a program of Healthy land & water

Literature review

Notes on rainforest and wet sclerophyll responses to fire

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1 Summary

This document is a summary of relevant literature around Australian rainforest and wet sclerophyll forest responses to fire. It provides short summary notes on each paper.

The search was limited to Australian papers, using a combination of the following search terms: 'rainforest + fire + Australia + plant response + obligate + seeder + resprouter + subtropical and wet sclerophyll + plant response + sub tropic + Lamington'.

The following authors were also searched:

- Ariane Allen.
- Andy Baker.
- Kirsten Benkendorff.
- David Bowman.
- Ross Bradstock.
- Hamish Clarke.
- Murray Ellis.
- Richard Geddes.
- Bec Gibson.
- Tom Lewis.
- Brett Murphy.
- Mark Ooi.
- Ross Peacock.
- Trent Penman.
- Owen Price.
- Cuong Tran.
- Tom Vigilante.
- Penny Watson.
- Rob Wheeler.
- Rob Whelan.
- Paul Williams.
- Alan York.

There are 31 papers for rainforest, 22 papers for wet sclerophyll and 7 papers for definitions.

RF = Rainforest

WSF = Wet sclerophyll forest

DSF = Dry sclerophyll forest

SEQ = South East Queensland

NP = National Park

NPWS = National Parks and Wildlife Service

C = Carbon

N = Nitrogen

P = Phosphorus

2 Rainforest

2.1 Baker, A. G. & Catterall, C. (2016). Managing fire-dependent vegetation in Byron Shire, Australia: Are we restoring the keystone ecological process of fire? *Ecological Management & Restoration*, 17, 47-55.

- Study includes wet sclerophyll forests (WSF) and Rainforest (RF) saplings in wet sclerophyll.
- Discusses fire suppression with some relevance, but not detailed.
- Restoring fire crucial for ecological processes and biodiversity.
- Number of plans and strategies exist that guide restoration of ecological processes.
- Study to determine appropriateness of fire intervals outlined in guidelines for sites threatened by fire exclusion.
- Examination of planning documents for fire excluded vegetation guidelines.
- Byron Shire study area vegetation communities: grasslands, heathlands, dry, wet, swamp sclerophyll, littoral, subtropical and warm temperate rainforest.
- 60 vegetation assessment and planning documents reviewed for 84 management sites.
- 33% of plans recognised fire dependent vegetation: 69% of NPWS and 20% non-NPWS.
- Significant difference between NPWS and non-NPWS fire recommendations, with NPWS recommending more fire.
- Reasons for recommended fire exclusion in fire dependent vegetation include: damage to rainforest understorey of WSF, threatened species, residential, koala mortality, and concern about WSF.
- Plans did not match recommendations for fire management.
- Higher fire exclusion than needed.
- Fire exclusion not recognised as a threat.
- Focus on rainforest in the region has inhibited understanding of fire exclusion threats and management for non- rainforest.
- No fire threatens wider community and ecological communities.
- Recommends guidelines and templates to identify fire exclusion appropriately.

2.2 Baker., A. G., Catterall., C. & Wiserman, M. (2022). Rainforest persistence and recruitment after Australia's 2019-2020 fires in subtropical, temperate, dry and littoral rainforests. *Australian Journal of Botany,* 70(3), 189-203.

- Numerous studies show that many rainforest plants survive fire by resprouting and post-fire seedling recruitment, but data is lacking for several major Australian rainforest types.
- Study examines fire resilience traits among 228 taxa of woody rainforest plants less than 1 year after 2019-2020 fires.
- ≥ 5 records of complete crown scorch, resprouting occurred in 63% of taxa overall and 61% of late-successional taxa.
- Species richness of woody plants increased 22% post fire due to high rates of persistence and emergence of new taxa.
- Stem density increased ~400% post fire due to high rates of resprouting and reproduction through suckering and seedling recruitment.
- Larger stems (>10 cm diameter at breast height) were not significantly reduced in forest stands.
- High resprouting rates in small rainforest plants (1 cm diameter at breast height, 1 cm tall).

- Study found high fire resilience extends to previously unstudied major rainforest classes (subtropical, dry, littoral) and late-successional rainforest taxa.
- Findings suggest that most rainforest pioneers can become resilient to removal by occasional fire.

2.3 Bowman, D. M. J. S. (2000). Australian Rainforests: Islands of Green in a Land of Fire, Cambridge, Cambridge University Press.

- Focus on how rainforests evolved and are influenced by fire.
- Generally understood that the main difference between rainforest and sclerophyll forests are their differing abilities to respond to recurrent fire – discusses this in detail.
- Frequently referenced book provides detailed information and case studies of rainforest and fire between the monsoon tropics and temperate Tasmanian rainforests.

The following section provides notes on each chapter with page references to points of interest.

Preface

- Webb (1959) and (1968) was key in defining rainforest and distribution which is still used in Australia today.
- Purpose of book is to pull together all rainforest literature including complementary books.

Chapter 2. What is Australian Rainforest?

- Definitions and trouble with defining Australian rainforest.
- Can be defined by light environment, susceptibility to fire, canopy, biogeographical taxa (p. 40).
- No consensus on definition of rainforest (p. 46).

Chapter 3. The sclerophyll problem

- Sclerophyll isn't objective enough to define rainforest and shouldn't be used.
- Discusses issues with current definitions of sclerophyll and rainforest.
- Differences in anatomical, chemical, physical characteristics of rainforest and non- rainforest should be used to help define rainforest.

Chapter 4. The edaphic theory I: The control of rainforest by soil phosphorus

- Rainforest not just restricted to high phosphorus soils – they grow in wide range of soils.
- Soils in SEQ subtropical rainforest (p. 76). Adjacent vegetation grows in soils with similar phosphorous levels or no difference to where rainforest grows.

Chapter 5. The edaphic theory II: Soil types, drainage, and fertility

- Rainforest grow in a range of soil textures, drainage and soil fertility.
- Subtropical rainforest generally restricted to highly fertile soils, but *Eucalyptus pilularis* occurs in same soils (p. 91).

Chapter 6. The climate theory I: Water stress

- Some rainforest trees extremely drought tolerant (p. 99).
- Some subtropical species are drought tolerant: *Flindersia collina*, *Excoecaria dallachyana*, *Mallotus philippensis*, *Araucaria cunninghamii* (p. 116).
- Rainforest not just restricted to high rainfall areas (e.g. desert species).

Chapter 7. The climate theory II: Light and temperature

- Subtropical rainforest frost tolerant (p. 150-151). Gives ranges for some species.

- Discusses frost and fire interaction. Frost makes vegetation more fire prone (e.g. bunyas and grasslands).
- *Casuarina litorali* maximum growth in shade.

Chapter 8. The fire theory I: Field Evidence

- Fire controls boundary.
- Ash (1988) made assumption rainforest can't survive fire (i.e. it is pyrophobic).
- Evidence suggests rainforest resprout from low intensity fires but not high intensity and can recover from a single fire.
- Resistant to mild fires but can retreat if compounded with other disturbances such as cyclones and droughts.
- Absence of fire/Aboriginal burning leads to rainforest invasion – fires control rainforest boundaries.
- Subtropics: Rainforest can expand if protected from fire (p. 176).
- Bunyas example: Rainforest -grassland maintained by Aboriginal fire.
- NE coast NSW: charcoal restricted to sclerophyll and ecotone, corresponding with *Nothofagus moorei.*

Chapter 9. The fire theory II: Fire nutrient cycling, and topography

- Nutrient cycles vary between rainforest types.

Chapter 10. The fire theory III: Fire frequency, succession, and ecological drift

- Inability to survive recurrent fires but can survive a single fire.
- Understanding frequency of fires is essential for management.
- Frequency of fires can alter landscape by causing ecological drift to a different ecosystem.

