IMPACTS OF GROUNDWATER EXTRACTION ON THE ECOPHYSIOLOGY OF SEVERAL AUSTRALIAN TREE SPECIES OF NSW

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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.

This research is supported by an Australian Government Research Training Program.

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- "*…que ya yo sé de experiencia que los montes crían letrados y las cabañas de los pastores encierran filósofos.*" Book 1, Chapter L, El Quijote, 1605

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

A_n	Net photosynthetic carbon uptake (µmol m^{-2} s^{-1})
A_{s_tree}	Stand sapwood area (cm^2)
ANPP	Aboveground net primary production (Mg C ha^{-1} y^{-1})
BACI	Before-after-control-impact
BoM	(Australian) Bureau of Meteorology
C_a	Atmospheric CO_2 concentration (µmol mol^{-1})
C_i	CO_2 concentration inside leaf air spaces (µmol mol^{-1})
CO_2	Carbon dioxide
DBH	Diameter at breast height (cm)
DG	Daily growth (µm)
DGW	Depth-to-groundwater (m)
E	Evaporation (mm)
ET	Evapotranspiration (mm d^{-1})
ET_s	Surface evapotranspiration (mm d^{-1})
ET_{ss}	Subsurface evapotranspiration (mm d^{-1})
GDEs	Groundwater-dependent ecosystems
GDV	Groundwater-dependent vegetation
GRO	Growth-induced irreversible expansion (µm)
g_s	Mean stomatal conductance (mmol m^{-2} s^{-1})
GW	Groundwater
$_{int}WUE$	Instantaneous water-use efficiency (g C kg^{-1} H_20)
J_s	Mean sap flux density (g m^{-2} s^{-1})
LAI	Leaf area index (m^2 m^{-2})
MAP	Mean annual precipitation (mm)
MDS	Maximum daily shrinkage (µm)

MNSD	Minimum stem diameter (µm)
MXSD	Maximum stem diameter (µm)
Non-GDEs	Groundwater-independent Ecosystems
NSW	New South Wales
NPP	Net primary productivity (Mg C ha^{-1} yr^{-1})
P	Precipitation (mm)
PAR	Photosynthetically active radiation (µmol m^{-2} s^{-1})
RH	Relative humidity (%)
R_n	Net radiation (MJ m^{-2} d^{-1})
RO	Run-off (mm h^{-1})
SPAC	Soil-plant-atmosphere continuum
SM	Soil moisture (%)
SVP	Saturation vapour pressure (kPa)
SWC	Soil water content (m^3 m^{-3})
T	Transpiration (mmol m^{-2} s^{-1})
TWD	Tree water deficit-induced stem shrinkage (µm)
VPD	Vapour pressure deficient (kPa)
WUE	Water-use efficiency (g C kg^{-1} H_20)
WUE_i	Intrinsic water-use efficiency (g C kg^{-1} H_20)
ΔW	Water-related changes in stem radius (µm)
Ψ_{md}	Midday potential (MPa)
Ψ_{pd}	Pre-dawn potential (MPa)
Ψ_{soil}	Soil water potential (MPa)

ABSTRACT

Groundwater extraction has increased seven-fold worldwide in the last century leading to extensive overexploitation of aquifers. A loss of groundwater involves considerable changes in the function of ecosystems that were previously dependent upon it. However, the significance of these changes due to extraction-induced increases depth-to-groundwater (DGW) is poorly understood in the mesic forests of Australia's East Coast, where water resources regulators require such information.

