10.1071/BT21110

Australian Journal of Botany

Supplementary Material

Appraising widespread resprouting but variable levels of postfire seeding in Australian ecosystems: the effect of phylogeny, fire regime and productivity

Michael J. Lawes[A,*], *Michael D. Crisp*[B,C], *Peter J. Clarke*[D], *Brett P. Murphy*[E], *Jeremy J. Midgley*[F], *Jeremy Russell-Smith*[G], *Catherine E. M. Nano*[H], *Ross A. Bradstock*[I], *Neal J. Enright*[J], *Joseph B. Fontaine*[J], *Carl R. Gosper*[K], *and Leigh-Ann Woolley*[E,L]

[A]School of Life Sciences, University of KwaZulu-Natal, Scottsville 3209, South Africa.

[B]Research School of Biology, The Australian National University, Canberra, ACT 2600, Australia.

[C]School of Biological Sciences, University of Queensland, St Lucia, Qld 4067, Australia.

[D]Botany, School of Environment and Rural Science, University of New England, Armidale, NSW 2351, Australia.

[E]Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT 0909, Australia.

[F]Department of Biological Sciences, University of Cape Town, P.Bag Rondebosch, Cape Town 7701, South Africa.

[G]Darwin Centre for Bushfire Research, Charles Darwin University, Darwin, NT 0909, Australia.

[H]Flora & Fauna Division, Department of Land Resource Management, Northern Territory Government, Arid Zone Research Institute, South Stuart Highway, Alice Springs, NT 0870, Australia.

[I]Centre for Environmental Risk Management of Bushfires, University of Wollongong, Wollongong, NSW 2522, Australia.

[J]Environmental and Conservation Sciences, Murdoch University, Perth, WA 6150, Australia.

[K]Biodiversity and Conservation Science, Department of Biodiversity, Conservation and Attractions and CSIRO Land and Water, Kensington, WA 6983, Australia.

[L]WWF-Australia, 3 Broome Lotteries House, Cable Beach Road E, WA 6725, Australia.

[*]Correspondence to: Michael J. Lawes School of Life Sciences, University of KwaZulu-Natal, Scottsville 3209, South Africa Email: MichaelLawes62@gmail.com; LawesM@ukzn.ac.za

Supplementary information – Figure captions

Fig. S1 Environmental domain of grid cells containing plots used in the analysis (n = 123; black dots), and unsampled cells across Australia (n =886; grey dots), in terms of: (a) mean annual rainfall and temperature and (b) mean annual rainfall and mean annual fire frequency from the 14-year Advanced Very High Resolution Radiometer satellite record, 1997–2010 (Russell-Smith *et al.*, 2007).

Russell-Smith J, Yates CP*, et al.* (2007) Bushfires 'down under': patterns and implications of contemporary Australian landscape burning. *International Journal of Wildland Fire* **16**, 361-377.

Fig. S2 Phylogeny of 2696 species sampled in plots, mapped with the binary trait postfire recovery mode (resprouting only). Grey branches have an equivocal reconstruction. This tree is scaled to time using constraints as labelled on nodes (Ma) taken from Stevens (2001 onwards). [Supp_Fig_S2_resprouter.pdf - attached]

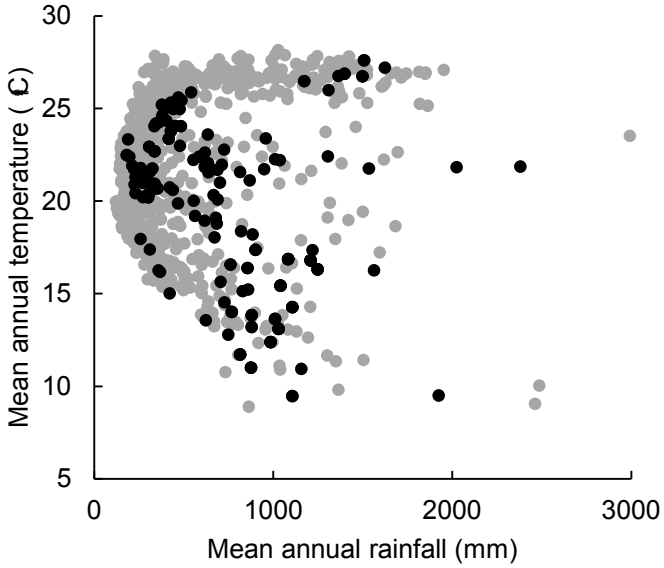
Fig. S3 Phylogeny of 2696 species sampled in plots, mapped with the multistate trait fire response. All trait states are variants on resprouting, except "killed", which is equivalent to obligate seeding. Grey branches have an equivocal reconstruction. This tree is scaled to time using constraints as labelled on nodes (Ma) taken from Stevens (2001 onwards). [Supp_Fig_S3_fire_response.pdf - attached]

