# Decline of eucalypt forests as a consequence of unnatural fire regimes

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## Summary

Fire was an integral part of the Australian environment before European settlement. The conventional view of fire as a 'disturbance', and the misconception that 'natural succession' occurs in the absence of 'disturbance' to eucalypt ecosystems, cause much confusion about eucalypt forest decline. Natural fire regimes stabilised eucalypt ecosystems so that they were self sustaining, whereas post-European interference has substantially changed the environment, initiating unnatural ecosystem processes. Eucalypts are declining whilst many of their arbivores and competitors are proliferating. The same types of changes have been reported in other parts of the world, especially North America. A more realistic approach to ecology can provide simple and operationally feasible solutions to eucalypt decline, but the confusion makes these solutions politically difficult.

*Keywords*: forest decline; fire ecology; succession; *Eucalyptus*; Australia

## Introduction

Fire is overwhelmingly important in the evolution and maintenance of the Australian biota, and changes to fire regimes have upset the ecological balance in many forests (Attiwill 1994). Ecologists are frequently frustrated in attempts to reconcile their data with traditional concepts (Attiwill 1994) of disturbance, succession, eutrophication, climax and stability (e.g. Kormondy 1969). These concepts are not applicable to the natural role of fire in maintaining eucalypts as the dominant species in most Australian forests (Jurskis 2005). A 'dynamic equilibrium' is the most appropriate reference point to use in fire ecology (Tolhurst 2004), but fire ecologists typically view long-unburnt treatments as 'controls' and report differences between them and repeatedly burnt areas as 'impacts' of burning (Jurskis 2003). Thus, fire is inappropriately viewed as a disturbance, and exclusion of fire is not recognised a disturbance (Jurskis 2003).

Attiwill (1994) considered that wet eucalypt forests are highly resilient, whilst dry eucalypt forests are highly resistant to disturbance by fire. However, recurrent fire is a stabilising influence rather than a disturbance because frequent low-intensity fire maintains the health and dominance of eucalypts in dry and moist ecosystems, whilst infrequent high-intensity fire regenerates and maintains the dominance of eucalypts in wet forests (Jurskis 2005). European settlement has had relatively little impact on fire regimes in wet forests (e.g. Hickey *et al.* 1999). On the other hand, fire regimes in drier forests have been affected substantially by post-European developments, and this is where forest decline is prevalent (Jurskis *et al.* 2003).

Frequent low-intensity fires can maintain forest health (e.g. Bowling and McLeod 1968; Mount 1969; Ellis *et al.* 1980; Farr *et al.* 2004; Jurskis 2005), whereas reduced use of low-intensity fires has caused declines in forest health, increases in pest and disease populations, invasion by shrubby understoreys and more extensive high-intensity fires (Jurskis and Turner 2002; Jurskis *et al.* 2003; Jurskis 2005). Similar problems have also been associated with changes in fire regimes in North America (Koonce and Roth 1980; Anderson *et al.* 1987; Bergeron and Leduc1998; Dwire and Kauffman 2003; Hessburg and Agee 2003). These problems reflect a breakdown of natural processes of nutrient cycling, competition, mortality and recruitment (e.g. Granger *et al.* 1994; Marsh and Adams 1995; Lunt 1998; Jurskis and Turner 2002; Jurskis 2005).

Unnatural exclusion of fire changes soils and nutrient cycling processes (Turner and Lambert 2005, this issue), creating an unfavourable environment for eucalypts and a more favourable environment for their arbivores and competitors (Jurskis 2005). For example, Stone (2005, this issue) found that eucalypt canopy decline was significantly correlated with ammonium concentrations and nitrogen/carbon ratios in soils. Sick trees provide abundant high-quality food, allowing pests and diseases to proliferate (White 1993, 2004). However, proliferation of shrubs and declining health of trees in 'undisturbed' reserves are viewed as a 'recovery' or a 'natural succession' by ecologists who do not recognise exclusion of low-intensity fire as a disturbance (e.g. Jurskis 2002, 2003; Wardell-Johnson *et al.* 2005, this issue). Outbreaks of pests and diseases are viewed as a cause rather than a symptom of declining health (e.g. Stone 2005, this issue), but attempts to halt decline by controlling pests and diseases have largely failed (Jurskis 2005). Some simple effective solutions are available to deal with decline of eucalypt forests (e.g. Mount 1969; Ellis *et al.* 1980; Jurskis 2005). However confusion about the role of fire in Australian ecosystems makes implementing these solutions difficult.