The research presented in this thesis thus sought: (a) to investigate the initial changes in ecophysiological adaptations such stem diameter, leaf water relations, and foliar ^{13}C to a short-term extraction-induced groundwater drawdown and (b) to identify any indication of stress in trees occupying the cone of depression in comparison with trees not affected by the groundwater drawdown. Three different bore-fields, located within the Hunter-Central Rivers area (New South Wales, Australia), were selected to conduct this research and where DGW fluctuates naturally from 0 m to 7 m. Twelve trees of two dominant species (*Angophora costata* and *Eucalyptus signata*) were studied at each site, radiating out from an extraction bore at near, intermediate, and distant locations (plots 1, 2, and 3). Once groundwater pumping began at one location (Tomago study site), DGW reached a depth of 9.88 m at the bore (outside the forest), 4.20 m at plot 1, and 2.61 m at plot 3. During most of the study period in 2018, the total amounts of rainfall were 14.3% and 2.9% wetter than the long-term average rainfall of the same periods at Tomago and Nabiac, respectively. The warmest and coldest months were January and July with average temperatures of approximately 23 ºC and 10 ºC at both study sites.

Litterfall production ranged from 0.1 to 1.8 Mg ha^{-1} month^{-1}. A significant increase in litterfall production in plot 1 relative to plot 3 occurred two months after extraction began. Similarly, there were larger increments of growth-induced irreversible expansion (GRO) in trees over deeper groundwater levels in plot 1 (4 – 6 mm / yr) than in trees over shallow groundwater in plot 3 (1.5 – 4 mm / yr). However, diurnal stem shrinkage (TWD) showed no significant differences across DGW levels, indicating a general absence of water stress. These results were only partially consistent with our initial hypothesis that as DGW increases, TWD and litterfall

production would increase, whereas GRO would experience lower increments compared to trees where DGW is shallower.

Leaf water relations were least affected by an artificial drawdown of groundwater level. Leaf water relations were evaluated from measurements of diurnal gas exchange and water potential, including predawn (Ψ_{pd}) and midday (Ψ_{md}) water potential. Contrary to my hypothesis, leaf gas exchange (net photosynthesis A_n, stomatal conductance g_s, transpiration T, and intrinsic water-use efficiency WUE_i) did not vary across the range of DGW. However, A_n and g_s exhibited larger values during the last month of the study (November) than in previous months due to an increasing trend in T during the springtime and the large availability of soil water. Transpiration was limited by low atmospheric vapour pressure deficit (VPD) and not by g_s during the study period.

Similar, to leaf gas exchange results, Ψ_{pd} remained stable across DGW levels, reflecting that trees were generally well-watered. However, Ψ_{md} declined (became more negative) once the phreatic level exceeded depths of 3 m DGW, suggesting that trees experienced more hydraulic tension when the water table was located in the lower portion of the root zone. The most negative water potential values were reached where the water table was 3.9 m DGW (-0.8 and -3 MPa for $\Psi_{pd,}$ and Ψ_{md} respectively).

Values of leaf $\delta^{13}C$ ranged from -27.4 ‰ to -30.2 ‰, as expected from previous studies. Unexpectedly, $\Delta^{13}C$ values were lower in trees at plot 3 with a relatively shallow water table (i.e., had a higher WUE) compared to those at plot 1 with a deeper water table. WUE_i values estimated from $\Delta^{13}C$ showed a negative correlation with increasing DGW surprisingly indicating that RuBisCo discriminated less against the heavier isotope where DGW was deeper.

Overall, the findings of this thesis highlight that vegetation responded positively to a DGW increase from 1 m to 4.2 m. This suggests that trees benefited from groundwater extraction and were well-watered across all levels of DGW. This can be explained as a lowered water table that still remains within the potential root zone opens up a temporary larger volume of soil water for the trees to access, suggesting that GW extraction is beneficial to trees by reducing waterlogging and anoxic conditions in soil and increasing the volume of soil with good aeration. Changes in DGW due to

groundwater extraction were immediate but short-lived, with DGW in plot 1 nearest the extraction bore declining relative to DGW in bores of the more distant plots for only the first week of extraction, despite the timing to coincide with regional drought leading to widespread bushfires. This research provides insight into the initial physiological responses of groundwater-dependent vegetation to short-term groundwater drawdown in a highly dynamic mesic ecosystem assisting pumping companies and state regulatory agencies to manage water resources under the rapidly changing conditions to which they are exposed in this region.