FIRE IN THE LANDSCAPE

Project 4 | Fires and hydrology of south-eastern Australian mixed species forests

DR TARRYN TURNBULL | RESEARCH FELLOW ECOPHYSIOLOGY
CENTRE FOR CARBON WATER AND FOOD | FAE

THE UNIVERSITY OF SYDNEY

bushfire CRC

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 aimed 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

MIXED SPECIES FORESTS – EXTENSIVE YET UNDER-STUDIED

- The catchments from which the cities of SE Australia draw their water are forested in equal (area-based) proportions of monospecific tall-open forests and mixed-species open forests of comprising up to eight species of eucalypt
  - Tall-open forests can be either mountain ash (*Eucalyptus regnans*) or alpine ash (*E. delagatensis*)
  - Mixed-species open forests can contain any combination of messmate (*E. obliqua*), narrow-leaved peppermint (*E. radiata*), broad-leaved peppermint (*E. dives*), manna gum (*E. viminalis*), candlebark (*E. rubida*), Eurabbie bluegum, (*E. globulus* ssp. *bicostata*), red stringybark (*E. macrorhyncha*), brown stringybark (*E. baxteri*), long-leaved box (*E. goniocalyx*) or red box (*E. polyanthemos*)
- Life-histories of the dominant eucalypt species differ for the two forest types:
  - Tall-open forests re-establish via germination of canopy-stored seed, as a result the forests are even aged
  - Mixed species open forests predominantly regrow via sprouts from the base (lignotuber) or stem (epicormic) but can also regenerate from seed, therefore can develop into multi-aged, multi-structured forests

TYPICAL BURNT MIXED-SPECIES FOREST

TYPICAL BURNT ASH-TYPE FOREST

STATE OF KNOWLEDGE

EFFECT OF FIRE ON CATCHMENT YIELD - FORESTED CATCHMENTS

- In tall-open forests, a prolonged period of decreased catchment yield follows any fire that is hot enough to kill the eucalypt overstorey
- This results from an increase in the amount of water used by vegetation:
  - dense stocking of seedlings (>30K ha^{-1} = ~ 7 m^2 ha^{-1} sapwood = LAI 4)
  - leaves of juvenille form (adapted to exploit abundant resources) with low water-use-efficiency
- The contribution of regenerating mixed species forests to reductions in catchment yield following fire had not been documented
  - that is we didn't know how resprouting eucalypts contribute to post-fire forest hydrological cycles

EFFECT OF FIRE ON CATCHMENT YIELD - FORESTED CATCHMENTS

- As the process of regeneration is different for a mixed species forest we thought it was unlikely that they would exhibit the same patterns of vegetation water-use seen in tall-open forests
  - stocking rates remain unchanged, sapwood areas only minimally altered (e.g. firescars), LAI to pre-fire rates within three years
- Whilst the extent and duration of post-fire reductions in catchment yield should differ for the two forest types, there was still potential for reductions in catchment yield after fire in mixed species forests
  - In recently burnt mixed species forests there exists a window where LAI is almost equal to that immediately preceding fire, but when the canopy is composed of heavily transpiring juvenile foliage rather than hydrologically-conservative adult foliage

OUR AIMS

QUANTIFYING OVERSTOREY WATER USE

- Examine the eco-hydrology of mixed-species eucalypt forests as they regenerate from crown-removing fires.
- The primary question we wanted to answer for the mixed-species forests burnt in the 2009 fires in SE Australia was:
  - Do mixed-species forests follow the same trend as Ash-type forests and have a lengthy period of reduced catchment yield following crown-removing fire?

OR

  - Do mixed-species forests have a shorter period of reduced catchment yield following crown-removing fire?

OUR AIMS

UNDERSTANDING LEAF PHYSIOLOGY

- Our secondary questions aimed at being able to extrapolate the findings from our particular study sites to other areas.
- Leaves are the site of greatest water loss from trees. We investigated the nature and extent of changes in the structure and physiology of leaves from regenerating eucalypts from mixed-species forests. Specifically our research questions were:
  - What leaf properties exert the most control over tree water use in juvenille leaves on epicormic branches?

  AND

  - What regulates gas exchange and leaf hydraulics in juvenille leaves on epicormic branches?

OUR AIMS

MODELLING

› Once we had a firm grip on the patterns of leaf ontogenetic development for leaves on epicormic branches, we wanted to see how well they could be described by existing eco-hydrological models. Specifically our research questions were:

- How uniform are our forests with those of the rest of the world, that is could patterns in overstorey transpiration be explained by an existing eco-hydrological model, such as “Soil-Plant-Atmosphere” (SPA)?

AND

- Can we develop a model for tree water use that bridges the gap between empirical models that are computationally efficient and have few parameters, and detailed process models with many parameters?

AND

- Can we develop a model that can be used by the general public, that is one that is robust with very minimal and easily-collected parameters?