Fig. S4 Phylogeny of 2696 species sampled in plots, mapped with the binary trait postfire seeding. Grey branches have an equivocal reconstruction. This tree is scaled to time using constraints as labelled on nodes (Ma) taken from Stevens (2001 onwards). [Supp_Fig_S4_reseeder.pdf - attached]

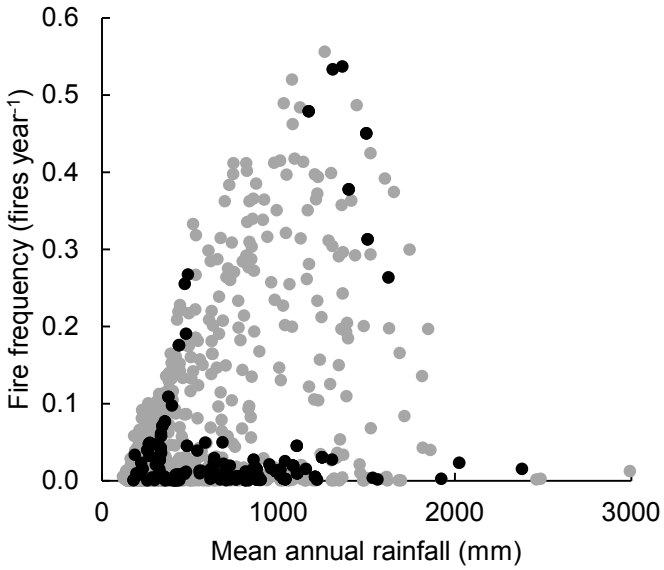
Supplementary information

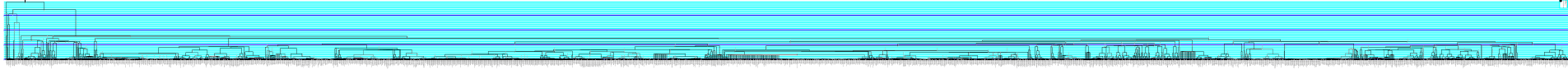
Fig. S1

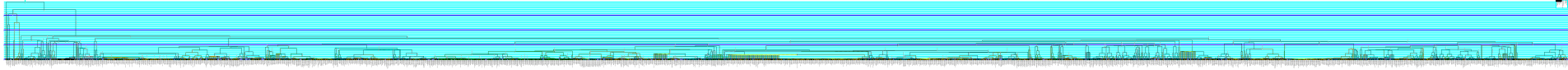
(a)

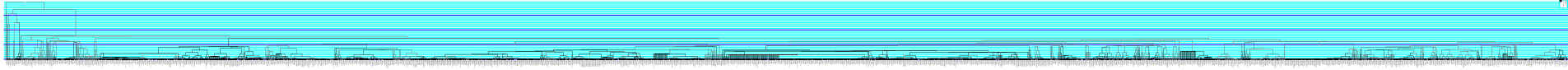


(b)









Notes S1. References for phylogenies at rank of Family and below, arranged alphabetically by Order

Apiales

Chandler GT, Plunkett GM, Pinney SM, Cayzer LW, Gemmill CEC (2007) Molecular and morphological agreement in Pittosporaceae: Phylogenetic analysis with nuclear its and plastid trnL, trnF sequence data. *Australian Systematic Botany* **20**, 390-401.

Nicolas AN, Plunkett GM (2009) The demise of subfamily Hydrocotyloideae (Apiaceae) and the re-alignment of its genera across the entire order Apiales. *Molecular Phylogenetics and Evolution* **53**, 134-151.

Arecales

Baker WJ, Asmussen CB, Chase MW, Dransfield J, Forest F, Harley MM, Savolainen V, Uhl NW, Wilkinson M (2009) Complete generic-level phylogenetic analyses of palms (Arecaceae) with comparisons of supertree and supermatrix approaches. *Systematic Biology* **58**, 240-256.

