Paradise burnt: How colonizing humans transform landscapes with fire

David M. J. S. Bowman[a,1] **and Simon G. Haberle**[b]

[a]*School of Plant Science, University of Tasmania, Hobart, Tasmania 7001, Australia; and* [b]*Department of Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Canberra, Australian Capital Territory 0200, Australia*

A striking feature of Southern Hemisphere landscapes is the occurrence of grasslands in regions that are climatically suitable for forests (Fig. 1). Ecologists and biogeographers working in these southern lands have developed a range of theories to account for the biogeographic anomaly of grassland–forest mosaics (1–7). Broadly speaking, these theories divide into those that privilege the importance of an ensemble of environmental factors, including fire, or those that stress the legacy of human landscape burning. The report by McWethy et al. in PNAS (8) provides incontrovertible evidence that anthropogenic burning transformed temperate forested landscapes on the South Island of New Zealand. They show that Polynesian (Māori) firing commenced shortly after colonization around A.D. 1280 and transformed 40% of the original forest cover of the island to grassland and fern-shrubland. There is little room for doubting their findings given the elegant integration of a range of paleoecological methodologies, very precise dating, and a high level of replication across the island. This report will spark renewed interest in the relative importance of fire, humans, and climate in shaping forest–grassland landscape mosaics worldwide (9).

New Zealand is a superb model system for understanding the effect of human fire usage on temperate forests for the following reasons. The north–south mountain chain, which forms a spine across the South Island, causes a pronounced rainfall, elevation, and vegetation gradient from dry [<650 mm mean annual precipitation (map)] low-elevation watersheds [<300 m above sea level (masl)] in the east to wet (>1600 mm map) montane (>800 masl) watersheds in the west. Across this gradient there is a high density of small lakes that trap sediments, charcoal, and pollen. The comparatively recent colonization by Māori some 800 y ago and Europeans in the mid 19th century means that ^{14}C dating can be used to develop robust chronologies to chart environmental change and fire activity. Before human settlement fire activity was remarkably low, with charcoal records indicating fires once or twice per millennium. In marked contrast to Australian eucalypt-dominated temperate forest flora, New Zealand forest trees have no adaptations to survive fire or any dependency on fire to regenerate and are easily killed by burning (10). Thus, these forests are highly responsive to slight changes in fire regime.

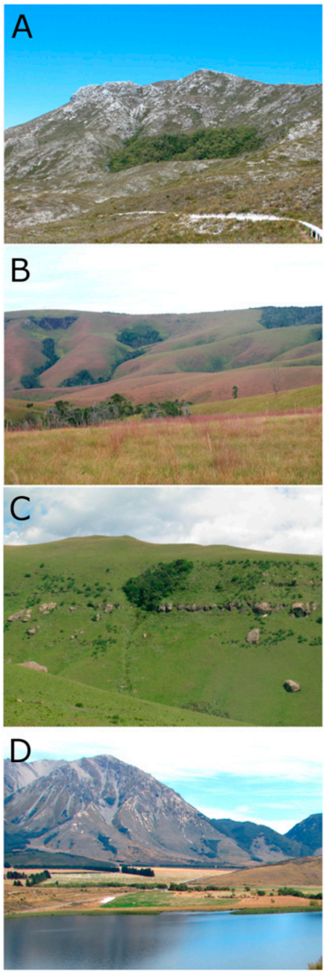

Fig. 1. Grassland forest mosaics are a feature of many Southern Hemisphere landscapes: (*A*) South West Tasmania, (*B*) the interior of Madagascar, (*C*) Drakenburg Mountains, South Africa, and (*D*) the South Island of New Zealand. Various theories have been proposed to explain these biogeographically puzzling vegetation patterns that in general emphasize the importance of anthropogenic landscape burning or climatically driven fire regimes (1–7, 9, 17, 18). The report by McWethy et al. (8), based on an extremely robust paleoecological database, leaves no doubt that the grasslands in the South Island are derived from a short burst of intense landscape burning associated with the colonization of the island by Māori 800 y ago. This Initial Burning Period was not associated with any anomalous climatic conditions. (Photo credits: *A* and *C*, David Bowman; *B*, William Bond; *D*, Matt McGlone).