PROGRESSION OF RESEARCH

PHASES OF RESEARCH

- Design the experiments (Jan 2010)
- Establish field sites (March 2010, April 2011)
- Maintain field sites (March 2010 – March 2013)
- Conduct field campaigns
- Analyse data (2010 – 2013)
- Prepare manuscripts for publication (2011 – 2013)
- Prepare Firenotes for distribution by BCRC (2012 – 2013)
- Present findings at forums and conferences (2011 – 2013)

SITE DESCRIPTIONS

“STANLEY” SITES

- Located in the mixed species forests of NE Victoria, to the south of Stanley
- Adjacent paired burnt (February 2009) and unburnt at two elevations:
  - “High” (800 m a.s.l.)
  - “Mid” (600 m a.s.l.)

PROGRESSION OF RESEARCH

ESTABLISHMENT OF EXPERIMENTAL DESIGN

- Two separate experiments were initiated for this project:
  - Quantifying overstorey water use
  - Understanding leaf physiology
- Quantifying overstorey water use
  - We decided upon paired burnt and unburnt plots for each of the dominant species within mixed species forests at Stanley, NE Victoria
  - We wanted two locations where the forest type differed such as high and mid elevation
  - Our intent was to measure sap-flow and environmental variables for all of 2011 and 2012
- Understanding leaf physiology
  - We needed three regenerating trees of the two most dominant species
  - We wanted to measure changes to the physiology and structure of leaves as the trees regenerated, so decided upon annual campaigns for the duration of the project

PROGRESSION OF RESEARCH

ESTABLISHMENT OF FIELD SITES

› Understanding leaf physiology:

2010

- We found a site with adjacent suitable trees in a secluded clearing
- Field site was established in March 2010

› Quantifying overstorey water use:

2011: All high- and mid-elevation sites were selected & established which involved:

- Full site description and inventory of overstorey trees;
- Photography of overstorey and understorey leaf area
- Installation of equipment to record sap-flow in overstorey trees, soil moisture within the plots and meteorological variables within the canopy (light, rain, wind, temperature and relative humidity).

PROGRESSION OF RESEARCH

DESCRIPTION OF FIELD CAMPAIGNS

› Understanding leaf physiology

- To understand how leaf physiology changes with recovery from fire we visited the forest for three annual campaigns in April of 2010, 2011 and 2012:
- Each year we measured
  - Structure of the canopy leaf area, leaf type and patterns of distribution along the bole
  - Aspects of leaf physiology such as leaf anatomy (for venation patterns, hydraulic conductance of leaves, stomatal features) leaf chemistry (nitrogen and bulk carbon isotope signature) and leaf gas exchange (stomatal conductance, photosynthesis and respiration) and leaf water status (water potential and PV curves)

PROGRESSION OF RESEARCH

DESCRIPTION OF FIELD CAMPAIGNS

- Quantifying overstorey water use
  - Tree water use was continually measured via heat ratio method
  - Sites were visited fortnightly for the duration of the experiment to ensure equipment was functional (goat-proofing, fixing burnt-out probes, cleaning solar panels)
  - We also periodically visited for imaged leaf area of overstorey trees and understorey vegetation, and measured parameters to describe the physiology and hydraulic features of leaves from burnt and unburnt trees
- Meteorological drivers of tree water use (soil moisture, light and vapour pressure deficit) were also continuously recorded on-site

COLLECTION AND ANALYSIS OF DATA

QUANTIFYING OVERSTOREY WATER USE - ENVIRONMENT

- The flow of water through soil, into a plant and out through its leaves (transpiration) is controlled by the environment within the soil (soil water content), the structure of a leaf and the atmosphere around the tree crown.
- Water moves from wetter environments to dry. As a result, soil moisture content and structure (the capacity to retain moisture), air temperature and relative humidity are all important factors in tree water use.
- Additionally, as water moves from soil, through a plant and into the atmosphere it meets resistance along the way. The greatest resistance arises in the leaf; at the pores (stomata) in the leaf surface through which water exits, and at the layer of air directly adjacent to the leaf surface.
- Bright sunlight, warm, dry air and moist soil cause the stomata to open. In contrast, darkness, cool air, wet weather and dry soil can all cause stomata to shut.
- Micro-meteorological stations were established at each research site for the duration of the experiment. This enabled continuous measurement of the environmental variables that drive plant water use.

QUANTIFYING OVERSTOREY WATER USE - SAPFLOW

- The structure of a forest influences the amount of water it transpires. Older forests transpire less water than younger forests, and burnt Ash-type eucalypt forests use more water than the older forests they replaced
- Within the trunk and stems of a tree, water moves through tissue called sapwood. Water moves through the sapwood of both old trees and young trees at the same rate
- As a result, the difference in water use between burnt and unburnt forests depends on the total amount of sapwood in the forest. To calculate how much water is transpired by trees, the number of trees in a given area needs to be known, along with what proportion of their trunk consists of sapwood.

