Fires and hydrology of south eastern Australian mixed-species forests

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bushfire CRC

PRESENTATION OUTLINE

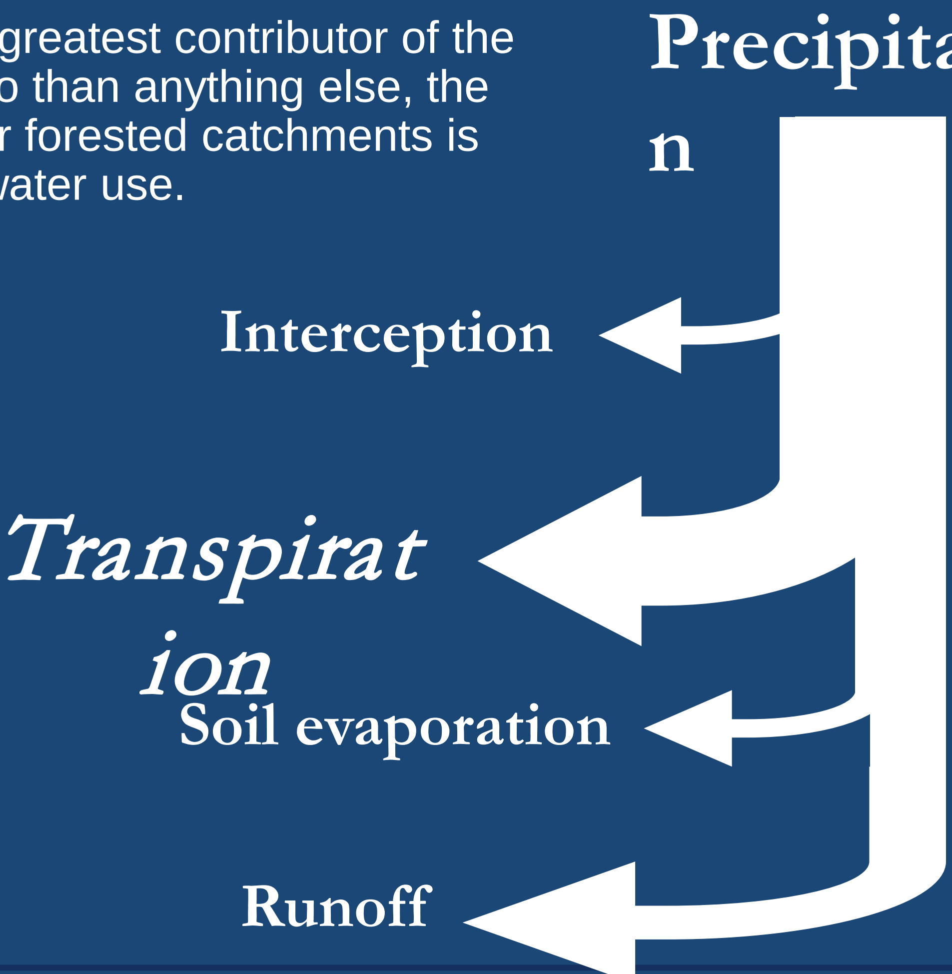
- Our project “Fires and hydrology of south eastern Australian mixed-species forests”
- History and nature fire in vegetated catchments
- Our approach to quantifying vegetation water use
- What’s been done to date
- What’s still to be done
- What questions are we answering
- Deliverables at the end of the project

PROJECT OUTLINE

- Project 4: Fires and hydrology of south-eastern Australian mixed species forests
  - Staff: Tarryn Turnbull & Michael Kemp (The University of Sydney)
  - Collaborators: Tom Buckley (Sonoma State University)
  - PhD Students: Jessica Heath (The University of Sydney)
- Project Outline:
  - The amount of water transpired by vegetation is tightly coupled to water yield (run-off) from forested sub-catchments;
  - There are a few models that predict overstorey water use for established forests typical of the Northern Hemisphere (i.e. with dominant trees being deciduous broadleaved species, or evergreen conifers);
  - This project aims to develop these existing models further so we can predict the water used by eucalypt forests regenerating after fire – paying particular attention to those eucalypts that regenerate via sprouting

DETERMINANTS OF WATER YIELD

- Transpiration is the greatest contributor of the outputs. So, more so than anything else, the water balance of our forested catchments is dominated by tree water use.



HISTORY AND NATURE FIRE IN VEGETATED CATCHMENTS

TREES FIRE AND WATER YIELD

- Previous research shows that eucalypt forests regenerating after a fire use more water than the original unburnt forest
- Leaves are the site of most water loss from a tree, and the total leaf area carried by a tree varies seasonally, annually and as the tree ages
- Water travels from roots to leaves via a wood tissue type called ‘sapwood’
- Leaf structure and physiology in regenerating leaves is different to that of the adult leaves of an unburnt forest
- We study all these aspects of tree structure and physiology to assess the potential for different species of eucalypts to transpire water as they regenerate after a fire
- Today we’ll discuss what determines differences in water yield before and after fire in tall open eucalypt forests and mixed species eucalypt forests

FORESTED CATCHMENTS IN SOUTH-EAST AUSTRALIA

- Melbourne water catchments are mostly forested:
  - Half of Melbourne's catchment is a tall open forest of *Eucalyptus regnans* and the other half is mixed species open forest of up to eight different eucalypts comprising the overstorey
- Similarly the majority of Canberra's catchment is a tall open forest of *E. delegatensis* and the other half is mixed species open forest
- Sydney's catchment is a little different, with only 37% covered with native vegetation. This vegetation is diverse too – made up of tall open forests, rainforest and heathlands to name a few.
- Plants have different requirements for water, and respond differently to fire – so forest type affects water yield and susceptibility of yield to fire

TYPICAL TALL OPEN FOREST

TYPICAL MIXED SPECIES FOREST

FOREST TYPE IMPACTS UPON WATER YIELD

- The contribution of each forest type (tall open and mixed species forests) to catchment yield is unequal
- 80% of the yield for Melbourne's catchment originates from the tall open *E. regnans* forests (which only comprise 50% of the catchment estate)
- This results predominately from geography – *E. regnans* forests grow on well draining soils in the areas that receive higher rainfall
- Not surprisingly then, most research into impact of forest type on water yield concerns these forests
- In these forests water yield is strongly leveraged to vegetation water-use, a 5% increase in forest water use = 20% reduction in streamflow!
- Only recently have we began to study how other eucalypt forests use water before and after a fire

HISTORY AND NATURE FIRE IN VEGETATED CATCHMENTS

FROM THE LITERATURE

- The tall open *E. regnans* forests characterising half of Melbourne's water catchment are particularly vulnerable to decreased catchment yield after a fire
- Three decades after a stand-replacing fire, catchment yields remain 6 mm y^{-1} less for every 1% of the catchment estate that was burnt (Kuczera 1987)
- The sustained decreased yield arises from increased transpiration of the regenerating forest (Vertessy *et al.* 1995)

HISTORY AND NATURE FIRE IN VEGETATED CATCHMENTS

FROM THE LITERATURE

- Sap velocity is conserved with tree age for *E. regnans* (Dunn and Connor 1993) so increased transpiration rates result from increased stand sapwood area of the heavily stocked regenerating forest (still 4000 stems ha at 7 yo, one every 1.5 m)
- Stand sapwood area steadily declines with forest age (7 m^2 ha^{-1} for a 50 yo forest to 4 m^2 ha^{-1} for a 'mature' forest > 100 yo, Dunn and Connor 1993)
- As does leaf area index from 4 in a 10 yo forest to 1 for a 'mature' forest > 100 yo (Vertessy *et al.* 2001)

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

THE LITERATURE – WHAT WAS MISSING?