Chapter 11. The fire theory IV: Aboriginal landscape burning

- Historical Aboriginal burning affected distribution of rainforests.
- Climate more of an influence than Aboriginal burning, based on palaeoecological data.
- Discusses rainforest distribution as a response to climate change.
- Grass mosaics in rainforest to favour game species.

Chapter 12. The fire theory V. Aridity and the evolution of flammable forests

- Adaption to fire and evolution of rainforest and eucalypt species.
- Rainforest and non-rainforest vegetation only differ in ability to withstand recurrent fire.

Chapter 13. The fire theory VI. Fire management and rainforest conservation

- No one size fits all, even rainforests require different fire regimes.
- Need communication and innovative means to manage rainforests in the future.

2.4 Campbell, M. L. & Clarke, P. J. (2006). Response of Montane Wet Sclerophyll Forest Understorey Species to Fire: Evidence from High and Low Intensity Fires. *Proceedings of the Linnean Society of New South Wales,* 127, 63-73.

- Response of wet sclerophyll shrub and subcanopy species to crown fire. Two study areas compared high and low intensity fires at Washpool National Park and Mummel Gulf National Park, NSW.

- To determine fire traits based on fire intensity, the study looked at difference in responses between overlapping rainforest and sclerophyll species and if environmental and historical variables correlate.
- Observations found that 80% of woody understorey species resprouted after both fires.
- Consistent with species in Northern NSW but in contrast to Victorian and SW WA wet sclerophyll species.
- **Results:** Rainforest species resprouted but did not exhibit seedling recruitment.
- Rainforest species responses vary between environments.

2.5 Clarke, P. J., Lawes, M. J., Murphy, B. P., Russell-Smith, J., Nano, C. E. M., Bradstock, R., Enright, N. J., Fontaine, J. B., Gosper, C. R., Radford, I., Midgley, J. J. & Gunton, R. M. (2015). A synthesis of postfire recovery traits of woody plants in Australian ecosystems. *Sci Total Environ,* 534, 31-42.

- Fire influences evolution, distribution, and plant abundance.
- Good for definition of resprouting and recruitment from seed.
- Brief mention of what affects fire and fire regimes.
- Summary of plant responses from 2880 taxa, 8 major fire-prone ecosystems covering 87% of Australia including all rainforest and eucalypt types.
- Results will be used to predict ecosystem and community shifts.
- Limited to herbaceous taxa.
- Each 2880 taxa attributed growth form, resprouting type, post-fire seed type and classed.
- **Results:** 78% rainforest taxa resprouted, second highest to savanna at 88%.
- Suggest rainforest resprouting is an ancestral state in Eudicots.
- Less WSF eucalypts are obligate seeders than thought.
- Rainforest unable to recruit after high intensity fires and will decline after frequent fires.
- Appendix 2: Temperate rainforest 67 – 90%, subtropical 60% resprout.
- Good for generalised taxa and ecosystem response to fire.

2.6 Clarke, P., J., Prior, L., D., French, B., J., Vincent, B., Knox, K., J. E. & Bowman, D., M. J. S. (2014). Using a rainforest-flame forest mosaic to test the hypothesis that leaf and litter fuel flammability is under natural selection. *Oecologia*, 176, 1123-1133.

- Rainforest no fire stimulated seed recruitment.
- New England Tablelands Gibraltar Range-Washpool NP.
- Tested flammability of rainforest, DSF, WSF based on litter fuel.
- Mentions rainforest resprouters.
- Comparison of WSF, DSF and rainforest flammability and recovery traits.
- Basic definition of WSF, DSF, rainforest and fire intervals: rainforest 50 – 200 years, generally low severity; eucalypt forests 10 – 20 years, generally high severity.
- Flammability traits: large narrow leaves, retention of dead branches, ladder fuels, leaf size, shape, chemistry, oil and water content.
- Study of flammability of leaves: fresh and oven dry.
- Rainforest has no fire stimulated seed recruitment, gaps in canopy trigger regeneration.
- Test Mutch hypothesis: species that can regenerate from fire are more flammable.
- Gibraltar Range-Washpool NP study site.

- Sampled ground and litterfall post bush fire 2002 and compared against forest type and three (3) fire severities of low, high, and long unburnt (40 – 80 years).
- No eucalypt species in rainforest to sample.
- **Results:** Leaf litter flammability wasn't significantly different between forest types.
- Litterfall flammability different to litter-bed flammability. Falls faster to ignite and burn hotter.
- Ignitability key to flammability.
- No difference in flammability of WSF, DSF, RF.
- Fire regimes influenced by canopy cover and microclimate.

2.7 Fensham, R. (2012). Fire regimes in Australian tropical savanna: perspectives, paradigms and paradoxes. *In:* WILLIAMS, R. J., BRADSTOCK, R. A. & GILL, A. M. (eds.) *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World.* Victoria: CSIRO Publishing.

- Looks at fire regimes and rainforest in Australia.
- Provides an overview of the relationship of tropical savanna, rainforest F, management and natural structure.
- Landforms, rainfall, soil and climate influence the expansion and contraction of rainforest.
- Rainforest sensitive to fire, those along rainforest -savanna ecotones are more resilient, except when exposed to frequent multiple fires.
- Relevant for understanding the dynamic relationship between rainforest, fire and savanna.
- Perspective on the impacts of climate change.

2.8 Frost, W. (2021). Environmental history of Australian rainforests until 1939 : fire, rain, settlers and conservation, Abingdon, Oxon, New York, NY, Routledge.

- Includes Gondwana rainforest s and Lamington.
- The Wet Frontier – settlement in rainforest along East coast.
- Rainforest definitions.
- Ch. 5: Clearing techniques, including burning (p. 71).
- Ch. 6: Rainforest regrowth – adapted to disturbances (cyclones, storms, fires) and regrow quickly (p. 83).
- Process to clear land: clear, burn, secondary regrowth clearing, increased fire risk and large fires.
- Historical accounts of slash and burn regrowth to clear for settlement in Lamington.
- Ch. 12: Lamington Plateau, mainly historical account.

2.9 Gibson, R. K., & Hislop, S. (2022). Signs of resilience in resprouting Eucalyptus forests, but areas of concern: 1 year of post-fire recovery from Australia's Black Summer of 2019–2020. *International Journal of Wildland Fire,* 31(5), 545-557.

- Study includes results of rainforest recovery to 2019-2020 fires.
- Study used Sentinel 2 satellite imagery to compare pre-fire (pre 2019-2020 fires) and one year post-fire Normalised Burn Ratio (NBR) values.
- **Results:** Found a strong positive trend in the return of vegetation, post-fire NBR values met or exceeded 80% of the pre-fire NBR value.
- Strong spectral recovery with more than 50% of the total burned area showing greater than 80% spectral recovery after one year.

- Rainforests were found to have a relatively high proportion of spectral recovery greater than 80%, but this fire-sensitive ecosystem is likely to have predominately understorey fire impacts with serious ecological effects that are not captured in remote sensing estimates of recovery.
- There is greater uncertainty in remote sensing accuracy of low severity fires in rainforest and wet forest communities – field-based measures of post-fire recovery may be warranted.

2.10 Hill, R. & Nowakowski, S. (2004). Yalanji Warranga Kaban: Yalanji people of the rainforest fire management book, Cairns, Qld., Little Ramsay Press.

- Hard copy at The University of Queensland and the State Library of Queensland.
- Aboriginal reference.
- Mentions of rainforest encroachment and one mention of burning small patches of rainforest for food.

2.11 Knox, K. J. E. & Clarke, P. J. (2012). Fire severity, feedback effects and resilience to alternative community states in forest assemblages. *Forest Ecology and Management,* 265, 47-54.