COLLECTION AND ANALYSIS OF DATA

QUANTIFYING OVERSTOREY WATER USE - SAPFLOW

- Sensors were installed into the sapwood of individual trees of a range of sizes to measure the rate of movement of water through the stem. Sapflow was measured using the Heat Ratio Method
- Each probe set consists of two needles and a heater probe
  - Each needle contains two thermocouples at different lengths (to accommodate varying sapwood areas)
  - Sap velocity is determined via the ratio of increase in sapwood temperature above and below a heater needle following a heat pulse, and is proportional to heat pulse velocity
- Sap flow was recorded at half-hourly intervals, and patterns of water movement were interpreted using micro-meteorological data.

COLLECTION AND ANALYSIS OF DATA

QUANTIFYING OVERSTOREY WATER USE - SAPFLOW

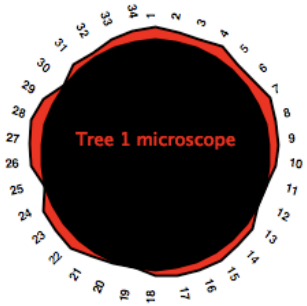
› Individual-tree measures of sapflow was then scaled to overstorey vegetation water use:

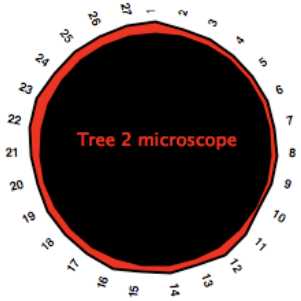
- We determined the species-specific relationship between sapwood area and bole diameter
- Measured the radial and azimuthal variation in sapflow for a subset of trees
- And combined this with results of our initial site inventories to obtain an estimate of tree water use per hectare

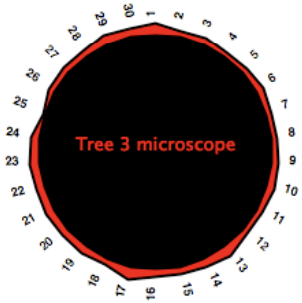
COLLECTION AND ANALYSIS OF DATA

QUANTIFYING OVERSTOREY WATER USE - LEAF AREA INDICIES

- Overstorey leaf area was measured as the average of repeated (at least 25) upward looking digital images (Macfarlane et al 2007)
- Overstorey and understorey foliage cover was also photographed using the methods of Macfarlane and Ogden (2011)
- From these images we estimated leaf area index of the understorey
- These images were collected three times throughout the experiment:
  - March & December 2011, and April 2012.


Tree 1 microscope


Tree 2 microscope


Tree 3 microscope

COLLECTION AND ANALYSIS OF DATA

QUANTIFYING OVERSTOREY WATER USE - PHYSIOLOGY

- We measured a range of physiological variables from leaves of regrowth and mature trees
- All trees were accessible via hydraulic platform
- Three trees of each species were measured twice during 2012 (early March and late April) for:
  - Photosynthesis
  - Stomatal conductance
  - Leaf transpiration rate
  - Leaf water potential

COLLECTION AND ANALYSIS OF DATA

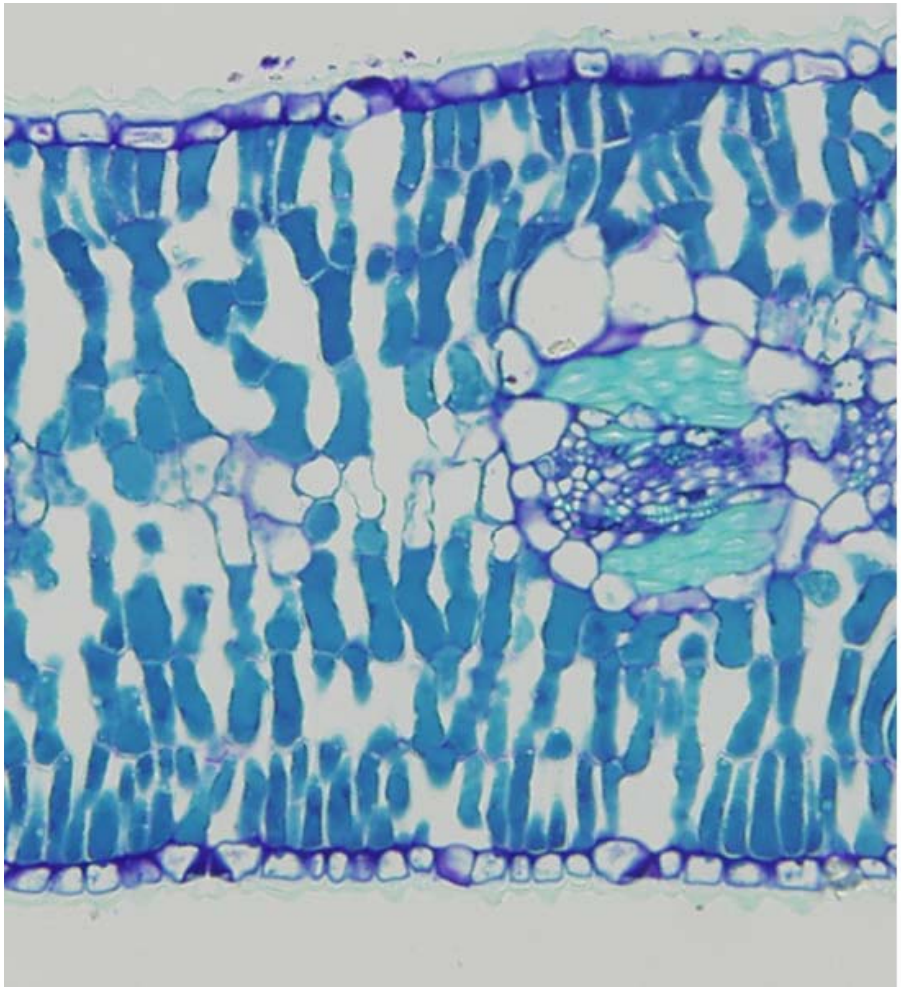
UNDERSTANDING LEAF PHYSIOLOGY – BRANCHING PATTERNS