- Response of *E. regnans* forests were well represented in the literature
- The other major forest types of our forested catchments were not:
  - The *E. delegatensis* and *E. pauciflora* forests at the headwaters of the Murray River catchment
  - The mixed species eucalypt forests at the foothills of all tall open forests in SE Australia
- The shortened growing season of the headwater forests and resprouting physiology of mixed species forests render them both unlikely to follow the *E. regnans*-type pattern of catchment yield after fire

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

MIXED SPECIES FORESTS – PROJECT AIMS

- We've been working in the forests of SE Australia for the last 7 years to quantify the effect of fire on catchment yields in both *E. delegatensis* and *E. pauciflora* monospecific forests that were burnt in 2003 and also mixed species eucalypt forests that were burnt in 2009 (HIGHFIRE, BCRC)
- Quantify and model tree water use in mixed species forests of SE Australia as the forests regenerate after a fire
  - Tree water use continually measured via heat ratio method
  - This combined with inventory of stems per hectare, stem size and the relationship between sap-conducting wood and stem size, and knowledge of wood characteristics, can enable us to quantify stand-level vegetation water use
- Meteorological drivers of tree water use (soil moisture, light and vapour pressure deficit) are also continuously recorded on-site
- Structural components are also measured periodically via targeted campaigns:
  - canopy leaf area, leaf type and patterns of distribution, stomatal physiology, venation patterns, leaf chemistry and leaf gas exchange

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

BURNT V UNBURNT *E. delegatensis* FOREST

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

ACCESSING THE 70 M TALL CANOPY *E. delegatensis*

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

INSTALLING SAPFLOW SENSORS IN *E. pauciflora*

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

REGENERATING MIXED SPECIES FORESTS

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

LEAF WATER RELATIONS IN MIXED SPECIES FORESTS

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

ACCESSING THE CANOPY IN MIXED SPECIES FORESTS

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

WEATHER AND SOIL WATER

› The flow of water through soil, into a plant and out of it's leaves is controlled by the environment within the soil, the structure of wood and leaves, and the atmosphere around the tree crown

- Water moves from wet to dry
- Influenced by soil moisture content and water holding capacity
- Air temperature and relative humidity i.e. how dry the air is
- Wind
- Light intensity/brightness…

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

A TYPICAL MICRO-METEOROLOGY STATION

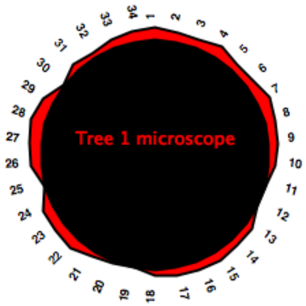
OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

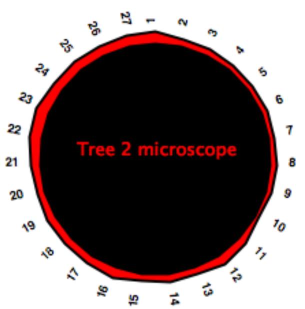
FOREST STRUCTURE AND TRANSPIRATION

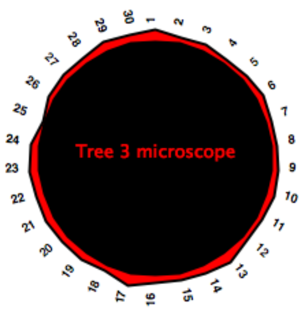
- Water moves through the sapwood of older trees at the same rate as through the sapwood of seedlings
- Forest structure influences the amount of water such that older forests transpire less than younger forests
- Younger forests have a greater stocking of trees
- Younger forests also have a greater amount of sapwood
- and a greater leaf area index (m^2 leaf per m^2 ground)

- Recently burnt eucalypt forests have juvenile leaves and if regenerating from seed, a greater proportion of wood as sapwood

SAPWOOD AREA DISTRIBUTION & LEAF AREA INDEX







OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

HRM SAPFLOW SENSORS

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

SOIL WATER AND WITHIN-CANOPY ATMOSPHERIC CONDITIONS

OUR APPROACH TO QUANTIFYING VEGETATION WATER USE

TREE STRUCTURE AND LEAF ANATOMY

- The rate at which water flows from the soil to the atmosphere via a plant is influenced by the demand for water by the canopy and resistances to water movement within the sapwood and leaves
- The two major resistances are found in the leaf
  - Leaf pores (stomata)
  - Layer of still air directly adjacent to leaf surface (boundary layer)

- Leaf water status, porosity of the leaf surface, physiology of stomatal opening and shutting, and structure and anatomy of leaves are all variables we study in order to model tree water use