- Study on feedback loops based on flammability of DSF, WSF, RF in the Gibraltar Range-Washpool NP, Northern NSW.
- Satellite imagery, remote sensing, fire severity mapping and ground data used to test stable state theory, fire feedback effects, floristic composition and flammability traits.
- Tested against three levels of fire severity across three vegetation communities on burnt and unburnt sites.
- No flammability feedback nor changes to floristic composition were found, even with extent of fire impact.
- All rainforest species resprouted – does not indicate a transition to pyrogenic community.
- Climatic and environmental variables such as daily temperatures and fragmented canopy cover have a greater impact.
- Rainforest more tolerant to fire than thought.

2.12 Krishnan, V., Robinson, N., Firn, J., Applegate, G., Herbohn, J. & Schmidt, S. (2019). Without management interventions, endemic wet-sclerophyll forest is transitioning to rainforest in World Heritage listed K'gari (Fraser Island), Australia. *Ecol Evol,* 9, 1378-1393.

- Study of WSF ecotones on Fraser Island.
- Lack of fire leads to rainforest recruitment and expansion.
- No mention of plant responses.
- Brief mention of fire to maintain WSF and rainforest boundaries.
- Mentions fire regimes for WSF and rainforest.
- Questions how to maintain WSF for biodiversity and conservation while pushing back rainforest encroachment.
- Suggested 100 – 350 year fire intervals for rainforest and without fire, with transition to rainforest.
- Public perception that fire is bad, making fire management difficult.
- Without fire in WSF, risk losing ecotone biodiversity.
- Study about natural disturbances of fire and cyclone and silviculture on WSF.
- Aboriginal fire management on island every two months of low intensity. Since colonisation, logging became an industry and fires became less frequent and of higher intensity.
- Logging stopped in 1991 when island became world heritage listed.

- Comparative study of two WSF plots from 1952 and 2017. Focus on *Syncarpia hillii* and *Lophostemon confertus* species (WSF myrtaceous canopy).
- Results found rainforest species *Backhousia myrtifolia* and *Schizomeria ovata* became dominant over WSF focus species.
- Difference in species composition between 1952 and 2017 was between 57.9 – 77.7%.
- **Table 7:** Species list.
- Predict without disturbances of fire and logging, WSF will transition to rainforest.

2.13 Lewis, T. O. M., Reif, M., Prendergast, E. & Tran, C. (2012). The effect of long-term repeated burning and fire exclusion on above- and below-ground Blackbutt (Eucalyptus pilularis) forest vegetation assemblages. *Austral Ecology,* 37, 767-778.

- Plant responses at Peachester, SEQ – same study site as other Peachester studies.
- Rainforest associated vegetation briefly mentioned. No other references to rainforest and fire.
- Long-term experiment in subtropical *Eucalyptus pilularis* forest.
- Aim to understand long-term consequences of frequent burns on vegetation composition and seed banks.
- Method: Vegetation sampling and germination.
- Results: 87 taxa (66 resprouters, 12 obligate seeders, 3 ephemeral, 6 no response).
- Fire treatments showed no effect on richness of native understorey.
- Composition varied with fire interval.
- Some rainforest species listed in discussion negatively impacted by recurrent fire.
- Density varied.
- No effect of heat and smoke on seed bank richness, density, and composition.

2.14 Marrinan, M. J., Edwards, W. & Landsberg, J. (2005). Resprouting of saplings following a tropical rainforest fire in north-east Queensland, Australia. *Austral Ecology,* 30, 817-826.

- Cairns based, Wet Tropics case study on different woody species patterns of resprouting post fire.
- Tropical rainforest species response to fire and how that may influence the rainforest composition and future management implications.
- Aim to determine advantages and disadvantages of species recovery with a predicted increase in fire frequency.
- Fires impacted 150 ha of the 180 ha of rainforest vegetation.
- Transects across burnt and unburnt sites.
- **Results:** Majority rainforest saplings resprout, even without fire as a disturbance.
- A small number of species showed a lower ability to resprout – possible disadvantage with frequent fires.

2.15 Nolan, R. H., Collins, L., Leigh, A., Ooi, M. K. J., Curran, T. J., Fairman, T. A., Resco de Dios, V., & Bradstock, R. (2021). Limits to post-fire vegetation recovery under climate change. *Plant, Cell & Environment,* 44, 3471-3489.

- Study presents scenario-based conceptual models on how overlapping disturbance events (such as severe drought, heatwaves and/or insect outbreaks) and shifting fire regimes interact differently to limit post-fire resprouting.
- Fire-cued recruitment in rainforest species is relatively uncommon, with only 20% of species exhibiting a fire-resistant seed bank.

- Seed recruitment in rainforest is likely to be heavily dependent on recruitment from fire refugia.
- Australian rainforest can recover from infrequent, low severity fires but with increased fire frequency, severity and/or drought, rainforest communities are likely to be invaded by pyrophytic species.
- High severity fires and invasion of pyrophytic species likely to occur in declining canopy cover and aboveground biomass, resulting in drier microclimates and rendering the rainforest more susceptible to fires.

2.16 Ondei, S., Prior, L., D., Vigilante, T. & Bowman, D., M. J. S. (2016). Post-fire resprouting strategies of rainforest and savanna saplings along the rainforest–savanna boundary in the Australian monsoon tropics. *Plant Ecology,* 217, 711-724.

- Frequent burning restricts rainforest encroachment.
- Comparative study of savanna- rainforest regeneration strategies of plants along boundary.
- Study area Mitchell Plateau, NW Kimberley.
- Looked at bark thickness and position of regenerative shoots.
- Low intensity controlled burn experiment.
- Seven rainforest species targeted: *Atalaya salicifolia* (A.DC.) Blume (Sapindaceae), *Canarium australianum* F.Muell. (Burseraceae), *Ficus aculeata* Miq. (Moraceae), *Sterculia quadrifida* R.Br. (Malvaceae), *Strychnos lucida* R.Br. (Loganiaceae), *Terminalia petiolaris* Benth. (Combretaceae) and *Vitex acuminata* R.Br. (Lamiaceae).
- **Results:** Rainforest species had thinner bark. One year post fire 81% survival with 41% regenerated via basal resprouting. Five species were aerial resprouters.
- One year post fire rainforest species recovered 60% of height and savanna nearly 100% recovered.
- Amount of rainfall and current fire regime restricts rainforest.

2.17 Pausas, J., G. & Keeley, J., E. (2014). Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. *New Phytol,* 204, 55-65.

- Rainforest resprouting ancestral in Eudicots.
- Explanation of traits and responses (definitions).
- History of resprouting.

2.18 Ross, T., Srivastava, S. K. & Shapcott, A. (2023). Investigating the relationship between fire severity and post-fire vegetation regeneration and subsequent fire vulnerability. *Forests,* 14, 222.

- 2019-2020 Australian wildfires impacted subtropical rainforest with variety of burn severities, increasing vulnerability to another burn.
- Sampled three national parks where rainforest burned in 2019-2020 across different fire severities to test if there are patterns in post-fire regeneration flammability.
- NPs studied were Bulburin NP, Main Range NP and Lamington NP.
- Study found that flammable species increased in regions where fire severity was higher.
- **Results** showed that herb layer density was significantly variable among fire-severity classes and was weakly but significantly positively correlated with increasing burn severity since the 2019-2020 fires.
- Herb layer had significantly higher cover at the high severity burn sites compared to low severity burn sites.

- Study found growing presence of fire-promoting species as fire severity increased.
- High severity fire can limit diversity of native rainforest species due to their inability to regenerate post fire, increasing fire-promoting grasses.
- 1.5 years post fire, resprouting regrowth was identified in all burn severities.
- Results highlight rainforest native species may not tolerate increased flammable conditions, as higher severity burns lead to increased presence of fire-promoting regrowth and decline of rainforest seedling presence.
- Low intensity burns had little negative impact on rainforest seedling regeneration.