Asparagales

Seberg O, Petersen G, Davis JI, Pires JC, Stevenson DW, Chase MW, Fay MF, Devey DS, Jorgensen T, Sytsma KJ, *et al.* (2012) Phylogeny of the Asparagales based on three plastid and two mitochondrial genes. *American Journal of Botany* **99**, 875-889.

Asterales

Carolin RC, Rajput MTM, Morrison D (1992) Goodeniaceae. In 'Flora of Australia. Volume 35. Brunoniaceae to Goodeniaceae'. (Ed. George, AS), pp. 4–300. (Canberra: Australian Government Publishing Service)

Cross EW, Quinn CJ, Wagstaff SJ. (2002) Molecular evidence for the polyphyly of Olearia (Astereae : Asteraceae). *Plant Systematics and Evolution* **235**, 99-120.

Jabaily RS, Shepherd KA, Gustafsson MHG, Sage LW, Krauss SL, Howarth DG, Motley TJ (2012) Systematics of the Austral-Pacific family Goodeniaceae: Establishing a taxonomic and evolutionary framework. *Taxon* **61**, 419-436.

Schmidt-Lebuhn AN, Constable L (2013) Phylogenetic relationships of the Australasian shrubby everlastings Ozothamnus and Cassinia (Asteraceae: Asteroideae: Gnaphalieae). *Cladistics* **29**, 574-588.

Brassicales

Mithen R, Bennett R, Marquez J (2010) Glucosinolate biochemical diversity and innovation in the Brassicales. *Phytochemistry* **71**, 2074-2086.

Canellales (Winteraceae only)

Thomas N, Bruhl JJ, Ford A, Weston PH (2014) Molecular dating of Winteraceae reveals a complex biogeographical history involving both ancient Gondwanan vicariance and long-distance dispersal. *Journal of Biogeography* **41**, 894-904.

Caryophyllales

Kadereit G, Gotzek D, Jacobs SWL, Freitag H (2005) Origin and age of Australian Chenopodiaceae. *Organisms Diversity and Evolution* **5**, 59-80.

Kapralov MV, Smith JAC, Filatov DA (2012) Rubisco evolution in C-4 eudicots: An analysis of Amaranthaceae *sensu lato*. *PLoS ONE* **7**, e52974).

Celastrales (Celastraceae only)

George AS (1984) 'Flora of Australia. Volume 22. Rhizophorales to Celastrales'. (Canberra: Australian Government Publishing Service).

Cycadales

Nagalingum NS, Marshall CR, Quental TB, Rai HS, Little DP, Mathews S (2011) Recent synchronous radiation of a living fossil. *Science* **334**, 796-799.

Dilleniales

Horn JW (2009) Phylogenetics of Dilleniaceae using sequence data from four plastid loci (rbcL, infA, rps4, rpl16 intron). *International Journal of Plant Sciences* **170**, 794-813.

Ericales

Johnson KA, Holland BR, Heslewood MM, Crayn DM (2012) Supermatrices, supertrees and serendipitous scaffolding: Inferring a well-resolved, genus-level phylogeny of Styphelioideae (Ericaceae) despite missing data. *Molecular Phylogenetics and Evolution* **62**, 146-158.

Quinn CJ, Crayn DM, Heslewood MM, Brown EA, Gadek PA (2003) A molecular estimate of the phylogeny of Styphelieae (Ericaceae). *Australian Systematic Botany* **16**, 581-594.

Schonenberger J, Anderberg AA, Sytsma KJ (2005) Molecular phylogenetics and patterns of floral evolution in the Ericales. *International Journal of Plant Sciences* **166**, 265-288.

Fabales

Cook LG, Hardy NB, Crisp MD (2015) Three explanations for biodiversity hotspots: small range size, geographical overlap and time for species accumulation. An Australian case study. *New Phytologist* **207**, 390-400. doi: 10.1111/nph.13199.

Lewis GP, Schrire BD, Mackinder B, Lock JM, eds. (2005) 'Legumes of the World. Kew'. (Royal Botanic Gardens: UK).

Mishler BD, Knerr N, González-Orozco CE, Thornhill AH, Laffan SW, Miller JT (2014) Phylogenetic measures of biodiversity and neo- and paleo-endemism in Australian Acacia. *Nature Communications* **5**, 4473.

Orthia LA, Crisp MD, Cook LG, de Kok RPJ (2005) Bush peas: A rapid radiation with no support for monophyly of Pultenaea (fabaceae: Mirbelieae). *Australian Systematic Botany* **18**, 133-147.