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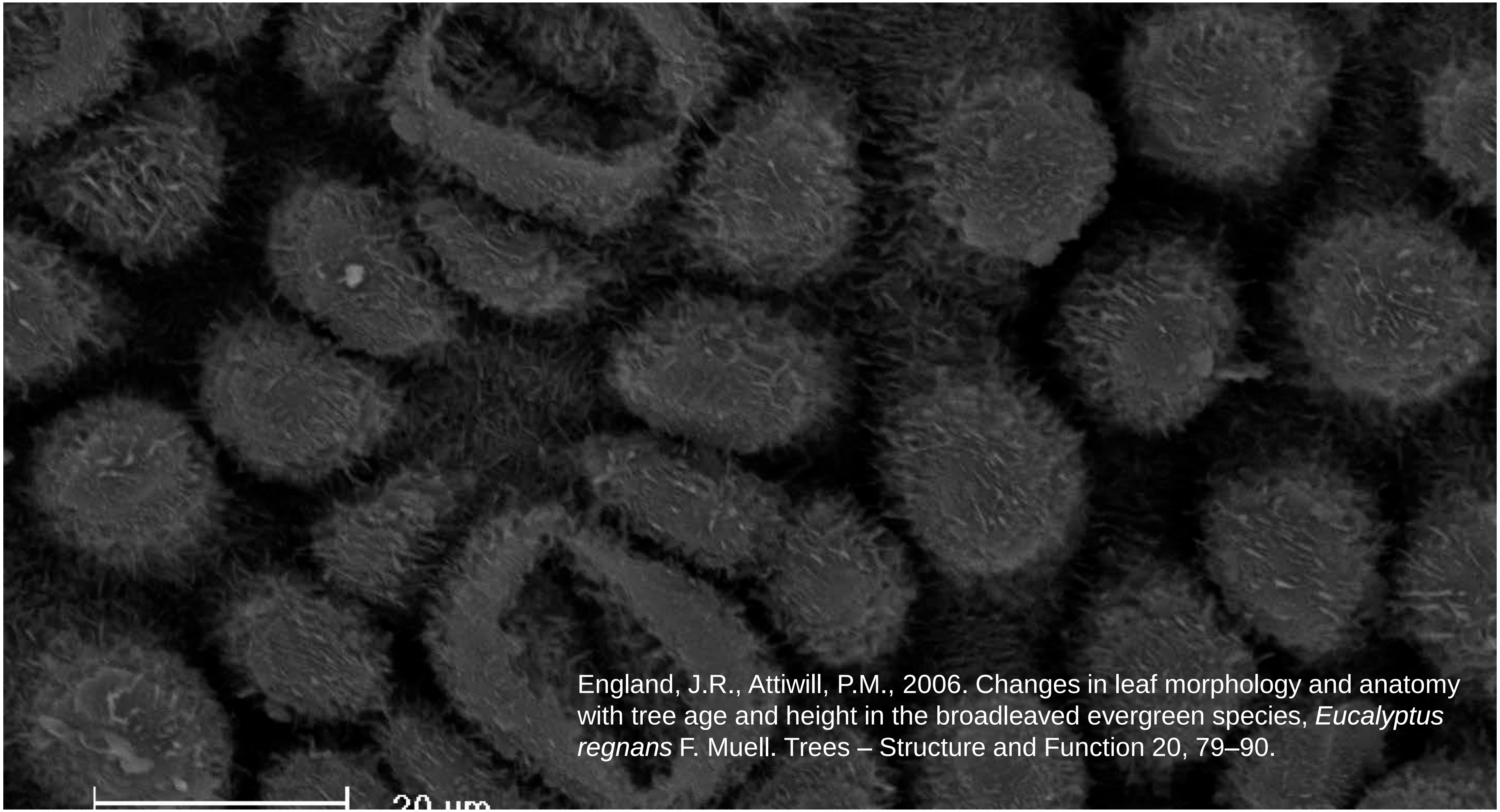
STOMATA CAN BE PHYSICALLY IMPAIRED AGAINST WATER LOSS



England, J.R., Attiwill, P.M., 2006. Changes in leaf morphology and anatomy with tree age and height in the broadleaved