2.19 Russell-Smith, J. & Stanton, P. (2002). Fire Regimes and Fire Management of Rainforest Communities Across Northern Australia. *In:* BRADSTOCK, R. A., WILLIAMS, J. E. & GILL, M. A. (eds.) *Flammable Australia: The fire regimes and biodiversity of a continent.* Cambridge, UK: Cambridge University Press.

- Hard copy at The University of Queensland and State Library of Queensland.
- Fire regimes in rainforest between Townsville and Broome.
- Rainforest and WSF included.
- Palaeo history of rainforest extent – pollen records show rainforest fires every 220 – 240 years (p. 333-34).
- Contraction of rainforest due to climatic conditions not Aboriginal burning – rainforest expansion with wetter and warmer conditions, Aboriginal burning slowed expansion. Aboriginal burning during Late Pleistocene replaced rainforest with sclerophyll, which was maintained into Holocene. Yalanji People of the Rainforest book also references this and is included in this document.
- WSF will transition to rainforest after 20 – 30 years with no fire and will become full rainforest after >100 years of no fire.
- Logging and burning disturbances promote coppice regrowth, suckers, and seed.
- *E. grandis* within rainforest and above rainforest canopy suggests transition from WSF to rainforest already occurred but needs fire to regenerate. This is contrary to Tng's 2012, 2013 and 2014 studies in this document.
- Geological boundaries control rainforest.
- A few pages on monsoon savanna rainforest boundaries.
- Aboriginal fire used to manage rainforest resources. Yalanji People of the Rainforest book also references this and is included in this document.
- Aboriginal fire used to maintain rainforest tracks, for ceremonies and for resource management.
- Concern about loss of WSF leading to a loss of biodiversity (e.g. yellow-bellied glider, eastern yellow robin, northern bettong).
- Management needs to be dynamic.

2.20 Steffensen, V. (2020). Fire country : how indigenous fire management could help save Australia, Richmond, Victoria, Hardie Grant Travel.

- Chapter about 'No Fire Country' and areas, such as wet rainforests, that do not need fire to stay healthy.
- In contrast, sandy soiled dry rainforests which are located in lower river and coastal areas were exposed to deliberate burning to encourage fresh growth for rainforest wallabies and tree kangaroos. Since fire suppression, these animals are rarely seen.
- This isn't a guide of how to, but rather a perspective on what cultural burning can do for the future of communities and ecosystems in Australia.

- Only two paragraphs about rainforest and fires.
- Mentions rainforest burning (p.46, Ch. 8: No Fire Country).

2.21 Stanton, P., Parsons, M., Stanton, D. & Stott, M. (2014). Fire exclusion and the changing landscape of Queensland's Wet Tropics Bioregion 2. The dynamics of transition forests and implications for management. *Australian Forestry,* 77, 58-68.

- Sister paper to one above (Stanton, P., Stanton, D., Stott, M. & Parsons, M. (2014). Fire exclusion and the changing landscape of Queensland's Wet Tropics Bioregion 1. The extent and pattern of transition. *Australian Forestry,* 77, 51-57).
- This paper focuses on conserving biodiversity.
- Some attempts to reintroduce fire but window is getting smaller and strong public perception that fire is destructive.
- This will lead to future fires being wild bushfires rather than planned burns.
- 25 – 79% forest types irreversibly changed.
- Rainforest expanding without fire.
- Sclerophyll forests evolved alongside rainforest.
- Lots of detail in this paper.
- Frequently referenced discussion paper.

2.22 Stanton, P., Stanton, D., Stott, M. & Parsons, M. (2014). Fire exclusion and the changing landscape of Queensland's Wet Tropics Bioregion 1. The extent and pattern of transition. *Australian Forestry,* 77, 51-57.

- Altered fire regimes are changing Wet Tropics, mostly in sclerophyll.
- Focus on vegetation changes in landscape.
- Study of documented habitat change between 1997 and 2004.
- Sclerophyll forests, woodlands and coastal beach complexes being invaded by rainforest understorey species.
- Fire exclusion and changes to fire regime most likely cause of vegetation transition.
- Frequently referenced report.

2.23 Tng, D., Y. P., Goosem, S., Jordan, G., J. & Bowman, D., M. J. S. (2014). Letting giants be – rethinking active fire management of old-growth eucalypt forest in the Australian tropics. *The Journal of Applied Ecology,* 51, 555-559.

- Old growth eucalyptus forests response to fire in tropics.
- Mentions of rainforest and fire but not species.
- Management of old-growth giant eucalypts by fire suppression and fuel reduction around subtropics and tropics – fuel reduction within and around giant forests recommended.
- Wet Tropics case study of *E. grandis* (obligate seeder).
- Hard to manage fire regimes for eucalypts in rainforest because of differing requirements.
- Unknown Aboriginal fire regimes, but enough to maintain *E. grandis*.
- Mentions Palaeo records.
- Promotes consideration that *E. grandis* is a secondary rainforest species that behaves as long-lived pioneer.
- May link rainforest -savanna boundaries.

- Considering *E. grandis* as rainforest begs rethinking of invasion terminology which is negative. If *E. grandis* is a rainforest species, that means rainforest doesn't invade.
- Burning of understorey should be targeted and localised for biodiversity.
- Expansion may be considered as part of vegetation – climate feedbacks for carbon storage.

2.24 Tng, D. Y. P., Jordan, G. J. & Bowman, D. M. J. S. (2013). Plant traits demonstrate that temperate and tropical giant eucalypt forests are ecologically convergent with rainforest not savanna. *PLoS One,* 8, e84378-e84378.

- Eucalypt savanna transition.
- Tall old growth eucalypts as rainforest species.
- No data on post-fire recovery.
- Differing opinions of ecotones – are they stable or unstable?
- Study of functionality traits of trees and shrubs in tropical and temperate regions to test Alternative Stable State Theory and convergence.
- North Queensland and Tasmanian study sites.
- Sampled rainforest, giant eucalypts, and open vegetation.
- Measured and analysed leaf and bole/trunk traits.
- **Results:** Rainforest and savanna are alternative stable states, giant eucalypts functionally closer to rainforest.
- Tropical and temperate rainforest functionally divergent, suggesting differences across the country, with clearer divergence in the tropics.
- In all traits except bark thickness, giant eucalypts are not significantly different from rainforest.
- Eucalypts create a two-tiered canopy. Eucalypts provide shade for rainforest species to establish.
- Authors would like to test functional traits and alternative stable state in SEQ and NSW.
- Recommends functional instead of floristic classification.

2.25 Tng, D. Y. P., Murphy, B. P., Weber, E., Sanders, G., Williamson, G. J., Kemp, J. & Bowman, D. M. J. S. (2012a). Humid tropical rain forest has expanded into eucalypt forest and savanna over the last 50 years. *Ecol Evol,* 2, 34-45.

- Study in Wet Tropics of drivers of rainforest boundaries across five sites.
- Comparison study of aerial photography between 1951 – 1955 and 2008.
- Most boundaries in study were stable.
- Expansion occurred into savanna.
- Average encroachment of 30 m since the 1950s.
- Topography and environmental factors are major influences that contribute to maintaining stability.
- Some predictions for future of expansion, suggesting tall forests and rainforest will remain constant.
- Suggests anthropological fire is not a key driver in the area – rather, global climate change due to positive feedbacks is the driver.

2.26 Tng, D. Y. P., Williamson, G. J., Jordan, G. J. & Bowman, D. M. J. S. (2012b). Giant eucalypts – globally unique fire-adapted rain-forest trees? *New Phytol,* 196, 1001-1014.

