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Severe dieback first noticed in the mid-1990s in eucalypt woodlands of the Shire of York

Novel Hypothesis of Growth-Imbalance Predicts A Worrying Trend for Eucalypt Woodlands Under Climate Change

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INTRODUCTION

Crown decline of *Eucalyptus wandoo* (Wandoo) in southwestern Australia (SWWA) has been episodic in contemporary times. **Pre-mature foliage yellowing**, **twig** and **branch dieback** occurred through the 1970s and 1990s, with **redistribution of live canopy** and occasionally death of trees. However, **canopy leaf area** of affected trees **recovered** by vigorous **re-sprouting of epicormics** in years interceding dieback (1980s and 2000s).

Several similar disorders in Australian eucalypt communities have been attributed to **drought**, **insect attacks** and **unnatural fire regimes**[1]; however, incipient **causes**, on the whole, remain **poorly understood.**

Our **objectives** were: to elucidate abiotic and biotic **causes of E. wandoo decline** in SWWA; **develop** and **evaluate a general hypothesis** for eucalypt decline in Australia.

METHODS & DATA

Eight sites in **four disjunct Wandoo stands**, ~50 km apart; monitored on-the-ground for canopy health from 2005-2008; assigned to **healthy**, **declining** and **recovering**

Long-term climate interpolated[2] **at the stand scale** (0.5°), analyzed for deviations:

- from mean monthly rainfall, 1890-2007
- from mean min/max temperature and vapour-pressure-deficit (VPD), 1957-2007

Healthy (2 per site) **versus dieback-affected** (2 or 3 per site) reference trees in six core sites measured for:

- **Wood-boring damage** by Cisseis fascigera (Coleoptera: Buprestidae); the principal biotic agent contributing to branch decline[3,4]
- Gradients in **branch moisture** (θ): (spring-summer-autumn)*(distal-proximal)
- Water-relations: **leaf xylem-pressure-potential** (Ψ_X), gravimetric **soil moisture** (θ_{VT}, to 50 cm), inferred **evapotranspiration** (Et);
- Growth: **stem increment** (BAI, at 1.3 m), inferred **leaf area** (LA), qualitative indices (reproductive capacity (RI), canopy flushing)
- **Micro-climate** (rainfall, temperature, relative humidity, instantaneous VPD)

RESULTS: ABIOTIC-BIOTIC CAUSAL FRAMEWORK

Decline causal agents summarized by hierarchical abiotic-biotic framework (Fig. 1).

- **Climatic pre-conditioning: Phase I.** Wet-dry climatic sequence of the 1990s. **Phase II.** Canopy development in disequilibrium with transpirational demand (Et) during high VPD ($+LA_1 \rightarrow -LA_2$).
- **Biotic consolidation: Phase III.** Water stress (cavitation), loss of negative feedback on borer populations (TH2, see Fig. 2) and ultimately, branch failure ($-LA_3$). **Phase IV.** Resumption of normal or sub-normal sapflow gradients (High θ) to established epicormics.