evergreen species, *Eucalyptus regnans* F. Muell. Trees – Structure and Function 20, 79–90.

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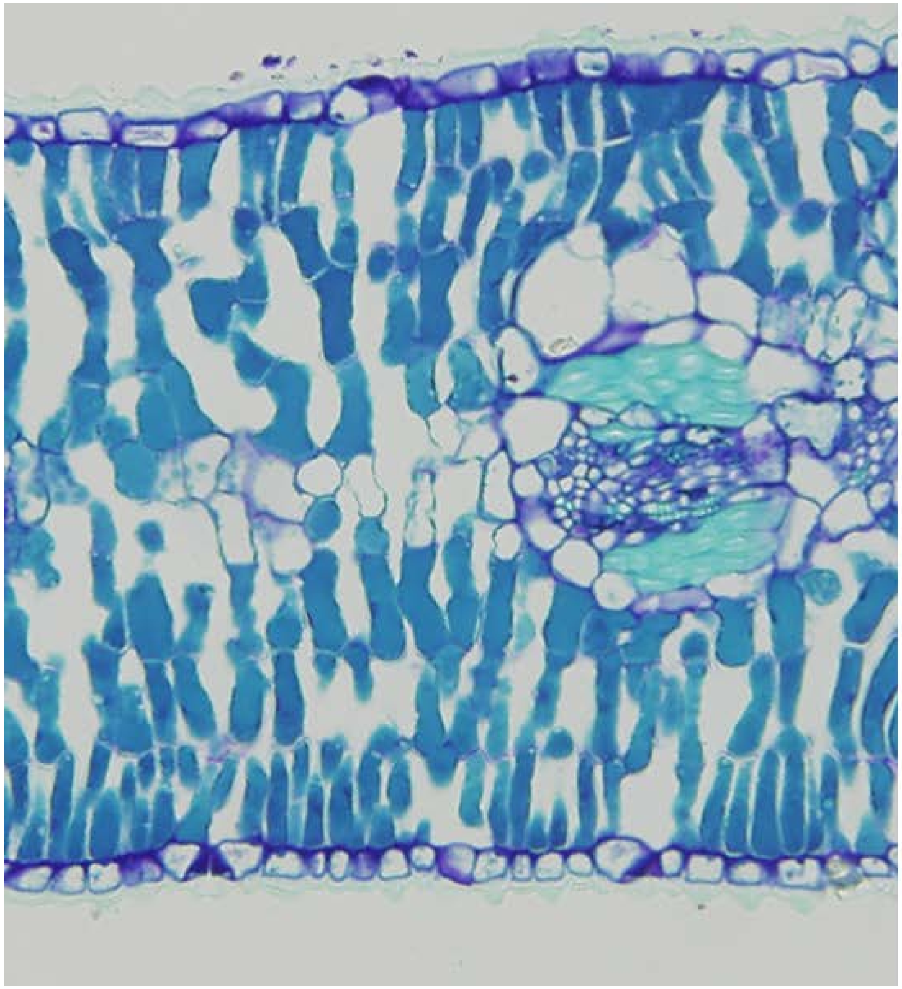
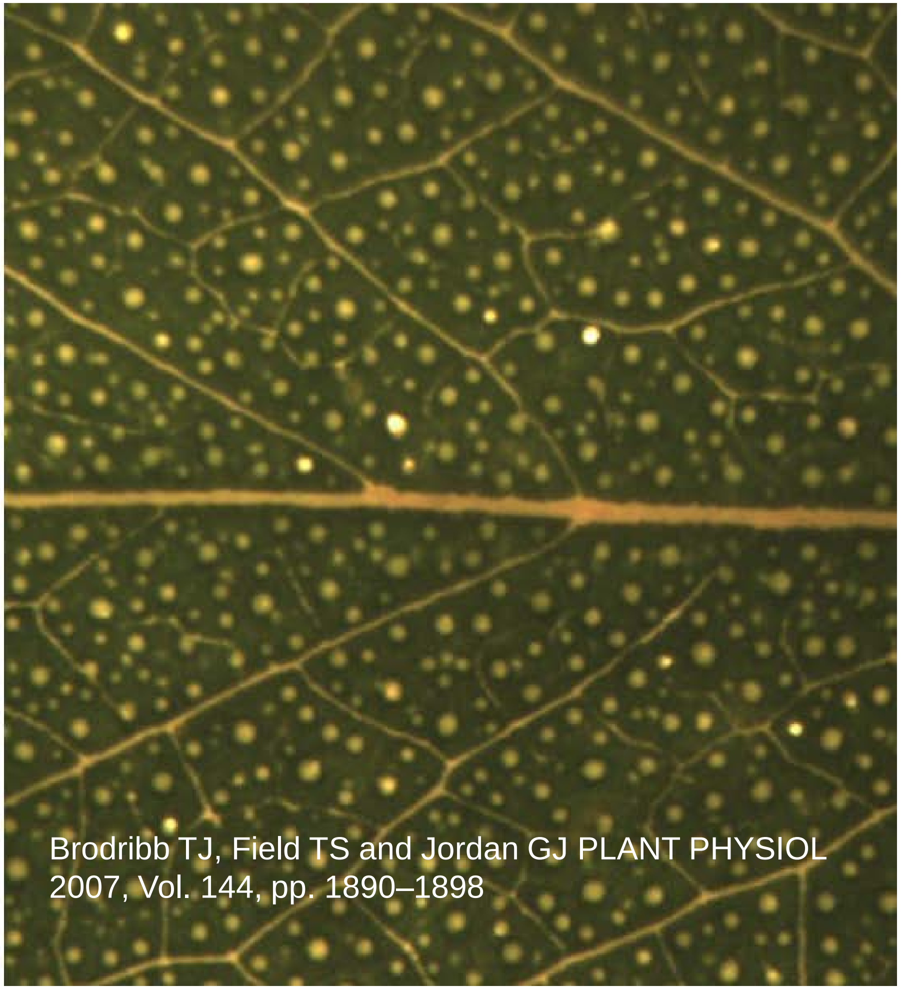
DIFFUSION OF WATER BETWEEN VEINS AND STOMATA