- Argues that giant eucalypts are rainforest species.
- Details fire-adapted eucalypts in rainforest and eucalyptus response to fire.

- Summary of how giant (>70 m) eucalypts fit into global context of giant trees, how eucalypts become giant in rainforest, the definition of rainforests and the relationship between the three and fire.
- Giant angiosperms grow in tropical and temperate regions – several species in mesic, subtropics of Australia (e.g. *Eucalyptus grandis).*
- Unusual relationship between fire-dependent forest and fire-intolerant rainforest.
- Two species also occur where rainforest became extinct three million years ago in SW Western Australia.
- Eucalypts Integrate with rainforest differently depending on location (e.g. size of ecotones differ between tropics, subtropics, eucalypt/savanna and with *Nothofagus* rainforest in Tasmania).
- Fire intensity key to landscape pattern ie. low intensity v high intensity– different species have different preferences (e.g. resprouter versus obligate seeder).
- Gives ranges for subtropical eucalypt species: *Eucalyptus pilularis* Sm. (rainfall 900 – 1750 mm, altitude < 0 – 700 m), *Ceratopetalum apetalum* D. Don (rainfall 1000 – 2000 mm, altitude 100 – 900 m).
- Eucalypt species have higher biomass compared with irradiance than ecotonal or rainforest species.
- Australian eucalypts are distinct because of their dependence on fire to regenerate in rainforest and develop canopy above rainforest.
- There is long-term controversy around if eucalypts are rainforest or not because of their dependence on fire.
- Interestingly, *E. deglupta* is considered a rainforest tree but not others.
- Are ecotones considered stable?
- Eucalypts should be considered rainforest pioneers because they colonise, grow, produce seed in early successional environments.
- Once established, they don't suppress rainforest.

2.27 Williams, P. R. (2000). Fire-stimulated rainforest seedling recruitment and vegetative regeneration in a densely grassed wet sclerophyll forest of north-eastern Australia. *Australian Journal of Botany,* 48, 651-658.

- Pioneer rainforest species expand the boundary of rainforest into wet sclerophyll, but are thought to be killed by fire.
- Permanent study sites in Lumholtz NP, Southern Wet Tropics near Ingham.
- Seedling recruitment surveys across five sites and a range of fire interval sites.
- Specific pioneer rainforest species responses were recorded and listed in Table 2 of the paper.
- Soil seed banks were tested.
- Rainforest species observed resprouting after low and moderate fires.
- Authors positive rainforest pioneers can regenerate after fire but call for more research in specific areas.

2.28 Williams, P. R. (2009). Contrasting demographics of tropical savanna and temperate forest eucalypts provide insight into how savannas and forests function. A case study using Corymbia clarksoniana from north-eastern Australia. *Austral Ecology,* 34, 120-131.

- Reference to tropical eucalypts in tropical savannas.

- Study of fire regime on *Corymbia clarksoniana*, a dominant eucalypt in savanna in coastal and subcoastal NE Australia, and to assess fire impact on seed production.
- Aim to determine if it is consistent with other tropical eucalypts.
- Study site: Cape Cleveland, Townsville.
- Method: Experimental burns in 1997 and 1999, followed by germination experiment.
- Fire and rainfall linked to recruitment.
- Key features that differentiate tropical savanna eucalypts from temperate forest eucalypts: ability to survive in frequently burnt grasslands, no canopy stored seeds, seed fall coincides with wet season, lack of mass germination after each fire, epicormically resprout, and large sapling bank.

2.29 Williams, P., Parsons, M. & Devlin, T. (2006). Rainforest Recruitment and Mortality in Eucalypt Forests of the Wet Tropics - Refining the Model for Better Management. *Bushfire Conference: Life In A Fire-Prone Environment: Translating Science Into Practice.* Brisbane, Australia.

- Long-term study of rainforest -eucalypt ecotones in the North Queensland Wet Tropics.
- 57 surveys of 19 plots over 10 years between Townsville and Cardwell, with high intensity bushfire in 2003.
- Study of how rainforest species respond post fire.
- **Results:** Rainforest resprout from subsoil buds rather than from trunks and branches like sclerophyll forests trees.
- Paper strongly presents argument rainforest recruit post fire by resprouting, are not killed by high intensity fire and some are more resilient to increased frequency.

2.30 Williams, P. R., Parsons, M., Jensen, R. & Tran, C. (2012). Mechanisms of rainforest persistence and recruitment in frequently burnt wet tropical eucalypt forests. *Austral Ecology,* 37, 268-275.

- Long term study of ecotone rainforest and eucalypt species.
- 85 surveys of 13 plots over 14 years across burnt and unburnt areas in Wet Tropics, NE Australia.
- Study sites in Girringun NP, Australian Wildlife Conservancy 's Taravale-Mt Zero Sanctuary Paluma Range near Ingham and Townsville.
- Aim to test rainforest recruitment in the absence of fire, if rainforest species in ecotones are killed by fire and how post-fire regeneration influences the boundary.
- Fires all prescribed burns, except for a high intensity bushfire in 2003.
- Found rainforest species are resilient to fires, with the majority resprouting post fire.
- Observations post fire noted that 49 out of 52 rainforest species resprouted, including a majority of pioneer species as well as some mature species.
- Some rainforest seeders observed, resprouting mainly via coppicing.
- Rainforest species ability to regenerate is mostly from ground level.
- Takes a number of years for species to gain height, which gives the impression that rainforests are killed by fire.

2.31 Younis, S., & Kasel, S. (2023). Do fire cues enhance germination of soil seed stores across an ecotone of wet eucalypt forest to cool temperate rainforest in the central highlands of South-Eastern Australia? *Fire*, 6,138.

- Soils from five replicates of each forest type were subjected to very low (45 ºC), low (65 ºC) and high (90 ºC) heat with or without smoke treatment.

- Responses to fire were consistent among forest types despite differences in diversity of soil seed banks.
- Fire germination cues do not play a strong role in germination of soil store seed banks in cool temperate rainforests of SE Australia.
- Other non-fire disturbances such as treefalls and soil movement by fauna may be more important for germination.

3 Wet sclerophyll

3.1 Ash, J. (1988). The Location and Stability of Rainforest Boundaries in North-Eastern Queensland, Australia. *Journal of Biogeography,* 15, 619-630.

- NE Queensland study site explaining the factors influencing rainforest boundaries. NE Queensland site chosen because difference in boundary vegetation is simple.
- Rainforest boundaries change with latitude.
- Mention of Southern Queensland rainforest: extensive wet-sclerophyll forests with rainforest species (p. 620). Soils unsuitable for rainforest so wet sclerophyll boundary is maintained as an ecotone.
- However, in humid east coastal tropics, boundary is narrow.
- Rainfall, fire, topography and substrate influence boundaries.
- 38% of 791 km study site boundary affected by substrate.
- Combination of factors maintain/advance boundaries.

3.2 Butler, O. M., Lewis, T., Rashti, M. R. & Chen, C. (2019). Energetic efficiency and temperature sensitivity of soil heterotrophic respiration vary with decadal-scale fire history in a wet sclerophyll forest. *Soil Biology & Biochemistry,* 134, 62-71.

- Long term (since 1969) prescribed burn study site in Peachester State Forest, Queensland.
- Study of soil carbon cycle, respiration, microbial biomass, and microbial energetic efficiency.
- Incubation experiment of fire regimes on soil respiration, response, abilities, microbial biomass C, N and P, and the potential activities of C, N and P-acquiring enzymes to air temperatures.
- Peachester is wet eucalypt forest dominated by *E. pilularis*, sandy soils.
- Method: 12 plots treated with fire and sampled. Soils analysed.
- **Results:** Fire affects microbial biomass, with more frequent fires having the most impact.
- Results improve understanding of C cycle.