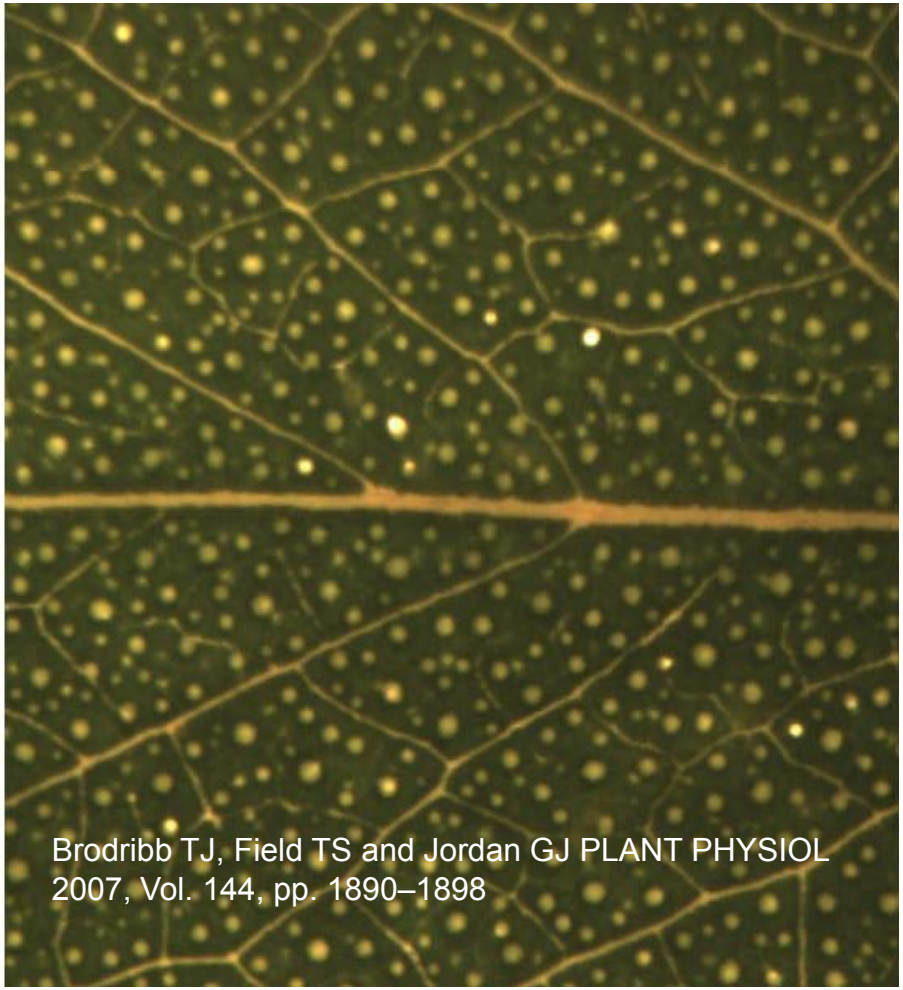
- The rate at which water flows from soil to the atmosphere through a plant is influenced by the demand for water by leaves in the canopy.
- We needed to know the 'leafiness' (leaf area) of the regenerating forests, along with the structural properties of leaves to assess how much water is used by the canopy throughout the day and during different times of the year.
- In forests that regenerate via sprouting photography sometimes does not work particularly well as leaves are clustered tightly around the trunk and stems and images are difficult to interpret.
- In situations like this, LAI photography is supplemented with actual measurements of leaf area. We counted number and measured the size of branches along the tree trunk and stems, and determined the relationship between branch size and leaf area
- From these measurements we calculated the total area of leaves for each tree.

