences ecophysiological, functional and structural attributes of remnant woodlands in southeast of Australia growing in a region with relatively high annual rainfall. The study area was located in the Kangaloon bore-field area, NSW, where depth-to-groundwater varies from 2.4 m to 37.5 m. To address this aim; seasonal measurements were made at seven sites at three scales (leaf-, tree- and stand-scales).

Structural attributes of woodlands, above-ground productivity were significantly different across sites. The three shallowest sites with 2.4m, 4.3 m and 5.5 m depth-to-groundwater had significantly larger above-ground biomass and productivity than the four deepest sites (sites where depth-to-groundwater was more than 9.8 m). A significant shift occurred in all measured variables when depth-to-groundwater increased from 5.5 m to 9.8 m. This result was found consistently for each structural trait examined (LAI, tree height, BA, ANPP, AGB, stem density). There were no differences in three structural traits (BA, height and LAI) nor ANPP across the four deepest sites. All these traits were significantly smaller at these deepest sites compared to the three shallowest sites.

Rates of stand transpiration rate tended to be smaller at all sites compared to many other studies conducted in a similar environment. This result was attributed to larger-than-average rainfall received across all sites across the entire study period, with concomitant reductions in solar radiation, temperature and VPD compared to long term means. Despite this, there were significant differences across sites and these differences were not consistent with my initial hypothesis: namely that as depth-to-groundwater decreases stand transpiration rates will increase. Rates of stand transpiration at the shallowest groundwater site (2.4 m) were the same as those at the deepest groundwater site (37.5 m) despite significantly larger tree density, BA, LAI at the shallowest site compared to the deepest site. Rates of stand transpiration were consistently the largest at the 4.3 m site compared to all other sites.

Tree hydraulic architecture was the least affected by depth-to-groundwater. Hydraulic architecture of trees was examined by measurement of the following traits: Huber value, branch hydraulic conductivity (leaf and sapwood specific), xylem sensitivity to embolism and sapwood density. Huber value (H_V) increased significantly as depth-to-groundwater increased, in agreement with my initial hypothesis: namely that H_V is larger at drier sites (deeper groundwater sites) than sites with shallow groundwater. Neither sapwood density nor branch hydraulic conductivity (sapwood and leaf area specific) varied significantly across sites, in contrast to expectations. Xylem vulnerability to embolism was assessed in summer and winter by determining the water potential associated with both a 50% and 88% loss of conductance (PLC_{50} and PLC_{88} respectively). PLC_{50} in both seasons was significantly and negatively correlated with depth-to-groundwater.

Leaf-scale measurements showed that trees occupying sites with the shallowest water table were more sensitive to drought stress than those growing at sites with the deepest water-tables. There were significant changes across some leaf traits, including: leaf turgor loss point, osmotic potential at full turgor and the relative water content at turgor loss point (RWC_{TLP}). All of these traits declined as depth-to-groundwater increased. In contrast, leaf volumetric elasticity was independent of depth-to-groundwater. The form of the relationship between depth-to-groundwater and leaf-scale and stand-scale structural traits differed between the two sets of data. In the former a negative and linear response to increasing depth-to-groundwater was observed but in the latter an exponential decay response was observed.

When all leaf-scale, tree-scale and stand-scale traits were normalized (zero to one) to produce a single, average response across all traits, as a function of depth-to-groundwater, a significant step-function response to increase in depth-to-groundwater was observed. For the three shallowest sites, there were minimal changes as a function of depth-to-groundwater but as depth-to-groundwater increased from 5.5 m to 9.8 m there was a significant reduction in mean normalised trait value. When depth-to-groundwater was larger than approximately 9-10 m a consistent reduction in normalised trait value occurred, with no significant difference across the four deepest sites.

This thesis has demonstrated that even in a mesic environment, groundwater can have an important impact on ecophysiological, structural and functional traits of trees. Understanding how trees respond to changes in groundwater availability is a crucial knowledge gap in our current understanding about groundwater and vegetation interactions. Determining this response function has management and conservation applications which indicate potential changes in ecosystem function, structure, growth and ultimately survival. It can also potentially determine the safe limit threshold for groundwater drawdown.

Whilst it is acknowledged that variation in traits along environmental gradients in the field are, by definition, correlative (that is correlated with variation in the environmental variable identified along the gradient), the use of multiple sites across a very small spatial gradient strongly supported the conclusion that trait variation was associated with variation in groundwater depth and not with variation in climate. Furthermore, consistency in trends across the gradient in groundwater depth also

support the conclusion that trait variation identified in this thesis can be attributed to variation in groundwater depth, rather than randomly occurring in space.