Fagales

Steane DA, Wilson KL, Hill RS (2003) Using matK sequence data to unravel the phylogeny of Casuarinaceae. *Molecular Phylogenetics and Evolution* **28,** 47-59.

Gentianales

Bremer B, Eriksson T (2009) Time tree of Rubiaceae: Phylogeny and dating the family, subfamilies, and tribes. *International Journal of Plant Sciences* **170**, 766-793.

Endress ME, Liede-Schumann S, Meve U (2007) Advances in Apocynaceae: The enlightenment, an introduction. *Annals of the Missouri Botanical Garden* **94**, 259-267.

Liede S, Tauber A (2000) Sarcostemma r.Br. (Apocynaceae - Asclepiadoideae) - a controversial generic circumscription reconsidered: Evidence from trnL-F spacers. *Plant Systematics & Evolution* **225**, 133-140.

Mouly A, Kainulainen K, Persson C, Davis AP, Wong KM, Razafimandimbison SG, Bremer B (2014) Phylogenetic structure and clade circumscriptions in the Gardenieae complex (Rubiaceae). *Taxon* **63**, 801-818.

Wilson A (1996) *'Flora of Australia. Volume 28, Gentianales'.* (Melbourne: CSIRO Australia).

Lamiales

Conn BJ (1992) Lamiaceae. In 'Flora of New South Wales, Vol. 3.'. (Ed. Harden, GJ) pp. 623–664. (Sydney: Royal Botanic Gardens and Domain Trust)

Wilson TC, Conn BJ, Henwood MJ (2012) Molecular phylogeny and systematics of Prostanthera (Lamiaceae). *Australian Systematic Botany* **25**,341-352.

Laurales

Chanderbali AS, van der Werff H, Renner SS (2001) Phylogeny and historical biogeography of Lauraceae: Evidence from the chloroplast and nuclear genomes. *Annals of the Missouri Botanical Garden* **88**, 104-134.

Rohwer JG, De Moraes PLR, Rudolph B, Van der Werff H (2014) A phylogenetic analysis of the *Cryptocarya* group (Lauraceae), and relationships of *Dahlgrenodendron, Sinopora, Triadodaphne*, and *Yasunia*. *Phytotaxa* **158**, 111-132.

Magnoliales

Chatrou LW, Pirie MD, Erkens RHJ, Couvreur TLP, Neubig KM, Abbott JR, Mols JB, Maas JW, Saunders RMK, Chase MW (2012) A new subfamilial and tribal classification of the pantropical flowering plant family Annonaceae informed by molecular phylogenetics. *Botanical Journal of The Linnean Society* **169**, 5-40.

Malpighiales

Kathriarachchi H, Samuel R, Hoffmann P, Mlinarec J, Wurdack KJ, Ralimanana HN, Stuessy TF, Chase MW (2006) Phylogenetics of tribe Phyllantheae (Phyllanthaceae; Euphorbiaceae

sensu lato) based on nrITS and plastid matK DNA sequence data. *American Journal of Botany* **93**, 637-655.

Webster GL (1994) Synopsis of the genera and suprageneric taxa of Euphorbiaceae. *Annals of the Missouri Botanical Garden* **81**, 33-144.

Xi ZX, Ruhfel BR, Schaefer H, Amorim AM, Sugumaran M, Wurdack KJ, Endress PK, Matthews ML, Stevens PF, Mathews S, Davis CC (2012) Phylogenomics and a posteriori data partitioning resolve the Cretaceous angiosperm radiation Malpighiales. *Proceedings of the National Academy of Sciences of the United States of America* **109**, 17519-17524.

Malvales

Carter R 2012. **'**Diversification of the Malvales, Sterculioideae and Brachychiton'. PhD thesis. (The Australian National University, Canberra, Australia).

Marinho RC, Mendes-Rodrigues C, Balao F, Ortiz PL, Yamagishi-Costa J, Bonetti AM, Oliveira PE (2014) Do chromosome numbers reflect phylogeny? New counts for Bombacoideae and a review of Malvaceae s.L. *American Journal of Botany* **101**, 1456-1465.

Motsi MC, Moteetee AN, Beaumont AJ, Rye BL, Powell MP, Savolainen V, van der Bank M (2010) A phylogenetic study of Pimelea and Thecanthes (Thymelaeaceae): Evidence from plastid and nuclear ribosomal DNA sequence data. *Australian Systematic Botany* **23**, 270-284.