## Environmental changes since European settlement

### Changed fire regimes

Despite prolonged and contentious debate (e.g. Keith *et al.* 2002; Cary 2005), the widely held view that European settlement brought a large increase in the frequency of fires is based on a very narrow consideration of evidence. Sediment cores, dendrochronological studies and general historical records are unlikely to record low-intensity fires (Jurskis *et al.* 2003). Some dendrochronological studies show a relatively high frequency of recent fire scars in dense young stands (e.g. Cary 2005), but older, larger, open-grown or dominant trees were rarely scarred by low-intensity fires (Ashton 1981; Pearson and Searson 2002; Cary 2005). Therefore, records from fire scars are not directly comparable between old and young stands. However, methods that can reliably 'detect' low-intensity fires typically show a reduced frequency of fire since European settlement (Fensham 1997; Ward *et al*. 2001; Abbott 2003).

Arguments often focus on burning by Aboriginal people whilst ignoring recent suppression of the great majority of fires ignited by lightning (Jurskis *et al.* 2003). Frequent, extensive, high-intensity fires were associated with fire suppression and limited low-intensity burning during the early to mid 20th century and in recent decades (Jurskis *et al.* 2003; Cheney 2005). The weight of evidence clearly indicates that natural fire regimes in dry and moist eucalypt forests were dominated by frequent low-intensity fires with high spatial variability (Jurskis *et al.* 2003).

Keith *et al.* (2002) argued that pre-European fire regimes were of little relevance to current management because they could not be determined precisely. However, the concept of precision has no value in relation to spatially and temporally variable regimes (Jurskis *et al.* 2003). For example, moist forests on the north coast of New South Wales, alpine ash forests in the Snowy Mountains, and high quality red gum forests in the Riverina are associated respectively with high summer rainfall, frequent snowfall or occasional flooding regimes. These regimes cannot be described with any precision, but the persistence of each forest type is dependent on its natural watering regime, just as the persistence of some forest types depends on particular fire regimes. Frequent low-intensity fires in drier forests and infrequent high-intensity fires in wet forests do not constitute disturbance anymore than a particular watering regime is a disturbance to the forest that depends on it.

## Changes in flora and fauna

Debate about changes to vegetation has paralleled debate about fire regimes (e.g. Ryan *et al.* 1995; Benson and Redpath 1997; Jurskis 2000). Benson and Redpath (1997) argued that Ryan *et al.* (1995) overstated the extent of grassy eucalypt ecosystems and burning by Aboriginal people. On the other hand, dense shrub layers have been erroneously portrayed as a natural feature of forests that were originally grassy (e.g. Keith and Bedward 1999; Henderson and Keith 2002; Keith 2004). This has happened because ecologists have failed to recognise exclusion of fire as a disturbance to fire-dependent ecosystems (Jurskis 2002, 2003).

Nevertheless, it is generally recognised that substantial changes have occurred in Australian vegetation as a result of changed fire regimes (e.g. AUSLIG 1990; Benson and Redpath 1997; Jurskis 2000; Florence 2005, this issue). For example, dense forests on the Murray River floodplains, and in the 'Pilliga Scrub', developed largely as a consequence of fire suppression. Proliferation of exotic weeds, shrubs, vines, parasitic plants or 'shade-tolerant' trees, in the absence of fire, has been widely reported (e.g. Anon. 1965; Gleadow and Ashton 1981; Stocker and Mott 1981; Smith and Smith 1990; Ellis and Pennington 1992; Rose 1997; Lunt 1998; Bradshaw 2000; Reid and Yan 2000; York 2000; Jurskis 2004b), and there is also evidence that tree declines involving *Phytophthora* and *Armillaria* are promoted by both fire exclusion and consequential high-intensity fires (Jurskis 2005).