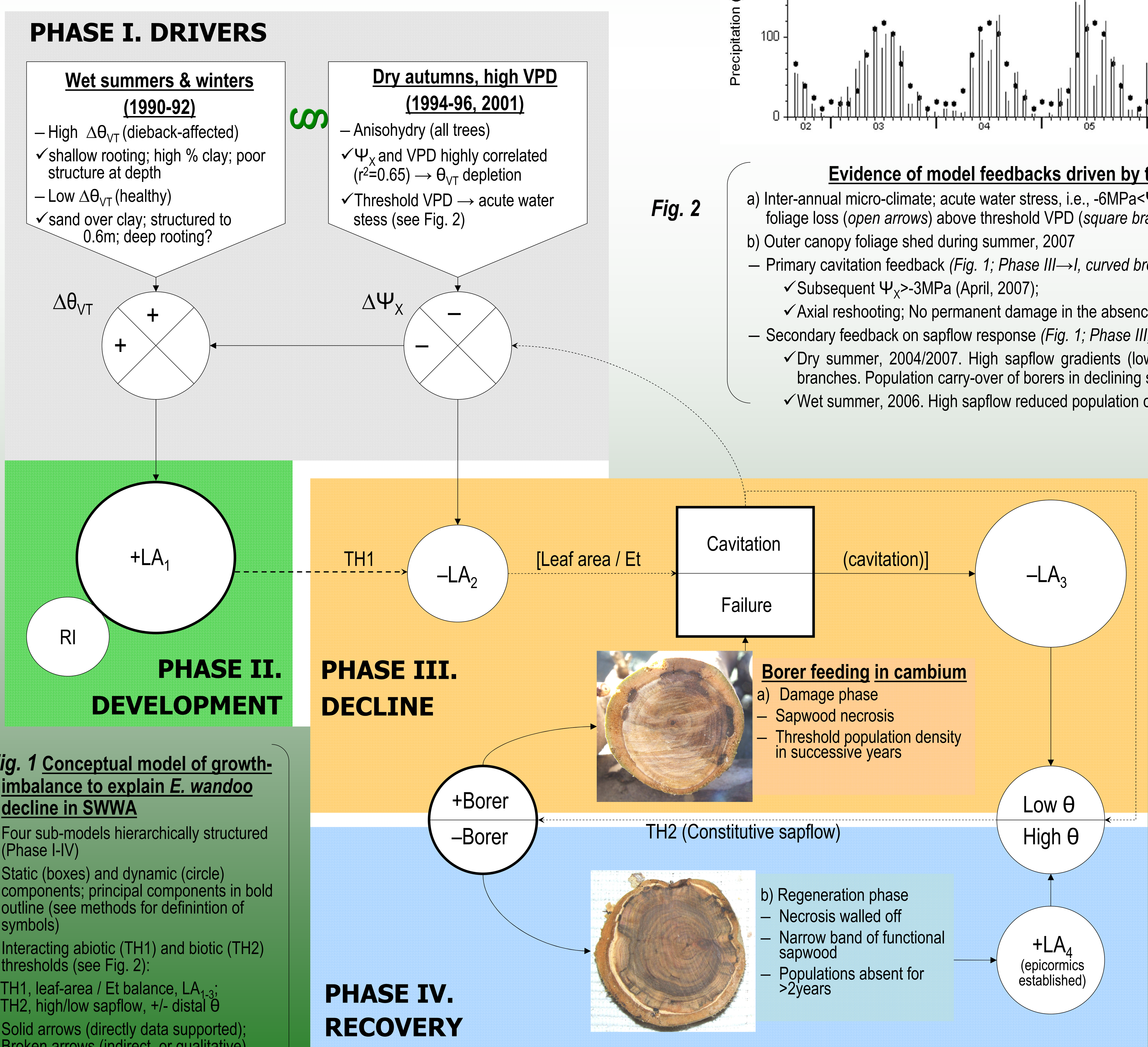
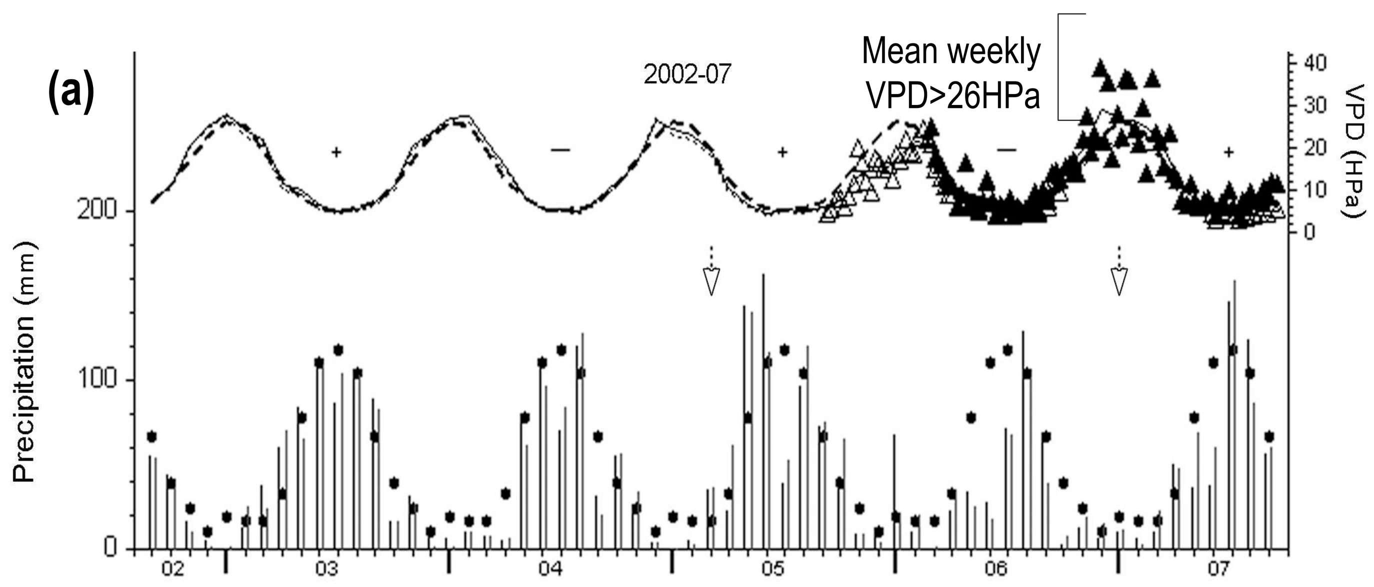


