Ecological Air Quality Standards

A Review of $PM_{2.5}$ Concentration Threshold Evidence

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RAMBOLL Bright ideas. Sustainable change.

Introduction | Australia's $PM_{2.5}$ ecological gap

WHAT IS ESTABLISHED

Human-health criteria. Australia's ambient $PM_{2.5}$ standards protect human health and wellbeing (NEPC, 2021).

Coarser dust. Vegetation effects are more commonly associated with dust loading and physical impacts on leaf surfaces.

THE ECOLOGICAL GAP

No ecological benchmark. No recognised $PM_{2.5}$ criterion protects vegetation and ecosystems.

Limited quantification. Vegetation is acknowledged in some AQIAs where it is considered a material receptor, but $PM_{2.5}$ effects are rarely assessed quantitatively.

WHY THIS REVIEW

Evidence indicates that elevated $PM_{2.5}$ can impair photosynthesis and stomatal conductance in plants. This review examines concentration–response evidence, observed effect levels and the knowledge gaps that constrain threshold development.

Can the evidence support an indicative quantitative benchmark?

Plant Physiological Responses

- Reduced net photosynthetic rate, constraining carbon assimilation and physiological performance
- Declines in stomatal conductance:
  - Reduce gas exchange and limits CO_2
  - Lowers transpiration rates

Plant Physiological Responses: Species Sensitivity

- The magnitude and timing of physiological responses vary among species due to differences in leaf surface morphology.
- Traits such as grooves, trichomes and surface roughness appear to influence particulate interception and the degree to which deposited particles affect stomatal function

Literature Review: Evidence Examined

- **Experimental evidence.** Controlled chamber studies were reviewed to assess concentration response patterns under short-term $PM_{2.5}$ exposure.
- **Field evidence.** Urban observational studies were reviewed to determine whether comparable physiological responses occurred under $PM_{2.5}$ exposure

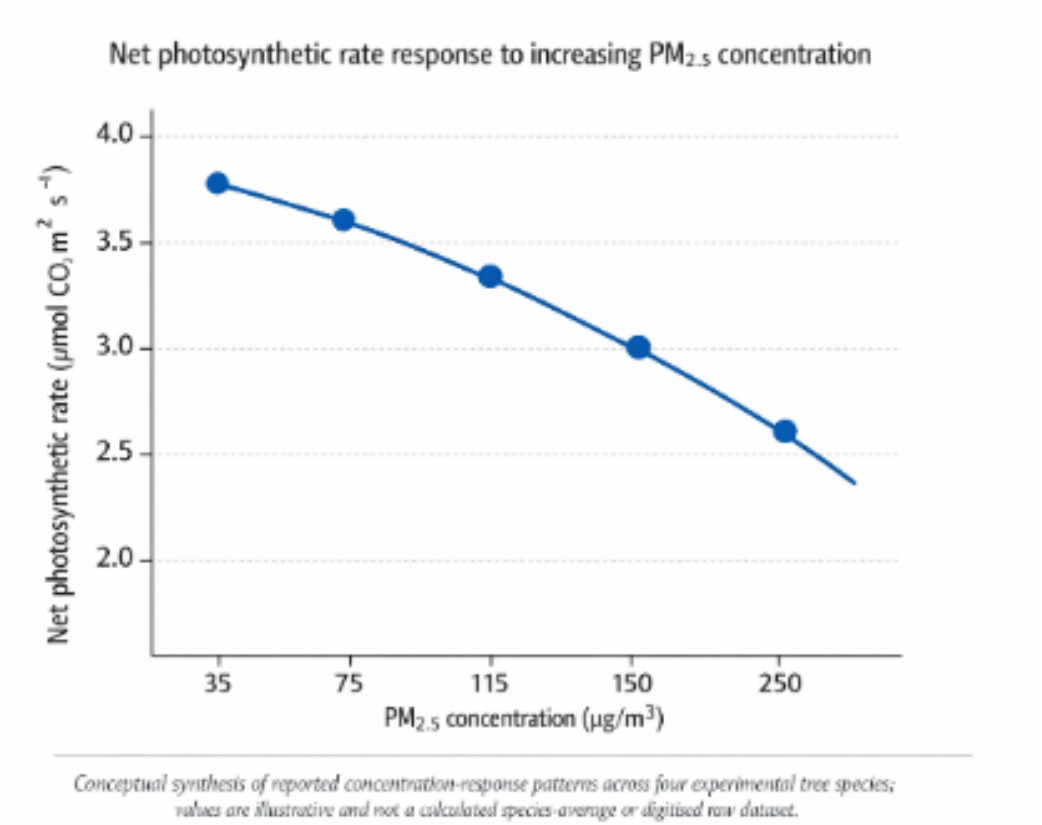
Concentration Response: Experimental Evidence