Competitors, parasites and diseases of eucalypts proliferate with exclusion of fire from drier forests because the trees are stressed by the changed environment and are less competitive, whilst their antagonists are favoured by both the changed environment and the physiological changes in the sick trees (Jurskis 2005). Koalas, possums, bellbirds, noisy miners, borers, Christmas beetles, leaf beetles, leaf skeletonisers, lerps, loopers, moths, sawflies, and stick insects have proliferated in declining eucalypt stands, and have been nominated as causes of tree decline (Carter *et al.* 1981; Martin 1985; Neyland 1996; Smith 2004; Jurskis 2004a,b,c, 2005). However, these animals proliferate because sick trees provide them with better food than healthy trees (White 1993, 2004). With unnatural fire regimes and increased populations of pests, parasites, pathogens and competitors in the landscape, there can be exaggerated temporal and spatial responses to any type of stress to the trees (Dwire and Kauffman 2003; Hessburg and Agee 2003). When this happens, even natural stressors such as drought can initiate or accelerate chronic decline (Jurskis and Turner 2002; Jurskis 2005).

Outbreaks of pests and predators are a symptom rather than a cause of decline, and they can be controlled by prescribed burning (e.g. Campbell and Hadlington 1967; Mount 1969; Martin 1985; Farr *et al*. 2004). Low-intensity burning does not kill these animals; rather, it maintains natural soil conditions and healthy trees that do not provide sufficient nutrition for the animals to proliferate (Jurskis 2005). Quarantine and hygiene measures against diseases, direct control of arbivores, and indirect measures to encourage their predators have failed to restore the health of declining eucalypt stands because the pests and diseases are secondary or tertiary contributing factors rather than causes of tree decline (e.g. Clarke and Schedvin 1999; Jurskis 2004b, 2005). On the other hand, fire regimes can have a large influence on the distribution of fauna (Kavanagh and Stanton 2005, Fig. 4).

## Grazing as a substitute for fire

Some eucalypt forests, that remained healthy and open despite long periods of fire exclusion, have declined in health following withdrawal of domestic stock (Jurskis 2005). Grazing, slashing or cropping can substitute for natural fire regimes and maintain the health and predominance of eucalypts in these forests (Jurskis 2004b). Withdrawal of grazing (often to 'protect' biodiversity) can initiate eucalypt decline, and this will continue unless more natural fire regimes are reinstated (Jurskis 2005). On the other hand, pasture improvement can initiate or accelerate decline of eucalypts in rural lands in much the same way that intense fires can exacerbate decline in drier forests (Jurskis and Turner 2002; Jurskis 2004b,c).

## Natural fire regimes and environmental stability

Eucalypts evolved as the dominant form of life in much of Australia while the environment was becoming increasingly arid and infertile (Barlow 1981; Attiwill 1994). There were frequent ignitions by lightning and Aboriginal people over many millennia, and the distribution of vegetation as well as the extent of fires was governed by climatic and edaphic conditions (Jurskis *et al.* 2003). For example, Turner (1984) found evidence of only one fire about 1000 y earlier in a rainforest stand on krasnozem, and eight fires at intervals of about 300 y in the surrounding wet eucalypt stand on brown forest soil. Ward *et al.* (2001) found that there were about three fires per decade in the relatively dry jarrah forests before European settlement, and Fensham (1997) concluded that there was a high frequency of burning by Aboriginal people in most of eastern Queensland. Frequent low-intensity fires prevented accumulation of 'mulch', proliferation of perennial understoreys, cooling and dampening of the microclimate under the canopy and acceleration of nutrient cycling processes (Jurskis 2004c, 2005). They also provided for regeneration of eucalypts, to replace trees that burnt down or collapsed, by maintaining receptive seedbeds, 'pools' of healthy lignotubers and open sunny conditions.