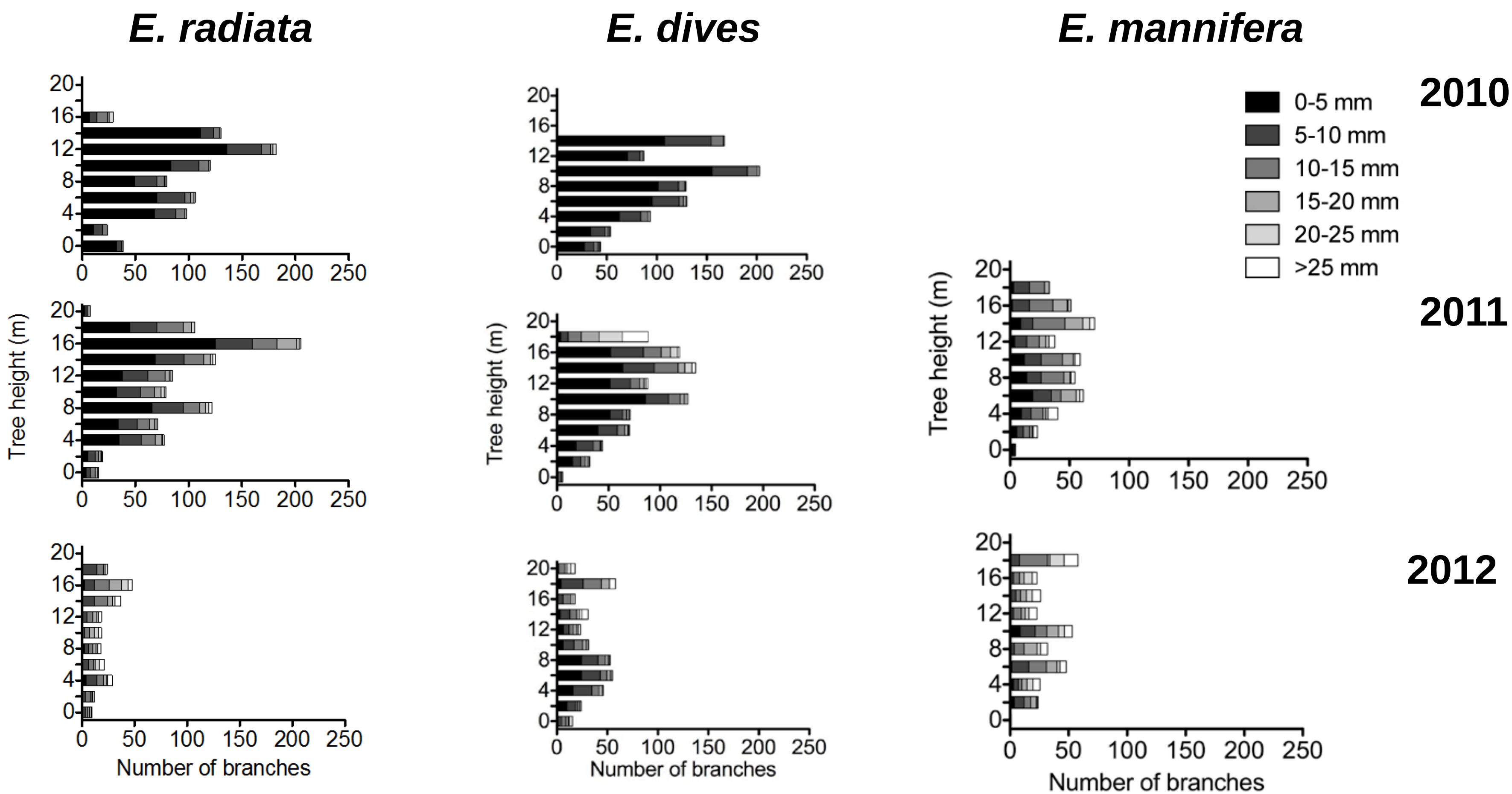




Brodribb TJ, Field TS and Jordan GJ PLANT PHYSIOL 2007, Vol. 144, pp. 1890–1898

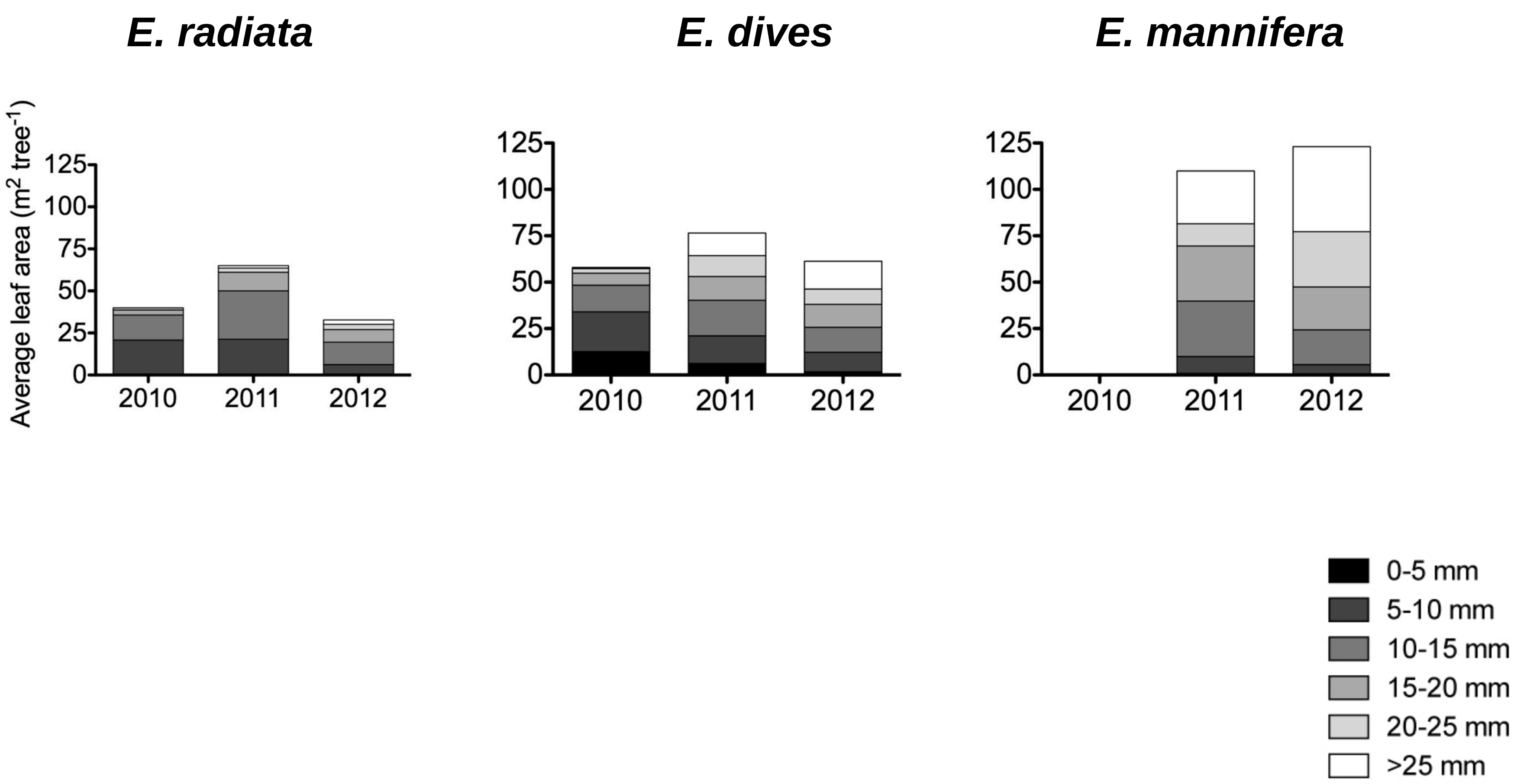
OUR RESULTS - WHAT'S BEEN DONE TO DATE

PHYSIOLOGY OF RESPROUTING EUCALYPTS CANOPY & LEAF CHARACTERISTICS



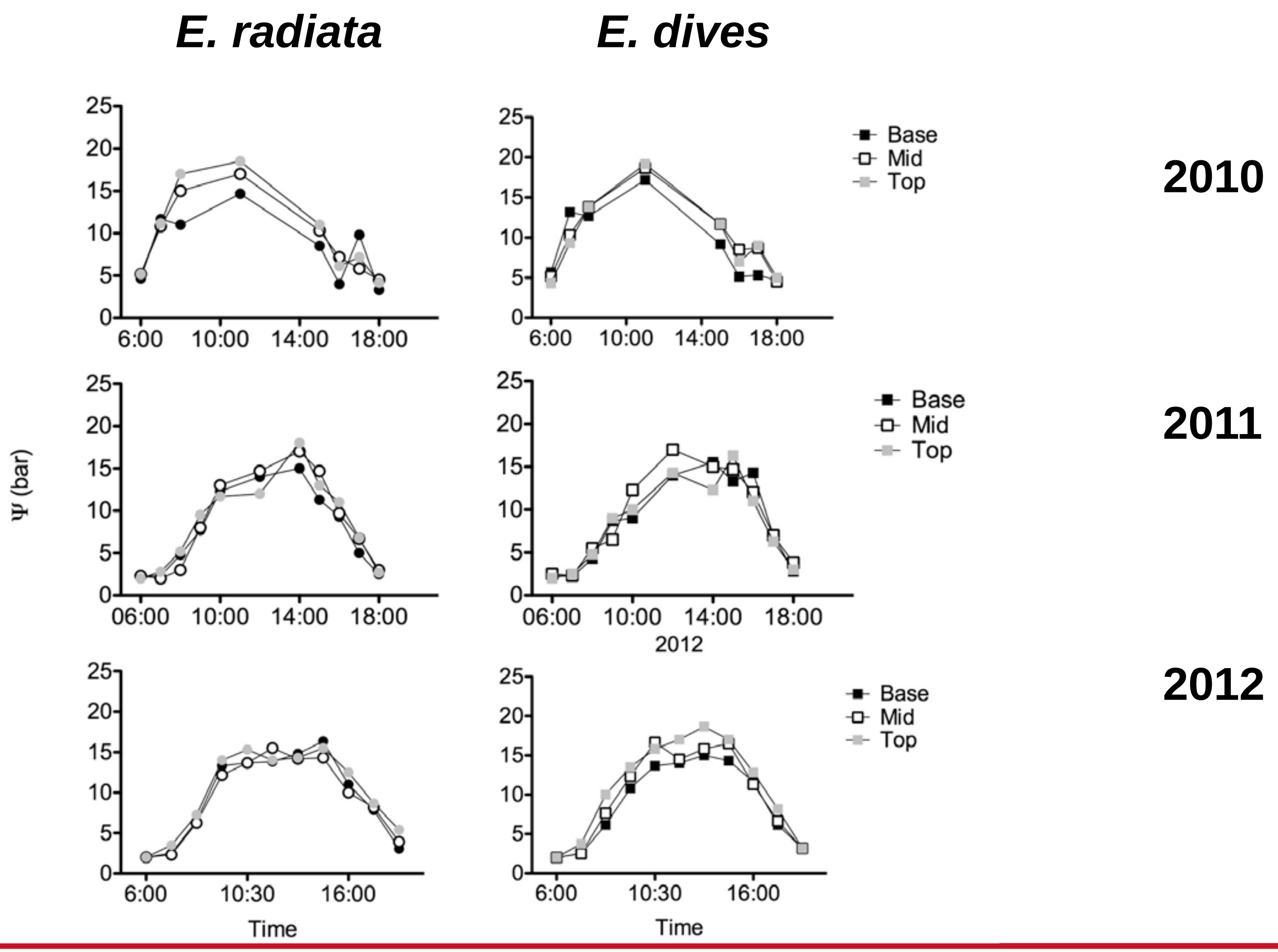