COLLECTION AND ANALYSIS OF DATA

UNDERSTANDING LEAF PHYSIOLOGY – LEAF ANATOMY

- Other sources of resistance to water loss within an individual leaf need to be investigated.
- The ‘porosity’ of leaves was determined by counting the number of stomata, measuring their size and the maximum aperture of the stomatal pore or how wide the stomata can open.
- Patterns in leaf anatomy were further examined in order to calculate the hydraulic conductivity of a leaf.
- This involved measuring the perimeter of ‘wet’ cells (that is, types of cells known to evaporate water) in relation to the volume of airspace within a leaf, and coupling these measurements to other anatomical features of leaves such as the density of water-supplying veins, and proximity of stomata.



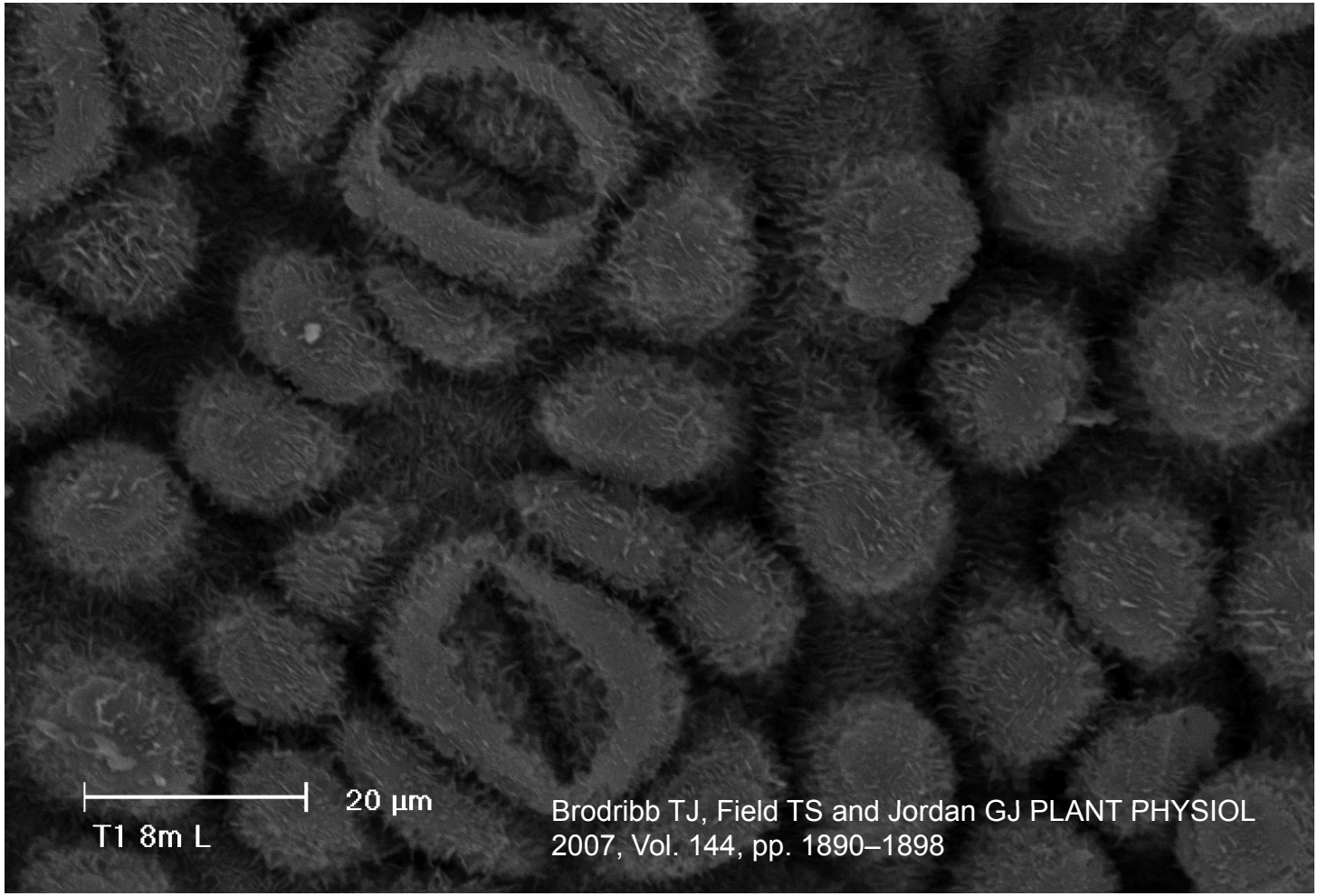


Brodribb TJ, Field TS and Jordan GJ PLANT PHYSIOL 2007, Vol. 144, pp. 1890–1898

COLLECTION AND ANALYSIS OF DATA

UNDERSTANDING LEAF PHYSIOLOGY – LEAF GAS EXCHANGE

- Trees cannot photosynthesise without losing water through their stomata, so knowing the photosynthetic physiology of regenerating eucalypts is another aspect we studied.
- In April 2010, April 2011 and April 2012 we assessed aspects of leaf physiology, all measurements were made *in situ* via an elevated work platform.
- On one leaf (the youngest full-expanded specimen) at three heights for each of the study trees we measured carboxylation capacity (V_{m25}), maximum potential electron transport rate (J_{m25}) and dark-adapted (> 12 hours in darkness) leaf respiration (R_d) using two recently calibrated infrared gas analysers (Li-Cor6400, Lincoln, NE, USA).
- During each campaign, on the same trees and at the same measurement heights we also measured stomatal conductance (g_s) and leaf water potential (Ψ) over the course of one day.