McWethy et al. are able to disclose the impact of Māori burning on the South Island by analyzing variation in macroscopic charcoal data, pollen records, limnobiota (diatom and chironomid taxa), and sediment geochemistry from 16 small lakes in watersheds spanning the dominant east–west precipitation gradient (8). They find that in the decades immediately after Māori colonization there was a burst of severe fire events. This “Initial Burning Period” was destructive of forest cover and an initiator of soil erosion and associated nutrient influx in all but the wettest and topographically fire-sheltered watersheds. After the Initial Burning Period there was less frequent and less severe burning, which enabled forests in higher-rainfall areas to recover. McWethy et al. are able to reject the hypothesis that the burst of fire activity after Māori settlement was associated with anomalous climates patterns given that the severe fires were neither synchronous nor associated with anomalous summer temperatures inferred from silver pine (*Lagarostrobos colensoi*) tree-ring chronologies calibrated against instrumental data (8). The importance of human ignition in forest destruction was further underscored by a surge of burning coincident with mid-19th century European settlement that also caused grassland expansion, soil erosion, and consequent changes to the chemistry of lake sediments.

McWethy et al. recognize that the conversion of forest to grassland and associated soil changes in drier sites due to Māori and then European landscape burning is a clear example of a fire-initiated ecological feedback process. Indeed such precise chronicling of the development of grassland–forest mosaic is important in developing the theory of alternate stable states that posits that extreme disturbance, such as recurrent landscape firing, can cause ecological systems to rapidly switch from one state to another and that ecological feedbacks

---

Author contributions: D.M.J.S.B. and S.G.H. wrote the paper.

The authors declare no conflict of interest.

See companion article on page 21343.

[1] To whom correspondence should be addressed. E-mail: david.bowman@utas.edu.au.

www.pnas.org/cgi/doi/10.1073/pnas.1016393108

provide strong resistance to a return to the predisturbance state (11). The McWethy et al. study contributes to tackling one of the key challenges presented by alternative state theory: discrimination of the feedback processes that maintain the alternative state from the disturbance regime that caused the switch from one state to another (e.g., forest to grassland) (12). In the New Zealand case there is little doubt the driver of the switch was a burst of severe burning by humans. Yet recovery to forest is clearly facilitated by high-rainfall but inhibited by low-rainfall environments. Such climate–anthropogenic fire interactions are of great significance in developing predictive capacity for the consequences of climate change (13). Settling the issue of the origin of grassland–forest mosaics also has immediate conservation policy implications (14, 15). For example, Bond and Parr (16) suggest that the perception, which they reject, that tropical grasslands are anthropogenically derived reduces their conservation value and makes them prime targets for agriculture and "reaforestation" programs designed to provide wood products and capture carbon.

The report in PNAS (8) highlights the importance of combining a range of paleoecological techniques, sampling across climate gradients, having high levels of replication, and using consistent methodologies to effectively disaggregate the effects of human fire use and natural fire regimes. This robust study provides an important exception to the recently proposed global generalization of the overwhelming importance of climate in driving fire activity before the industrial revolution (A.D. 1750), based on a pioneering analysis of a compilation of charcoal records from around the world (13).

> **Anthropogenic burning transformed temperate forested landscapes on the South Island of New Zealand.**

It remains to be seen whether, if the high-resolution paleoecological approach used by McWethy et al. were to be applied to other flammable landscapes, it will challenge this paradigm that before industrialization climate, not humans, was the primary driver of both fire activity and vegetation patterns.

The time is certainly ripe to undertake comparative analyses of southern hemisphere island systems given the current contrasting perspectives of the importance of climate and anthropogenic burning in the Southern Hemisphere. For example, researchers working on the islands of Tasmania and Madagascar have reached opposite conclusions regarding climatically anomalous treeless vegetation. On the strength of ecological and historical biogeographic evidence, Bond et al. have argued that the expanses of subtropical grasslands in the drier areas of Madagascar are not derived from human fire use after colonization some 2000 y B.P., in contrast to a well-established theory developed by several generations of French scientists (3, 17). Conversely, on the basis of pollen and ecological evidence, Fletcher and Thomas (18) claim that that the sedgelands that dominate more than 40% of the humid temperate western Tasmanian landscape are the legacy of sustained Aboriginal burning, which effectively preserved a Pleistocene landscape these colonists found some 35,000 y ago.