OUR RESULTS - WHAT'S BEEN DONE TO DATE

CANOPY AND LEAF CHARACTERISTICS: SPECIES VARIATION IN LEAF AREA



OUR RESULTS - WHAT'S BEEN DONE TO DATE

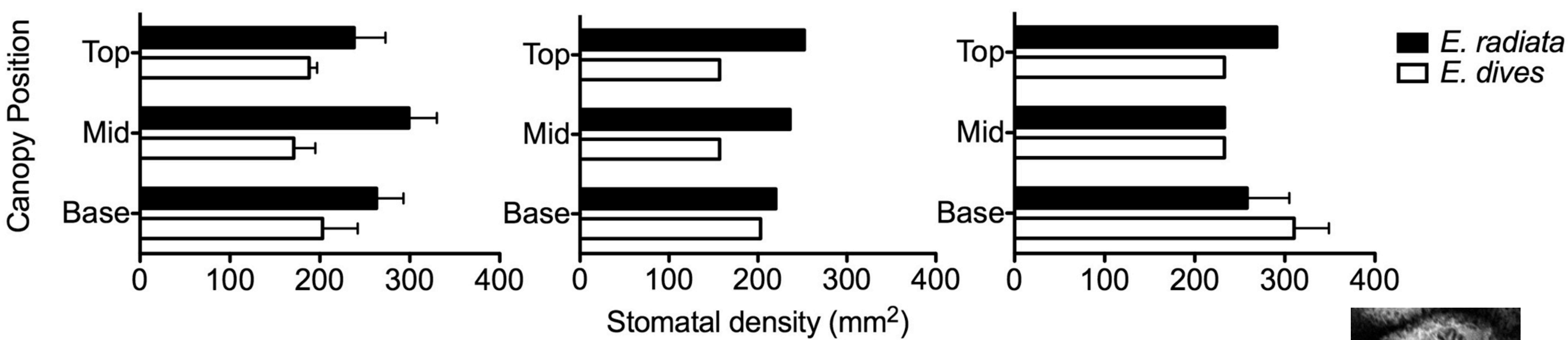
LEAF WATER RELATIONS: GRADIENTS FOR WATER MOVEMENT (WATER MOVES FROM LESS NEGATIVE TO MORE NEGATIVE PRESSURE), DIURNAL PATTERNS IN LEAF WATER POTENTIAL