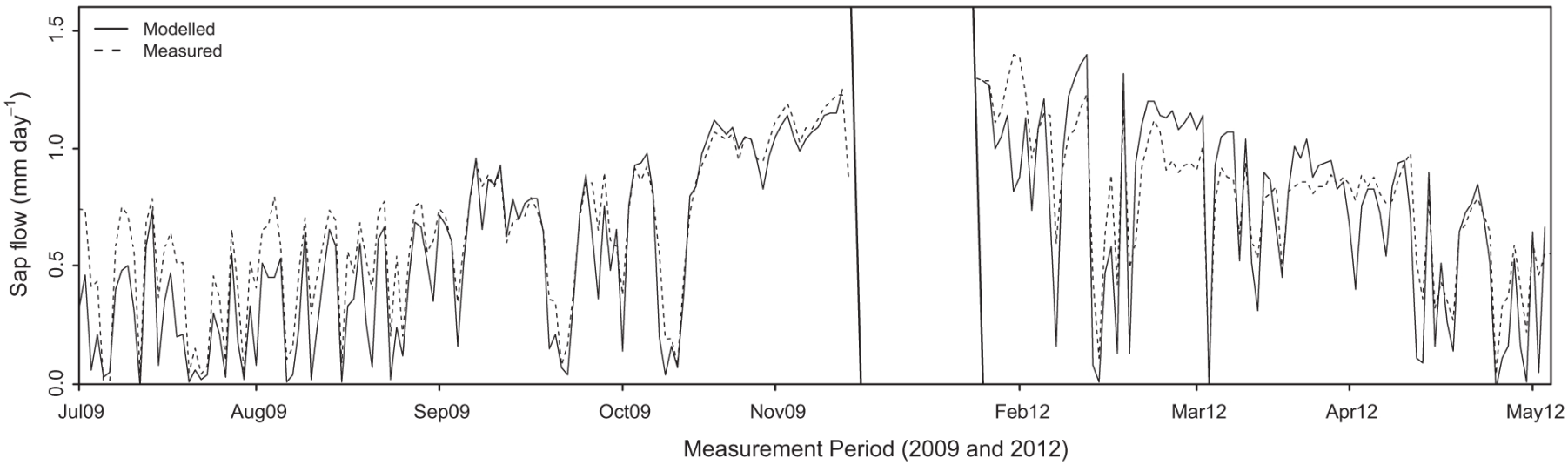


Brodribb TJ, Field TS and Jordan GJ PLANT PHYSIOL 2007, Vol. 144, pp. 1890–1898


DO NOT
OVERTAKE
TURNING VEHICLE
S.W.L. 350 KG.