3.3 Campbell, M. L., Clarke, P. J. & Keith, D. A. (2012). Seed traits and seed bank longevity of wet sclerophyll forest shrubs. *Australian Journal of Botany,* 60, 96-103.

- WSF as ecotone is rarely flammable.
- Fire intervals 50 – 100 years for WSF.
- Study of soil seed bank of four understorey shrub species in New England Bioregion: 1. Cunnawarra NP, Guy Fawkes River NP, Mummel Gulf NP, Washpool NP.
- Species studied: *Banksia integrifolia* subsp. *monticola* K. R. Thiele (Proteaceae), *Goodia lotifolia* Salisb. (Fabaceae), *Trochocarpa laurina* (Rudge) R. Br. (Ericaceae) and *Tasmannia stipitata* (Vickery) A. C. Sm. (Winteraceae), hereafter *Banksia, Goodia, Trochocarpa* and *Tasmania.*
- Tested infrequent disturbance – fire promotes seed banks and frequent disturbance, tree fall increases seed production.
- Species that prefer infrequent disturbances may have long dormant seed banks compared to species which prefer sites frequently disturbed which have continuous production of non-dormant seeds.
- Repeated fires may deplete carbohydrate storage and bud banks.

3.4 Campbell, M. L., Keith, D. A. & Clarke, P. J. (2016). Regulation of seedling recruitment and survival in diverse ecotonal temperate forest understories. *Plant Ecology,* 217, 801-816.

- Ecotones have vegetation of high and low flammability but can become unstable with positive feedback loops.
- Study of montane WSF in New England Tableland – Cunnawarra NP and Mummel Gulf NP.
- Comparison of two high flammability dry sclerophyll species and two low flammability rainforest species within ecotone WSF.
- Low intensity prescribed fire and high intensity bushfire.
- Field observations recorded and germination (including litter) experiment conducted.
- Shrubs in wet and infrequently burnt forests may recruit from seed but not survive.
- Shrubs in open flammable forests recruit and establish, even with random post fire factors. This maintains ecotone.

3.5 Clarke, P. J., Knox, K. J. E., Bradstock, R. A., Munoz-Robles, C. & Kumar, L. (2014). Vegetation, terrain and fire history shape the impact of extreme weather on fire severity and ecosystem response. *Journal of Vegetation Science,* 25, 1033-1044.

- Study in Gibraltar Range-Washpool NP.
- Expect sclerophyll to epicormically resprout, healthlands to recover slowly and rainforest to be top-killed and basally resprout the slowest.
- Five vegetation communities in study site: DSF, dry heath, wet heath, WSF, RF.
- Major bushfires in 1964, 1980, 1989, 2002 (lightning ignition). Dry conditions leading up to all fires.
- **Results:** Topography controlled fire severity but only with low/moderate fire weather, not extreme.
- Fuel consumption and severity higher in recently burnt areas.
- Fire severity moderated by vegetation – vegetation responds differently under same fire weather.
- Rainforest resilient to crown fuel consumption even under extreme weather, making them relatively stable.
- Higher weather threshold is needed for fires to reach canopy of WSF.
- Rainforest and WSF mosaics experienced mixed fire severity, even when weather conditions were extreme.
- Rainforest and sclerophyll evolved to rapidly resprout by basal and canopy (p. 1042).
- Fire management difficult to balance in mixed severity and World Heritage Area.
- Very relevant.

3.6 Clarke, P. J., Knox, K. J. E., Wills, K. E. & Campbell, M. (2005). Landscape Patterns of Woody Plant Response to Crown Fire: Disturbance and Productivity Influence Sprouting Ability. *The Journal of Ecology,* 93, 544-555.

- Study of woody species (excluding eucalyptus) response to crown fire across five habitats.
- New England Tablelands.
- Five communities: grassy woodlands, DSF, rocky outcrop, wet heath, WSF.
- RF excluded from study because rarely burnt.
- First WSF records taken in 2002/03 after first fire in 50 years.
- Most habitats showed resprouting, but this decreased in WSF (p. 551).
- Suggest species in rainforest resprout due to canopy disturbance rather than fire (p. 551).

3.7 Floyd, A. G. (1966). Effect of fire upon weed seeds in the wet Sclerophyll forests of Northern New South Wales. *Australian Journal of Botany,* 14, 243-256.

- Study of weeds in regeneration of eucalypts for silviculture.
- Logging site study in Lower Bucca State Forest, Coffs Harbour.
- Area clear felled then burnt.
- Soil samples taken for germination.
- Burning rather than clearing by tractor promotes weed growth.
- Acacia is a coloniser that can be minimised with a low intensity burn.

3.8 Harrington, G. N. & Sanderson, K. D. (1994). Recent Contraction of Wet Sclerophyll Forest in the Wet Tropics of Queensland Due to Invasion by Rainforest. *Pacific Conservation Biology,* 1, 319.

- 400 km region of Wet Sclerophyll Forest (WSF) boundary in the Wet Tropics.
- Fire is needed to maintain sclerophyll.
- Without fire, there is a risk of losing WSF biodiversity.
- Boundary vulnerable to influences.
- Study of aerial photos between 1943 – 1945 and 1991 – 1992 to determine changes in boundary and inform fire management of Wet Tropics.
- Three study sites: North, Central, South.
- Comparison of aerials and vegetation types showed that fire was maintaining grass and boundaries.
- Without fire, rainforest invades boundaries.
- Changes to Aboriginal burning regimes observed.
- Swing between rainforest and WSF is a constant.
- Prediction that large, high intensity bushfires can be prevented, but may be needed at boundary. However, this recommendation is controversial.

3.9 Hopkins, M. S. & Graham, A. W. (1983). The Species Composition of Soil Seed Banks Beneath Lowland Tropical Rainforests in North Queensland, Australia. *Biotropica,* 15, 90-99.

- Study of seed soil bank composition in four tropical rainforest sites with different soils in Wet Tropics between Tully and Innisfail.
- Four sites: 1) Complex mesophyll vine forest, 2) Notophyll-mesophyll vine forest, 3) Mixed mesophyll vine forest, and 4) Complex mesophyll vine forest.
- All sites were historically logged.
- 12 soil samples taken for germination experiments.
- Total germination rates for primary forest trees was 0.09%, secondary trees and shrubs >50%, secondary vines, shrubs and weeds >40%.
- Table 1. List of all species (p. 92).
- Observed that many primary rainforest species in study are obligate seeders and short-lived seeds.

3.10 Hopkins, M. S., TracEY, J. G. & Graham, A. W. (1990). The size and composition of soil seed-banks in remnant patches of three structural rainforest types in North Queensland. *Australian Journal of Ecology,* 15, 43-50.

- Seed banks show regeneration potential of rainforests.
- Study to compare viable soil seed banks in three rainforest types in Atherton Tableland in North Queensland. All sites surrounded by farmland.

- Complex mesophyll vine forest, complex notophyll vine forest, and semi-evergreen vine thicket vegetation communities.
- Method: Soil samples collected from plots, samples spread across germination trays and monitored for five months.
- **Results:** 94 species germinated – made up of vine, herb, shrub, and trees all common in pioneer and secondary rainforest.
- Seed bank and parent vegetation were mainly pioneer and secondary standing forest species.
- Very few common species between seed banks and trees of standing forests.
- Seed bank reflected composition of site and was different across the three rainforest types.
- Large seed bank in complex forest sites, even larger seed bank in semi-evergreen.
- Differences in seed banks possibly due to domination of rapidly maturing herbs, deciduous trees causing seasonal canopy fragmentation, and disturbance by cattle and pigs.