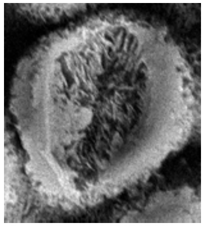


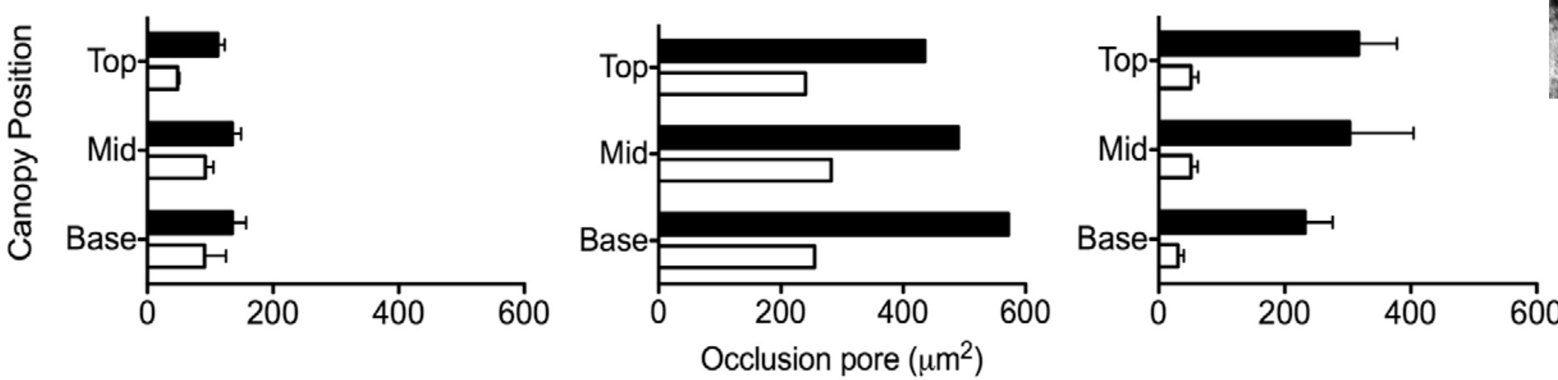
OUR RESULTS - WHAT’S BEEN DONE TO DATE

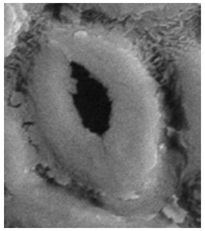
LEAF WATER RELATIONS - STOMATA

2010 **2011** **2012**





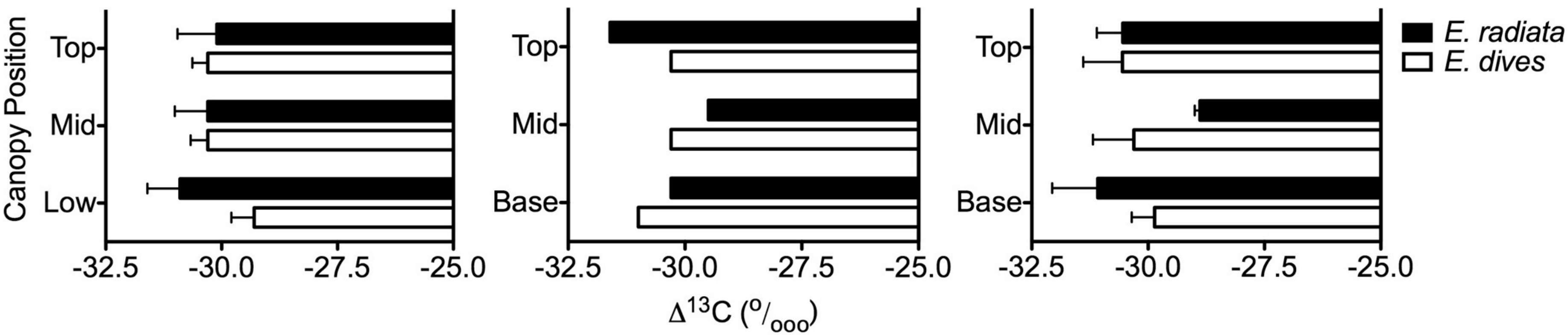




OUR RESULTS - WHAT'S BEEN DONE TO DATE

LEAF PHYSIOLOGY – WATER-USE EFFICIENCY

2010 **2011** **2012**



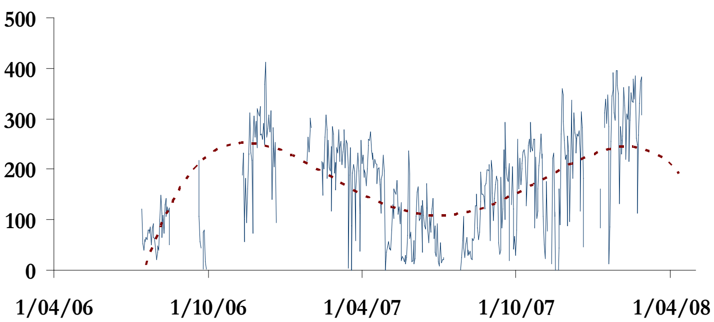
WHAT'S STILL TO BE DONE?

CALCULATING STAND WATER USE FOR 18-MONTHS DATA

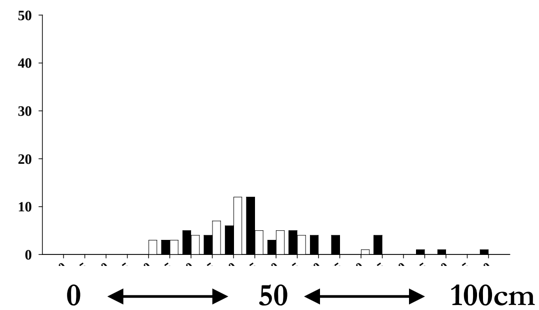
Alpine Ash

Tree water use (L day^{-1})

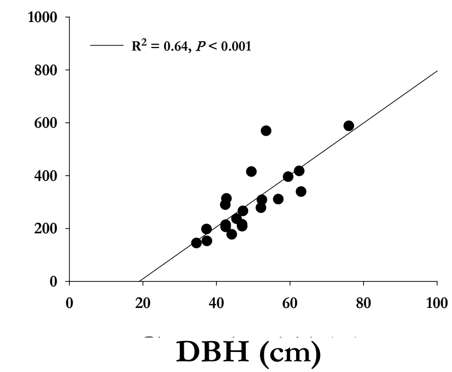
Alpine Ash
(Tree 82; 52cm)



Stems ha^{-1}



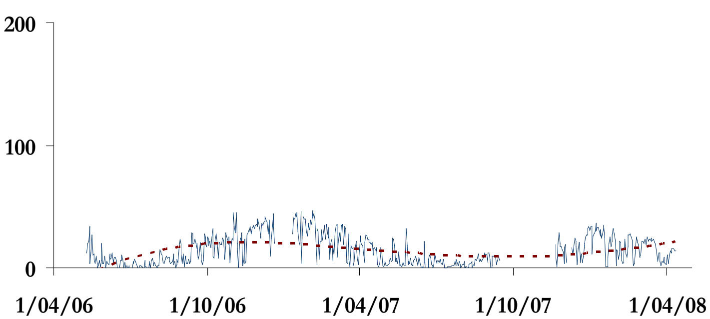
Sapwood area (cm^2)



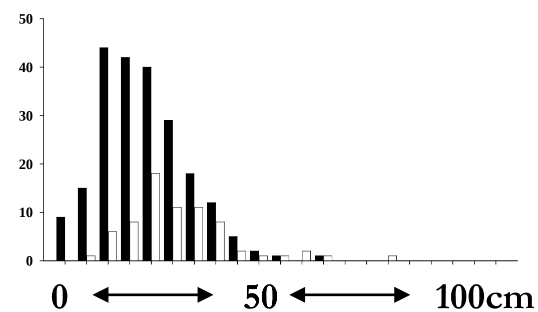
Snowgum

Snowgum
(Tree 111; 29cm)

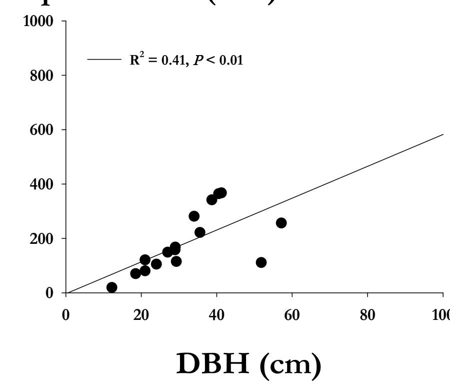
Tree water use (L day^{-1})



Stems ha^{-1}



Sapwood area (cm^2)



WHAT’S STILL TO BE DONE?