RESULTS

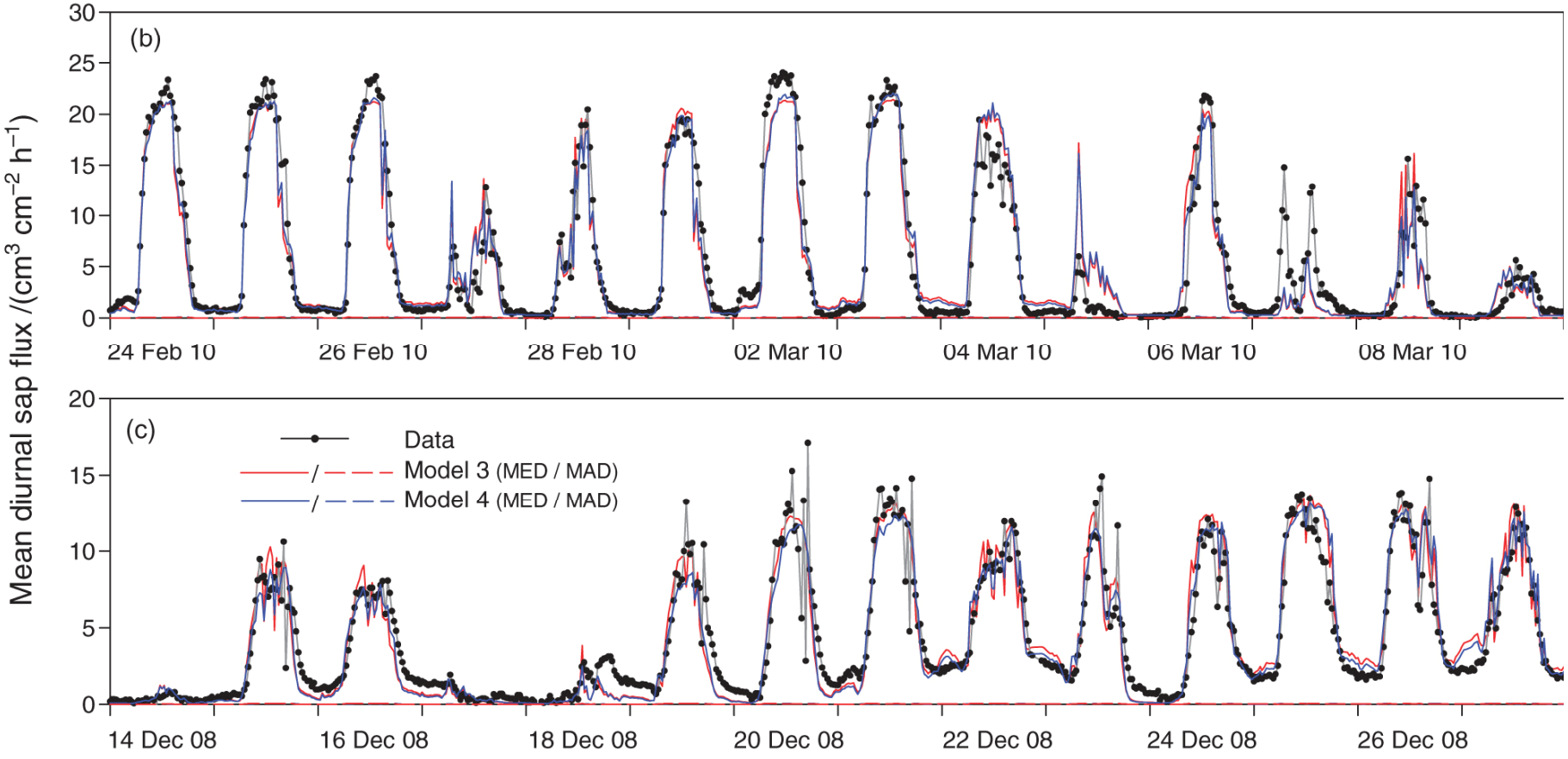
MODELLING FOREST WATER USE WITH EXISTING MODELS



Gharun M, Turnbull T & Adams M (2013) Validation of canopy transpiration in a mixed-species foothill eucalypt forest using a soil–plant–atmosphere model. *Journal of Hydrology* 492: 219–227

RESULTS

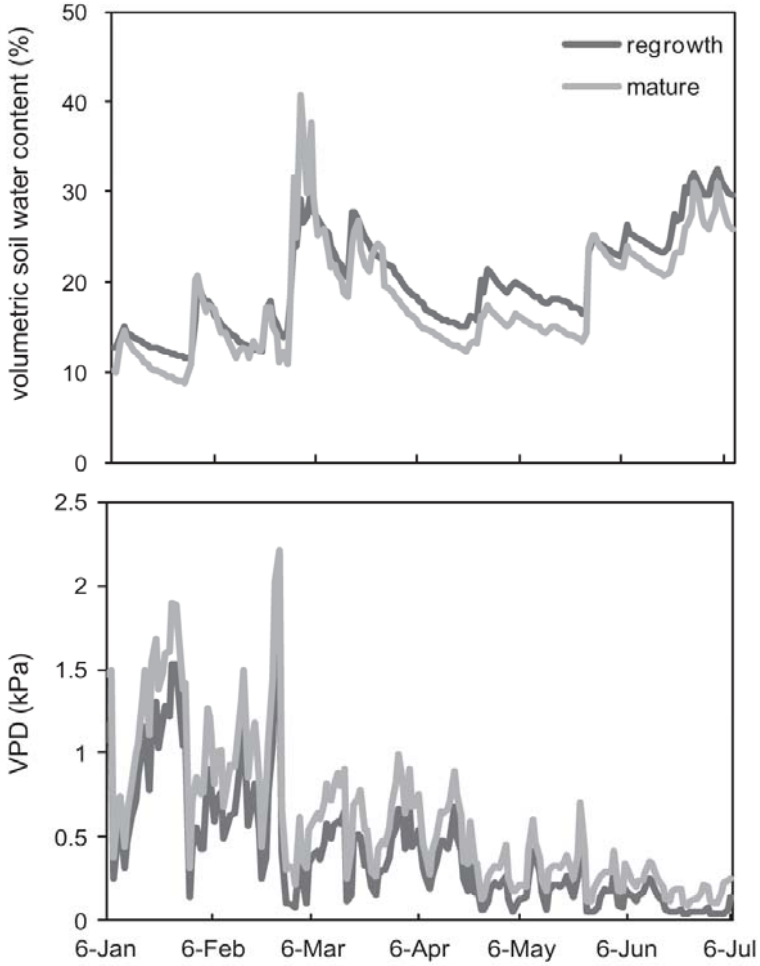
MODELLING MIXED SPECIES FOREST WATER USE WITH OUR MODELS



Buckley T, Turnbull T & Adams M (2012) Simple models for stomatal conductance derived from a process model: cross-validation against sap flux data. *Plant, Cell and Environment* 35: 1647–1662.