3.11 Knox, K. J. E. & Clarke, P. J. (2011). Fire severity and nutrient availability do not constrain resprouting in forest shrubs. *Plant Ecology,* 212, 1967-1978.

- Comparison and WSF and DSF plant protection traits and how the traits work together.
- Gibraltar Range-Washpool NP, NSW.
- Crown fires occur at 10 – 50 year intervals at site.
- In 2002, high and low fire severity affected sites and were sampled.
- Tested growth and protection traits and resprouting ability (volume and number) across high and low nutrient environments.
- Compared traits and responses against non-sprouters or seeders.
- Plots surveyed again five years after fire.
- Understorey species in the Fabaceae, Rutaceae, Myrtaceae, Lauraceae and Proteaceae family were sampled in both the DSF and WSF (with the exception of Lauraceae, where species could only be found in the WSF).
- **Results:** No difference in ratio of plant response to fire severity between WSF and DSF.
- WSF have greater volume of resprouts and less shoots.
- DSF have less volume of resprouts and higher number of shoots. Shoots didn't thin over first stage growth.
- No differences in responses to fire severity.
- WSF and DSF have same proportion of woody resprouters but different fire frequencies.
- No evidence of trait coordination.

3.12 Mariani, M., Tibby, J., Barr, C., Moss, P., Marshall, J. C. & Mcgregor, G. B. (2019). Reduced rainfall drives biomass limitation of long-term fire activity in Australia's subtropical sclerophyll forests. *Journal of Biogeography,* 46, 1974-1987.

- Palaeo record for Swallow Lagoon, North Stradbroke Island (ca. 8 kyr).
- Aim to understand drivers of biomass in sclerophyll forests.
- DSF, woodland and heath vegetation communities.
- Vegetation changes linked to precipitation variation.
- Potential relevance as palaeo reference.

3.13 Muqaddas, B. & Lewis, T. (2020). Temporal variations in litterfall biomass input and nutrient return under long-term prescribed burning in a wet sclerophyll forest, Queensland, Australia. *Sci Total Environ,* 706, 136035-136035.

- C and N held in litterfall and adds nutrients to soil.
- Prescribed burning may reduce C and N storage and affect nutrient cycle.
- Long-term prescribed burn study site at Peachester (39 years, since 1972).
- Mix of burn treatments, low intensity prescribed burns every two years, four years, and no burning.
- Monthly litterfall collected over three years.
- Samples dried and analysed for C and N concentrations.
- Litterfall varied throughout year with water stress and hot dry periods, with highest variance during this time.
- Low temperatures = low litterfall, high temperatures and water stress = higher litterfall.
- Long-term prescribed burning = lower litterfall and therefore less C and N in the cycle.

3.14 Muqaddas, B., Zhou, X., Lewis, T., Wild, C. & Chen, C. (2015). Long-term frequent prescribed fire decreases surface soil carbon and nitrogen pools in a wet sclerophyll forest of Southeast Queensland, Australia. *Sci Total Environ,* 536, 39-47.

- Study of effect of repeated prescribed burns on soil labile, biologically active and recalcitrant C and N pools.
- Soil labile lower after two-year burns versus four-year burns.
- Lower soil C and N after two-year burns versus no burns. No difference between two and four year burns.
- Soil microbial C:N significantly lower than four years and no burns.
- Two-year burns had lower moisture content than no burns.
- More frequent prescribed burns (two years) result in lower total C and N in soil, lower soil labile, lower soil recalcitrant C and N pools. No difference with four-year burns.
- Therefore, four-year intervals are a more sustainable management practice for the site.

3.15 Prior, L. D., Foyster, S. M., Furland, J. M., Williamson, G. J., David, M. J., & Bowman, S. (2022). Using permanent forest plots to evaluate the resilience to fire of Tasmania's tall wet eucalypt forests. *Forest Ecology and Management*, 505.

- Two wildfires affected five one-hectare forest plots of tall wet eucalypt forests in Tasmania.
- Study characterised wildfires using remote sensing and field measurements of char height and canopy scorch.
- Assessed influence of tree diameter, fire intensity and seedling densities on the survival and resprouting response.
- Fires were low to moderate intensity and severity.
- Study found that mature eucalypts were most resilient to these wildfires with overall eucalypt survival of 75%.
- Understorey species suffered high mortality (85% overall), with few species showing substantial resprouting.
- Fire resistance increased with tree diameter.
- Fire weather is the predominant influence in fire severity in both wet and dry eucalypt forest.
- Fires in tall wet eucalypt forests are often of low to moderate severity and burn at lower severity than in dry eucalypt forests.

- Overall, 33% of trees survived fire, with post-fire survival higher in eucalypts (75%) than understorey species (15%).
- *E. delegatensis* had the lowest survival (60%) of the dominant eucalypt species.
- *E. delegatensis* was less fire tolerant than *E. obliqua* and *E. regnans*.
- Little resprouting in understorey.
- Fire resistance and resilience generally increase with tree size, as larger trees have thicker bark and elevated canopy away from surface fires.

3.16 Shen, J.-P., Chen, C. R. & Lewis, T. (2016). Long term repeated fire disturbance alters soil bacterial diversity but not the abundance in an Australian wet sclerophyll forest. *Sci Rep,* 6, 19639-19639.

- Peachester State Forest study site.
- Since 1972, three burn treatments have been applied: 1) Every two years, 2) Every four years, and 3) No burning. All low intensity burns.
- Soil was tested at 0 – 10 cm and 10 – 20 cm depths.
- Vegetation structure dominated by *Eucalyptus pilularis* Smith with lesser proportions of other canopy species including *Corymbia intermedia*, *Eucalyptus microcorys*, *Eucalyptus resinifera*, *Syncarpia glomulifera* and *Lophostemon confertus*.
- Both prescribed fire and bushfires impact soil microbial processes, but to what degree is not well known.
- Study to understand recurring fires on microbial processes by looking at long-term prescribed fire and identifying main factors which alter bacterial composition.
- Results found that soil bacterial communities are significantly altered by fire.
- Burnt and unburnt sites had different diversities of bacteria and fungi in topsoil.
- Microbial diversity increased over time post fire. Intermediate fire intervals are best for maintaining high microbial diversity.
- Shift in bacterial structure due to changes in soil chemistry. pH was the main factor.
- Long-term frequent fires alter bacterial communities.
- Microbial health affects recovery.
- Sister study by Lewis et al. (2012) found long-term fires have impact of vegetation structure.

3.17 Tang, Y. & Kitching, R. L. (2003). Heat and smoke effects on the germination of seeds from soil seed banks across forest edges between subtropical rainforest and eucalypt forest at Lamington National Park, south-eastern Queensland, Australia. *Australian Journal of Botany,* 51, 227-237.

- Fire as a process affecting ecotones and abrupt edges – notes most studies have focussed on savanna rainforest boundaries.
- Seed germination study to understand the processes of subtropical (*notophyll vine forest*) and WSF (eucalyptus species).
- Three study sites (all ecotones) adjacent to Lamington National Park on private land.
- Three transects, with multiple soil samples taken at each site and treated with smoke, heat and no treatment.
- 1215 seeds germinated, 67 species, 34 families (see Appendix in paper).
- **Results** showed seed density decreased further into rainforest, with no primary rainforest species recorded in seed bank.

- Heat and smoke more important for species on eucalypt side of boundary rather than rainforest side.
- Has appendices of specific species and species discussed throughout.

3.18 Tanner-McAllister, S. L., Rhodes, J. R. & Hockings, M. (2018). A comparison of climate change impacts on park values on four Queensland World Heritage National Parks in Australia. *Australasian Journal of Environmental Management,* 25, 267-284.