Pfeil BE, Brubaker CL, Craven LA, Crisp MD (2002) Phylogeny of Hibiscus and the tribe Hibisceae (Malvaceae) using chloroplast DNA sequences of ndhF and the rpl16 intron. *Systematic Botany* **27**, 333-350.

Tate JA, Aguilar JF, Wagstaff SJ, La Duke JC, Slotta TAB, Simpson BB (2005) Phylogenetic relationships within the tribe Malveae (Malvaceae, subfamily Malvoideae) as inferred from its sequence data. *American Journal of Botany* **92,** 584-602.

Whitlock BA, Hale AM, Indorf JL, Wilkins CF (2011) Polyphyly of Rulingia and Commersonia (Lasiopetaleae, Malvaceae s.L.). *Australian Systematic Botany* **24**, 215-225.

Myrtales

Bayly MJ, Rigault P, Spokevicius A, Ladiges PY, Ades PK, Anderson C, Bossinger G, Merchant A, Udovicic F, Woodrow IE, *et al*. (2013) Chloroplast genome analysis of Australian Eucalypts - *Eucalyptus, Corymbia, Angophora, Allosyncarpia* and *Stockwellia* (Myrtaceae). *Molecular Phylogenetics and Evolution* **69**, 704-716.

Biffin E, Lucas E, Craven L, Ribeiro da Costa I, Harrington M, Crisp MD (2010) Evolution of exceptional species richness amongst lineages of fleshy-fruited Myrtaceae. *Annals of Botany* **106**, 79-93.

Crisp MD, Burrows GE, Cook LG, Thornhill AH, Bowman DMJS (2011) Flammable biomes dominated by eucalypts originated at the Cretaceous–Palaeogene boundary. *Nature Communications* **2**, 193.

Edwards RD, Craven LA, Crisp MD, Cook LG (2010) Melaleuca revisited: cpDNA data confirm that *Melaleuca s.l.* (Myrtaceae) is not monophyletic. *Taxon* **59**, 744-754.

O'Brien MM, Quinn CJ, Wilson PG (2000). Molecular systematics of the *Leptospermum* suballiance (Myrtaceae). *Australian Journal of Botany* **48**, 621-628.

Wilson PG, Heslewood MM, Lam N, Quinn C (2004) Progress towards a phylogeny of the *Chamelaucium* alliance (Myrtaceae). *Australian Biologist* **17**, 28-33.

Wilson PG, O'Brien MM, Heslewood MM, Quinn CJ (2005) Relationships within Myrtaceae *sensu lato* based on a matK phylogeny. *Plant Systematics and Evolution* **251**, 3-20.

Oxalidales

Bradford JC, Barnes RW (2001) Phylogenetics and classification of Cunoniaceae (Oxalidales) using chloroplast DNA sequences and morphology. *Systematic Botany* **26**, 354-385.

Crayn DM, Rossetto M, Maynard DJ (2006) Molecular phylogeny and dating reveals an Oligo-Miocene radiation of dry-adapted shrubs (former Tremandraceae) from rainforest tree progenitors (Elaeocarpaceae) in Australia. *American Journal of Botany* **93**, 1328-1342.

Pinales (*Callitris*)

Crisp *et al*. Unpublished data.

Poales

Toon A, Crisp MD, Gamage H, Mant J, Morris DC, Schmidt S, Cook LG (2015) Key innovation or adaptive change? A test of leaf traits using Triodiinae in Australia. *Scientific Reports* **5**, 12398. doi:10.1038/srep12398

Proteales (Proteaceae only)

Bennett EM (1995). Conospermum. In 'Flora of Australia. Volume 16. Eleagnaceae, Proteaceae 1'. (Ed. PM McCarthy) pp. 224-271. (Melbourne: CSIRO Australia)

Cardillo M, Pratt R (2013) Evolution of a hotspot genus: Geographic variation in speciation and extinction rates in Banksia (Proteaceae). *BMC Evolutionary Biology* **13**, 155.

Makinson RO (2000). 'Flora of Australia. Volume 17a. Proteaceae 2, Grevillea'. (Melbourne: Australian Biological Resources Study / CSIRO)

Mast AR, Milton EF, Jones EH, Barker RM, Barker WR, Weston PH (2012) Time-calibrated phylogeny of the woody Australian genus *Hakea* (Proteaceae) supports multiple origins of insect-pollination among bird-pollinated ancestors. *American Journal of Botany* **99**, 472-487.