- **Study design.** Controlled chamber experiments examined $PM_{2.5}$ concentration–response effects across four tree species with contrasting leaf characteristics.
- **Exposure.** Plants were exposed to combustion-derived $PM_{2.5}$ concentrations from 35 to 250 μg/m^3 over approximately 10 hours.
- **Measurements.** Net photosynthetic rate and stomatal conductance were monitored throughout exposure (Yu *et al*. 2018; Li *et al*. 2019).

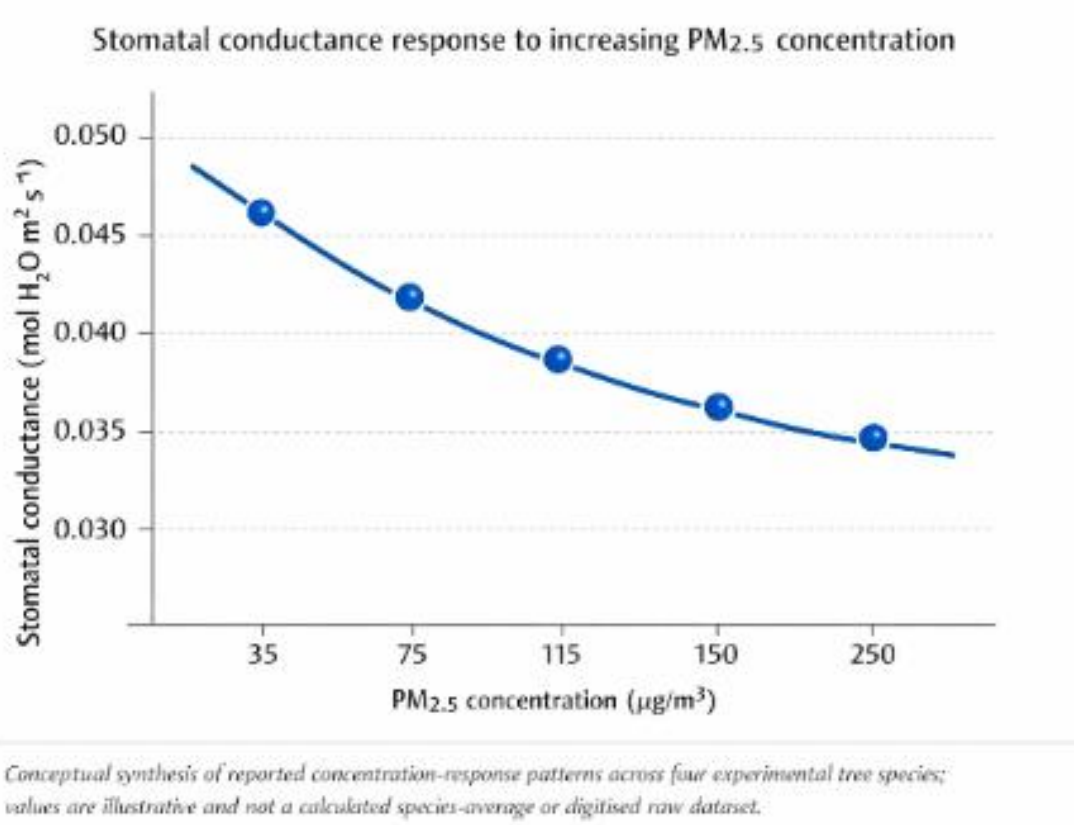
Concentration Response: Experimental Evidence