- Impacts of climate change and park management across parks in a similar region.
- Decision making for how Queensland's Gondwana rainforests should be managed. Includes Main Range, Mt Barney, Lamington and Springbrook study sites.
- Research focus on stream-dwelling frogs, cool temperate forest and walking tracks.
- Bayesian models were developed for each focus – total of 12 models and ranked best to worst scenarios.
- Fire spoken about as an influential factor across the models.
- Results showed that each protected area should be managed differently due to different responses.
- Topography important in resilience to impacts.
- Fire risk will increase, how will that impact the area and be managed.

3.19 Toberman, H., Chen, C., Lewis, T. & Elser, J. J. (2014). High-frequency fire alters C : N : P stoichiometry in forest litter. *Glob Chang Biol,* 20, 2321-2331.

- Same Peachester study site.
- Investigate the long-term impact of repeated fire on stoichiometric relationships during litter decomposition.
- **Results:** Two year burns have slowed leaf litter cycle with higher C:N and lower C:P and N:P
- Microbial activity limited by N.
- Fire drives stoichiometric change.

3.20 White, D. J. & Vesk, P. A. (2019). Fire and legacy effects of logging on understorey assemblages in wet-sclerophyll forests. *Australian Journal of Botany,* 67, 341-357.

- Study of disturbances (logging and bushfires) on WSF of Victoria Central Highlands.
- Investigated three questions: 1 What was the difference in effects of wildfire and clear-fell logging on understorey species and how did this relate to the regeneration strategy of the plants?; 2) How did the type of disturbance influence the capacity of understorey species to recover after subsequent intense fire?; 3) How has the time between intense wildfire and a previous wildfire (inter-fire interval) influenced the frequency of occurrence of our focal species (Mountain Ash)?
- Comparison of times between logging and bushfires events for WSF understorey.
- 21 understorey species representative of area.
- **Results** found understorey species resilient to burning at intervals between 26 – 150 years.
- Resprouters recovered better from bushfires than logging disturbance.
- Mainly Mountain Ash forests, so may not be as relevant.

3.21 Williams, P., Watson, P., Kington, D. & Collins, E. (2022). Frequently Burnt Subtropical Eucalypt Forest Is More Resilient to Wildfire Than Rarely Burnt Forest. *Proceedings of the Royal Society of Queensland,* 131.

- Two years after wildfire at Mt Lindsay, two sections of subtropical eucalypt forest surveyed – one rarely burnt, one frequently burnt.
- Frequently burnt plot maintained healthy grassy subtropical eucalypt forest – regular burns have limited excessive post-fire sapling recruitment.
- High intensity fires promote abundant recruitment of some woody species, especially wattles, other legumes and some rainforest trees.
- Excessive sapling density also corresponds with loss of native grasses and herbs.
- Frequently burnt plot reduced connectivity between understorey and canopy cover.
- Long-term frequent burning in subtropical grassy eucalypt forest, under mild conditions, promoted and maintained a healthy understorey of grasses and herbs, with scattered saplings.

3.22 Wood, S. W., Murphy, B. P. & Bowman, D. M. J. S. (2011). Firescape ecology: how topography determines the contrasting distribution of fire and rain forest in the south-west of the Tasmanian Wilderness World Heritage Area: Topography, fire and rain forest in south-west Tasmania. *Journal of Biogeography,* 38, 1807-1820.

- Study of topography-fire interactions in SW Tasmania, especially in fire-sensitive rainforest.
- Remote sensing used for spatial analysis of fire in landscape.
- Vegetation communities: sedge/heath moorland, sclerophyll scrub, wet sclerophyll eucalypt forest and rainforest.
- WSF dominated by *Eucalyptus nitida, Leptospermum nitidum, Leptospermum scoparium, Banksia marginata, Melaleuca squarossa*, and fire-sensitive temperate rainforest (c. 23%) dominated by *Nothofagus cunninghamii* with other species including *Eucryphia lucida , Atherosperma moschatum* and *Phyllocladus aspleniifolius*.
- Study to understand how topography affects rainforest distribution and how fire is influenced by topography.
- Cool maritime climate.
- **Results:** RF correlated with topography – valleys, steep and moderate slopes, mostly southern slopes, and least likely to grow on northern slopes, ridges, flats and gentle slopes.
- Grasslands more likely to burn than boundary forest but rainforest occupies areas least likely to burn.
- Climate and location too different to be relevant?

4 Definitions

4.1 Bowman, D. M. J. S. (2000). Australian Rainforests: Islands of Green in a Land of Fire, Cambridge, Cambridge University Press.

- Chapters on how rainforest and eucalypts are defined and the issues this causes.

4.2 Clarke, P. J., Lawes, M. J., Murphy, B. P., Russell-Smith, J., Nano, C. E. M., Bradstock, R., Enright, N. J., Fontaine, J. B., Gosper, C. R., Radford, I., Midgley, J. J. & Gunton, R. M. (2015). A synthesis of postfire recovery traits of woody plants in Australian ecosystems. *Sci Total Environ*, 534, 31-42.

- Good for definition of resprouting and recruitment from seed.

4.3 Clarke, P., J., Prior, L., D., French, B., J., Vincent, B., Knox, K., J. E. & Bowman, D., M. J. S. (2014). Using a rainforest-flame forest mosaic to test the hypothesis that leaf and litter fuel flammability is under natural selection. *Oecologia*, 176, 1123-1133.

- WSF, DSF, rainforest discussion.

4.4 Pausas, J., G. & Keeley, J., E. (2014). Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. *New Phytol*, 204, 55-65.

- Evolutionary background information.

4.5 Tng, D. Y. P., Jordan, G. J. & Bowman, D. M. J. S. (2013). Plant traits demonstrate that temperate and tropical giant eucalypt forests are ecologically convergent with rainforest not savanna. *PLoS One*, 8, e84378-e84378.

- Definition of eucalypts in rainforest.

4.6 Tng, D. Y. P., Williamson, G. J., Jordan, G. J. & BOWMAN, D. M. J. S. (2012). Giant eucalypts – globally unique fire-adapted rain-forest trees? *New Phytol*, 196, 1001-1014.

- For controversial rainforest definition – to include eucalypts?

4.7 Whelan, R. J., Rodgerson, L., Dickman, C. R. & Sutherland, E. F. (2002). Critical Life Cycles of Plants and Animals. In: Bradstock, R. A., Williams, J. & Gill, M. (eds.) Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge, UK: Cambridge University Press.

- Plant responses (p. 114).

Rainforest and wet sclerophyll forest

Defining Australian rainforest and wet sclerophyll forest will inevitably raise debate, as there is no agreement on a single definition. There are almost as many definitions as there are rainforest types (Bowman, 2000; Russell-Smith and Stanton, 2002) and while wet sclerophyll forests are defined separately, they occur within and as an ecotone of rainforest. Some argue they should be considered rainforest species (Bowman, 2000; Tng et al., 2012; Tng et al., 2013).

Many people have developed taxonomic systems to classify rainforest and sclerophyll forests, notably Webb (1959; 1968; 1978), Bowman (2000), and Russell-Smith and Stanton (2002). In light of the ongoing debate around definitions, it would be best practice to define the meaning of rainforest for the discussion of this paper.

Resprouter and obligate seeders

Disturbances such as fire trigger response traits in plants. Australia is a fire-prone continent, and as such, woody plants have adapted responses to fire which influence species persistence (Clarke et al., 2015). Species responses to fire are classified as either being resprouters or obligate seeders. In some cases, a combination of both occurs, which is referred to as facultative resprouters or facultative seeders (Pausas and Keeley, 2014; Clarke et al., 2015). Resprouters survive fire and grow new shoots, even when the host plant sustains significant damage. Obligate seeders are killed by fire, and new recruits germinate from seed (Whelan et al., 2002; Pausas and Keeley, 2014).

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