PARTITIONING WATER USE AMONGST TRANSPIRATION AND REFILLING

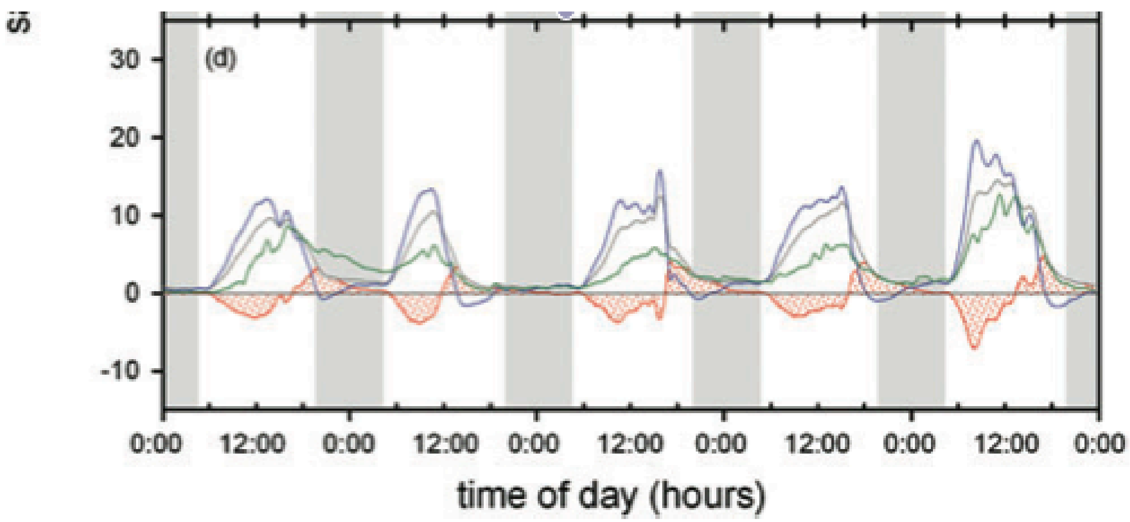


Figure 4. Sample results from each site for a 5-day period (09–13 December, 2009), showing sap flux (gray lines) and its transpiration (blue lines) and refilling components (red lines and red stipling) inferred using the method described in the Appendix, using $\beta = 0.5$. Evaporative demand (green lines) is shown for reference. Gray areas indicate dark periods. (A) A 44-cm (DBH) *E. delegatensis* from site AA1, with refilling time constant, τ, of 3.80 ± 0.15 h. (B) A 76-cm *E. delegatensis* from site AA2, $\tau = 1.63 \pm 0.19$ h. (C) A 21-cm *E. pauciflora* from site SG1, $\tau = 1.56 \pm 0.24$ h. (D) A 27-cm *E. pauciflora* from site SG2, $\tau = 4.23 \pm 0.26$ h. These examples are all from outer probes.

2011 Buckley, Turnbull Pfautsch & Adams. Nocturnal water loss in mature subalpine *Eucalyptus delegatensis* tall open forests and adjacent *E. pauciflora* woodlands ECOLOGY AND EVOLUTION 1(3) 435–450

WHAT'S STILL TO BE DONE?

PARAMETERISE SIMPLE MODEL FOR TREE WATER USE

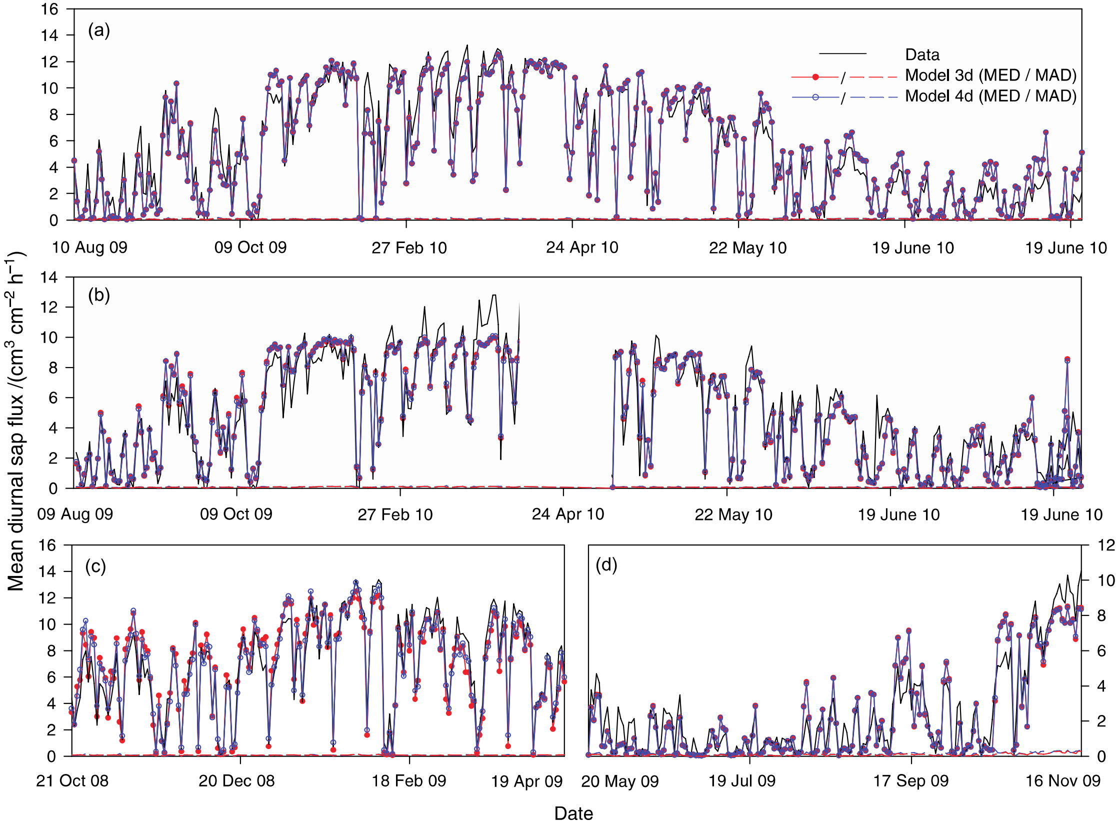


Figure 4. Representative time courses of diurnally averaged sap flux (solid line) and corresponding median predictions from Models 3d (red line, closed symbols) and 4d (blue line, open symbols), for one tree in each species/age class group: (a) tree Dm1_1 (*E. delegatensis*, mature); (b) tree Dr2_4 (*E. delegatensis*, regrowth); (c) tree Pm1_6 (*E. pauciflora*, mature); (d) tree Pr2_4 (*E. pauciflora*, regrowth). Median absolute deviations (MADs) of predictions among cross-validation runs are shown with dashed lines.

2012 Buckley, Turnbull & Adams. Simple models for stomatal conductance derived from a process model: cross-validation against sap flux data. PLANT, CELL & ENVIRONMENT 35 (9) 1647–1662,

WHAT QUESTIONS ARE WE ANSWERING?

- The contribution of mixed species forests to reductions in catchment yield have not been documented
  - Mixed species are unlikely to incur the same dramatic increase in sapwood area after a fire
  - Yet the morphology and water-use characteristics of regenerating foliage could lead to a reduced yield
    - Juvenile leaves are heavily transpiring
    - Adult leaves are hydrologically conservative
  - …Especially for the period about three years after a fire in which leaf area index approaches that of an unburnt forest.
- How well does tree water use data from regenerating mixed species forest fit our simple model for tree water use in other species of eucalypt?

DELIVERABLES AT THE END OF THE PROJECT

- Knowledge of magnitude and (potentially) duration of changes in water yield in catchments vegetated with mixed species forest
- Parameterised simple model of regenerating mixed species forest water use:
  - Our derived models are driven by irradiance and evaporative demand
  - Each have two to four parameters that represent sums and products of biophysical parameters in the process model
  - Models reproduced a median 83–89% of observed variance in half-hourly and diurnally averaged sap flux, and performed similarly whether fitted using a random sample of all data or using 1 month of data from spring or autumn.
  - Our simple models are an advance in predicting plant water use because their parameters are transparently related to reduced processes and properties, enabling easy accommodation of improved knowledge about how those parameters respond to environmental change and differ among species.

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