RESULTS

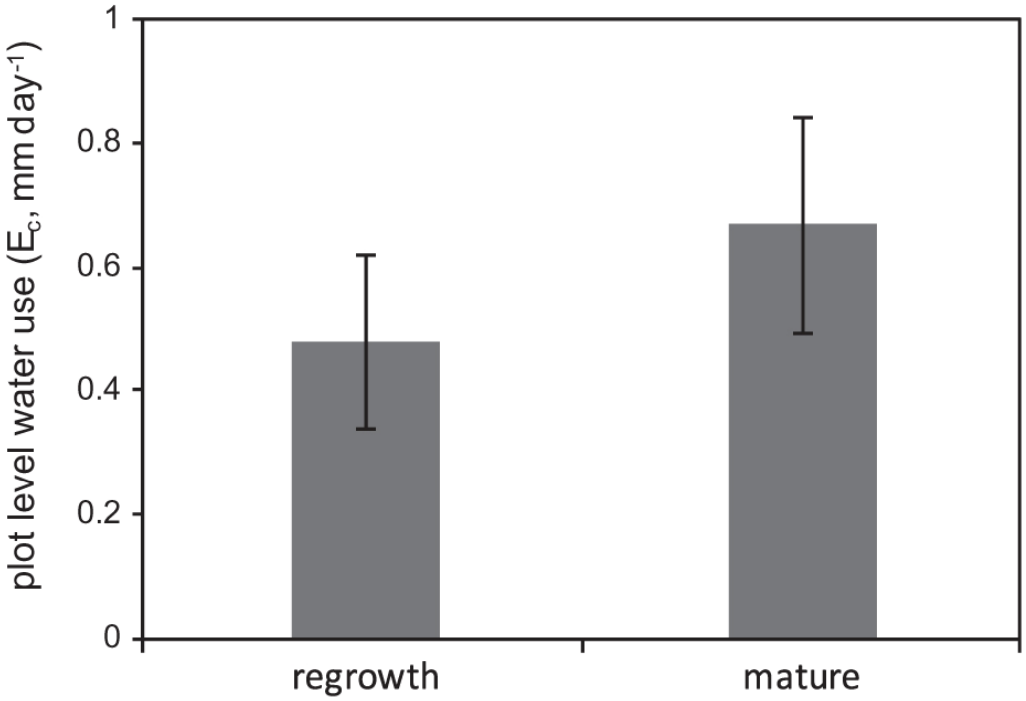
COMPARISON OF ENVIRONMENT AFTER FIRE IN MIXED SPECIES FOREST



Gharun M, Turnbull T & Adams M (2013) Stand water use status in relation to fire in a mixed species eucalypt forest. *Forest Ecology and Management* 304: 162–170.

RESULTS

COMPARISON OF TREE WATER USE IN MIXED SPECIES FOREST



Gharun M, Turnbull T & Adams M (2013) Stand water use status in relation to fire in a mixed species eucalypt forest. *Forest Ecology and Management* 304: 162–170.

OUTPUTS

For the BCRC

- 12 internal quarterly reports
- Two annual reports (2011, 2012)
- One final project report (2013*)

- Three posters for BCRC/AFAC conference (2011, 2012, 2013)
- Two RAF presentations (October 2011, October 2012)
- One field-day for end-users (March 2012)

- One literature review (2011)
- Two Fire Notes (2013 & *in prep)

- One proposal for long-term maintenance of sites (2011)

OUTPUTS

Peer reviewed manuscripts & conference attendance

- Buckley T, Turnbull T & Adams M (2012) Simple models for stomatal conductance derived from a process model: cross-validation against sap flux data. *Plant, Cell and Environment* 35: 1647–1662.
- Gharun M, Turnbull T & Adams M (2013) Validation of canopy transpiration in a mixed-species foothill eucalypt forest using a soil–plant–atmosphere model. *Journal of Hydrology* 492: 219–227.
- Gharun M, Turnbull T & Adams M (2013) Stand water use status in relation to fire in a mixed species eucalypt forest. *Forest Ecology and Management* 304: 162–170.
- **
- Gharun M *et al.* (2011) Post fire Water Use Dynamics in Mixed Species Eucalypt Forests *IAHS Banff Wildfire and Water Quality Conference*
- Turnbull T *et al.* (2011). Canopy re-establishment and leaf physiology of resprouting eucalypts after wildfire**.** *IAHS Banff Wildfire and Water Quality Conference*

STATE OF KNOWLEDGE NOW

- What we know now
- Did we expect that?
- What challenges remain…

ACKNOWLEDGEMENTS

- Mark Adams
- Tom Buckley
- Mana Gharun
- Alexandra Barlow

- Mike Kemp
- Neil Murdoch
- Audrey Dehienzelin
- Jeremy Platt
- Jessica O’Brien