Fig. 1 **Conceptual model of growth-imbalance to explain *E. wandoo* decline in SWWA**

- Four sub-models hierarchically structured (Phase I-IV)
- Static (boxes) and dynamic (circle) components; principal components in bold outline (see methods for definintion of symbols)
- Interacting abiotic (TH1) and biotic (TH2) thresholds (see Fig. 2): TH1, leaf-area / Et balance, LA_{1-3}; TH2, high/low sapflow, +/- distal θ
- Solid arrows (directly data supported); Broken arrows (indirect, or qualitative)

(a)



(b)

Flynn forest block. Feb, 2007

Fig. 2

Evidence of model feedbacks driven by threshold VPD

a) Inter-annual micro-climate; acute water stress, i.e., $-6MPa < \Psi_X < -4MPa$; negative BAI, and foliage loss (*open arrows*) above threshold VPD (*square bracket*)

b) Outer canopy foliage shed during summer, 2007

- Primary cavitation feedback *(Fig. 1; Phase III→I, curved broken arrow)*
  - ✓Subsequent $\Psi_X > -3MPa$ (April, 2007);
  - ✓Axial reshooting; No permanent damage in the absence of borers
- Secondary feedback on sapflow response *(Fig. 1; Phase III, square broken arrow)*
  - ✓Dry summer, 2004/2007. High sapflow gradients (low distal θ) on borer attacked branches. Population carry-over of borers in declining stands from 2004 to 2005;
  - ✓Wet summer, 2006. High sapflow reduced population carry-over

DISCUSSION

E. wandoo lowered Ψ_X under increasing VPD: critical **to extract tightly held soil water** in shallow clayey subsoils. 'Anisohydrists' tolerate drought[5,6]; however, our study identified a tipping point: very efficient **harvest of surface soil-water continues under atmospheric drought**.

Wet-dry climatic **oscillation** (over 5 or so years) including **very high VPD** late in growing season **drove** higher insect damage and **severe decline in 1990s**. **Twig** and **branch feeding C. fascigera favoured** high sapflow gradients of **water-stressed trees** (i.e., reduced distal θ)[4,7].

But why some trees, and not others? Answer: specific **soil micro-habitats preconditioned** to decline:

- **Healthy** on free-draining soils. Deeper roots and/or low inputs ($+LA_1$) **buffered to rapidly changing conditions.**
- **Dieback-affected** on heavy textured, and/or shallow soils. Shallow rooting and/or high $+LA_1$; **unsustainable Et during autumn**. Borer damage 'consolidated' through loss of feedback (i.e., TH2) (Fig. 2).

Growth-imbalance is an abiotic-biotic cascade (Fig. 1) **driven by** drought tolerant traits: **'opportunistic' growth**[8]; a **broad water-use envelope**, predicting an ominous future for E.wandoo and analogues under rapid climate change. Our results suggest **episodic decline is a 'natural' adaptation of certain eucalypts** to drought. However, **oscillations may** unhinge dynamic above-belowground equilibria and **drive long-term carbon deficit** if climatic trends continue.

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