Contrasts of fire activity in the Southern Hemisphere clearly can provide crucial insight into how human burning has modified landscape, the relative importance of biotic history, and the interplay with climate variation (18). Such a project, of which the McWethy et al. study (8) can be considered the first step, will also bring to international attention the insights and data that have been accumulated by generations of Southern Hemisphere ecologists, archaeologists, and biogeographers who have been studying the impacts of fire on Southern Hemisphere landscapes and islands, often in intellectual isolation from each other (1–5, 17). We believe that, when combined carefully, the findings from such "miniworlds" that serve as model systems hold the answer to globally significant questions about the impact of anthropogenic landscape burning, climate change, and their interactions on forest cover (19, 20).

1. Ellis RC (1985) The relationships among eucalypt forest, grassland and rainforest in a highland area in north-eastern Tasmania. *Aust J Ecol* 10:297–314.
2. Jackson WD (1968) Fire, air, water and earth—an elemental ecology of Tasmania. *Proc Ecol Soc Aust* 3:9–16.
3. Bond WJ, Silander JA Jr., Ranaivonasy J, Ratsirarson J (2008) The antiquity of Madagascar's grasslands and the rise of C4 grassy biomes. *J Biogeogr* 35:1743–1758.
4. McGlone MS (2001) The origin of the indigenous grasslands of southeastern South Island in relation to pre-human woody ecosystems. *N Z J Ecol* 25:1–15.
5. Webb LJ (1964) An historical interpretation of the grass balds of the Bunya Mountains, South Queensland. *Ecology* 45:159–162.
6. Fensham RJ, Fairfax RJ (2006) Can burning restrict eucalypt invasion on grassy balds? *Austral Ecol* 31:317–325.
7. Bowman DMJS, Wood SW (2009) Fire driven land cover change in Australia and W.D. Jackson's theory of the fire ecology of southwest Tasmania. *Tropical Fire Ecology: Climate Change, Land Use and Ecosystem Dynamics*, ed Cochrane MA (Springer-Praxis, Heidelberg), pp 87–111.
8. McWethy DB, et al. (2010) Rapid landscape transformation in South Island, New Zealand, following initial Polynesian settlement. *Proc Natl Acad Sci* 107:21343–21348.
9. Bond WJ, Woodward FI, Midgley GF (2005) The global distribution of ecosystems in a world without fire. *New Phytol* 165:525–537.
10. Burrows G, et al. (2010) A wide diversity of epicormic structures is present in Myrtaceae species in the northern Australian savanna biome—implications for adaptation to fire. *Aust J Bot* 58:493–507.
11. Scheffer M, Carpenter S, Foley JA, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. *Nature* 413: 591–596.
12. Petraitis PS, Latham RE (1999) The importance of scale in testing the origins of alternative community states. *Ecology* 80:429–442.
13. Marlon JR, et al. (2008) Climate and human influences on global biomass burning over the past two millennia. *Nat Geosci* 1:697–702.
14. Motzkin G, Foster DR (2002) Grasslands, heathlands and shrublands in coastal New England: Historical interpretations and approaches to conservation. *J Biogeogr* 29:1569–1590.
15. Willis KJ, Gillson L, Brncic TM (2004) Ecology. How 'virgin' is virgin rainforest? *Science* 304:402–403.
16. Bond WJ, Parr CL (2010) Beyond the forest edge: Ecology, diversity and conservation of the grassy biomes. *Biol Conserv* 143:2395–2404.
17. Willis KJ, Gillson L, Virah-Sawmy M (2008) Nature or nurture: The ambiguity of C4 grasslands in Madagascar. *J Biogeogr* 35:1741–1742.
18. Fletcher M-S, Thomas I (2010) The origin and temporal development of an ancient cultural landscape. *J Biogeogr* 37:2183–2196.
19. Cochrane MA (2003) Fire science for rainforests. *Nature* 421:913–919.
20. Bowman DMJS, et al. (2009) Fire in the Earth system. *Science* 324:481–484.