Milner ML, McIntosh EJ, Crisp MD, Weston PH, Rossetto M (2013) Microsatellite variation for phylogenetic, phylogeography and population genetic studies in *Lomatia* (Proteaceae). *Australian Systematic Botany* **26**, 186-195.

Sauquet H, Weston PH, Anderson CL, Barker NP, Cantrill DJ, Mast AR, Savolainen V (2009) Contrasted patterns of hyperdiversification in Mediterranean hotspots. *Proceedings of the National Academy of Sciences of the United States of America* **106**, 221-225.

Weston PH (1995) Persoonia. In 'Flora of Australia. Volume 16. Eleagnaceae, Proteaceae 1'. pp. 50-125. (Melbourne: CSIRO Australia)

Ranunculales

Wefferling KM, Hoot SB, Neves SS (2013) Phylogeny and fruit evolution in Menispermaceae. *American Journal of Botany* **100**, 883-905.

Rosales

Kellermann J, Udovicic F, Ladiges PY (2005) Phylogenetic analysis and generic limits of the tribe Pomaderreae (Rhamnaceae) using internal transcribed spacer DNA sequences. *Taxon* **54**, 619-631.

Clement, WL, Weiblen GD (2009) Morphological evolution in the mulberry family (Moraceae). *Systematic Botany* **34**, 530-552.

Santalales

Der JP, Nickrent DL (2008) A molecular phylogeny of Santalaceae (Santalales). *Systematic Botany* **33**, 107-116.

Malecot V, Nickrent DL (2008) Molecular phylogenetic relationships of Olacaceae and related Santalales. *Systematic Botany* **33**, 97-106.

Nickrent DL, Malecot V, Vidal-Russell R, Der JP (2010) A revised classification of Santalales. *Taxon* **59**, 538-558.

Vidal-Russell R, Nickrent DL (2008) Evolutionary relationships in the showy mistletoe family (Loranthaceae). *American Journal of Botany* **95**, 1015-1029.

Sapindales

Appelhans MS, Wen J, Wagner WL (2014) A molecular phylogeny of *Acronychia, Euodia, Melicope* and relatives (Rutaceae) reveals polyphyletic genera and key innovations for species richness. *Molecular Phylogenetics and Evolution* **79**, 54-68.

Armstrong JA (2002) *Zieria* (Rutaceae): A systematic and evolutionary study. *Australian Systematic Botany* **15**, 277-463.

Bayly MJ, Holmes GD, Forster PI, Cantrill DJ, Ladiges PY (2013) Major clades of Australasian Rutoideae (Rutaceae) based on rbcL and atpB sequences. *PLoS ONE* **8**, e72493.

Buerki S, Forest F, Stadler T, Alvarez N (2013) The abrupt climate change at the Eocene-Oligocene boundary and the emergence of south-east Asia triggered the spread of Sapindaceous lineages. *Annals of Botany* **112**, 151-160.

Harrington MG, Gadek PA (2010) Phylogenetics of hopbushes and pepperflowers (Dodonaea, Diplopeltis - Sapindaceae) based on nuclear ribosomal ITS and partial ETS sequences incorporating secondary-structure models. *Australian Systematic Botany* **23**, 431-442.

Mole BJ, Udovicic F, Ladiges PY, Duretto MF (2004) Molecular phylogeny of Phebalium (Rutaceae : Boronieae) and related genera based on the nrDNA regions its 1+2. *Plant Systematics and Evolution* **249**, 197-212.

Morton CM, Telmer C (2014) New subfamily classification for the Rutaceae. *Annals of the Missouri Botanical Garden* **99**, 620-641.

Muellner AN, Samuel R, Chase MW, Coleman A, Stuessy TF (2008) An evaluation of tribes and generic relationships in Melioideae (Meliaceae) based on nuclear its ribosomal DNA. *Taxon* **57**, 98-108.

Wannan BS (2006) Analysis of generic relationships in Anacardiaceae. *Blumea* **51**, 165-195.

Solanales

Olmstead RG, Bohs L, Migid HA, Santiago-Valentin E, Garcia VF, Collier SM (2008) A molecular phylogeny of the Solanaceae. *Taxon* **57**, 1159-1181.

Vitales

Rossetto M, Crayn DM, Jackes BR, Porter C (2007) An updated estimate of intergeneric phylogenetic relationships in the Australian Vitaceae. *Canadian Journal of Botany* **85**, 722-730.