- **Concentration response.** Photosynthesis and stomatal conductance declined with increasing short-term $PM_{2.5}$ exposure; effects were clearer above approximately 50 µg/m^3 (Yu *et al*. 2018; Li *et al*. 2019).
- **Species sensitivity.** Leaf grooves, trichomes influenced particle interception and response magnitude. Species with greater groove proportion or the presence of trichomes may experience a partial buffering effect (Li *et al*. 2019).

Both physiological indicators deteriorate as exposure rises



Conceptual synthesis of reported concentration-response patterns across four experimental tree species; values are illustrative and not a calculated species-average or digitised raw dataset.



Conceptual synthesis of reported concentration-response patterns across four experimental tree species; values are illustrative and not a calculated species-average or digitised raw dataset.

Concentration Response: Field Based Evidence

- Demonstrates whether $PM_{2.5}$ related vegetation impacts observed under controlled conditions are also detectable under ambient exposure.
- Less precise than chamber experiments for defining concentration response relationships, it provides an essential basis for assessing ecological relevance under real world conditions.
- Australian field studies directly linking ambient $PM_{2.5}$ exposure to plant physiological responses limited, the field-based evidence reviewed based on overseas studies.

Concentration Response: Field Based Evidence

Field study design. Over four months, five plant species were compared at two Warsaw sites with similar weather but contrasting ambient PM_{10} exposure (Przybysz *et al.* 2014).

POLLUTED CITY-CENTRE SITE

47.9 $\mu g/m^3$

Monthly PM_{10} range: 38.5–63.3 $\mu g/m^3$

MODERATELY CLEAN CAMPUS

26.5 $\mu g/m^3$

Monthly PM_{10} range: 20.1–37.7 $\mu g/m^3$

WHAT THE COMPARISON SHOWED

At the more polluted site, most species showed **lower chlorophyll, fluorescence and photosynthetic rates** together with **higher stomatal resistance.**

Interpret with caution: responses varied by species, and local factors such as shading and other urban stressors could not be excluded.

Concentration Response: Field Based Evidence

Longer-term field study. Seven plant species were compared at the same two Warsaw sites over three years (Popek *et al.* 2018).

CITY-CENTRE SITE

25.5 $\mu g/m^3$ $PM_{2.5}$

CAMPUS SITE

19.6 $\mu g/m^3$ $PM_{2.5}$

AVERAGE PHOTOSYNTHETIC RESPONSE

13% lower at the more polluted city-centre site

Lower photosynthetic rates corresponded with **increased stomatal resistance.**

Species responses varied, reinforcing that sensitivity is not uniform.

Knowledge Gaps

- **No robust threshold or averaging period.** Short-term responses cannot be directly translated into an ecological benchmark and don't consider long-term ecological effects.
- **Limited Australian field evidence.** Direct links between ambient $PM_{2.5}$ and plant physiological responses remain poorly tested under local conditions.
- **Species sensitivity is uncertain.** Evidence covers few species, and the influence of leaf morphology—Australian native vegetation remains unclear.
- **Particle source and composition matter.** Chamber studies using combustion soot may not represent the complex mixtures found in ambient $PM_{2.5}$.

Conclusions

- **Ecological effects are credible.** Controlled and field evidence indicates that $PM_{2.5}$ can reduce photosynthesis and alter stomatal function.
- **Current evidence is indicative, not definitive.** It can inform effect ranges, but not a robust ecological threshold or averaging period.
- **Human-health standards are an interim reference.** They may support screening. Not derived to protect vegetation.
- **A precautionary approach is warranted.** AQIAs should explicitly consider ecological receptors based on available evidence but more research is required