Since European settlement, reduced occurrence of low-intensity fires in drier forests (Jurskis *et al.* 2003) has destabilised them (e.g. Florence 2005, this issue) via a 'vicious cycle' of (i) accumulating litter on the forest floor, (ii) accumulating organic matter, nitrogen and moisture in the topsoil, (iii) increasingly dense understoreys or ground layers, (iv) increasing mineralisation and cycling of nitrogen in soils and vegetation, (v) declining available phosphorus in soils, (vi) increasing shade at ground level, (vii) increasing nitrogen content of trees' foliage, (viii) increasing rates of leaf fall, and (ix) increasing organic matter and nutrient content of litter and topsoil (e.g. Raison *et al.* 1993; York 1999, 2000; Guinto *et al.* 2001). These changes weaken edaphic control of fires so that fires are less likely to propagate in mild conditions whilst they propagate explosively in severe conditions (Jurskis *et al.* 2003). Increased occurrence of high-intensity fire reinforces the changes by further stimulating nutrient cycling processes and understoreys (and sometimes through hydrological impacts such as raised watertables, e.g. Jurskis 2004b, 2005).

Nitrogen is the main factor that limits populations of arbivores (White 1993, 2004), and human interference has accelerated nitrogen cycling throughout the world, more so than cycling of any other element (Magill *et al.* 2004). There is increasing worldwide recognition that tree decline is associated with 'nitrogen saturation' (e.g. Kandler 1992; Kreutzer 1993; Ohrui and Mitchell 1997; Wardle *et al.* 2004). Eutrophication has been recognised as a threat to aquatic ecosystems for some time (e.g. Kormondy 1969) and more recently as a threat to some eucalypt ecosystems (e.g. Clements 1983; Granger *et al.* 1994; Prober *et al.* 2002). However, there is little recognition that unnatural fire regimes can cause widespread eutrophication and decline of eucalypt forests, because exclusion of fire is mostly not recognised as disturbance (Jurskis 2003, 2005). For example, eutrophication is recognised as a threat to stromatolites in Lake Clifton (near Perth), but not as a threat to the surrounding tuart forests (Jurskis 2005).

There are striking parallels between eutrophication in polluted lakes, and eutrophication in eucalypt forests where fire has been excluded. Nutrients accumulate, sunlight and oxygen are depleted, dominant species decline, pests and weeds proliferate, and sites where 'percolation' of water and nutrients are physically impeded are the worst affected (e.g. Kormondy 1969; Monastersky 1998; Jurskis 2005). Lakes with restricted water circulation, like forests on poorly drained and aerated soils, are prone to decline whereas lakes with free water circulation and forests on well structured soils are relatively healthy. Eutrophication through agricultural development is recognised as a cause of eucalypt decline in rural lands (Landsberg *et al*. 1990; Reid and Yan 2000; Jurskis and Turner 2002; Jurskis 2003, 2005; Jurskis *et al*. 2003, McCulley *et al.* 2004). Sites with depositional soils on concave topography at low elevations are predisposed to tree decline because they are more prone to eutrophication and other changes such as rising watertables and soil compaction (Jurskis 2005).

Hessburg and Agee (2003) recognised that fire was a critical factor in the environment of Inland Northwest North America before European settlement, and that fire suppression has caused declining forest health, changes in forest structure and composition, and more extensive outbreaks of intense fires, pests and diseases. The same process has occurred widely in temperate Australian forests (Jurskis and Turner 2002; Jurskis *et al.* 2003; Jurskis 2005). Bell-miner-associated dieback in eastern Australia is an example, as are most other forest declines, including 'high altitude dieback' in Tasmania, 'armillaria root disease' in central Victoria, and tuart decline in Western Australia (Jurskis 2004b, 2005).

## Conventional hypotheses of eucalypt decline

Conventional theories of eucalypt decline do not stand critical examination. The germ theory fails because pests and pathogens are usually present in healthy stands; climatic stress cannot account for contrasting health of similar stands experiencing the same climate; and complex explanations are unnecessary when decline can be simply attributed to chronic abiotic stress as a result of human interference with fire regimes (Jurskis 2005).

Florence (2005, this issue) suggests that unnaturally dense, young, even-aged stands can deplete their sites leaving them susceptible to *Armillaria* or drought, and unable to develop normally. However, the examples given do not support this hypothesis because southern regrowth dieback in Tasmania was not related to stand density, and was actually exacerbated by thinning and fertilisation (Wardlaw 1989; Jurskis and Turner 2002), whilst *Armillaria* outbreaks occurred in fully developed mature eucalypt stands on high quality sites in central Victoria and south-western Australia (Kile 2000; Jurskis 2004b, 2005). Furthermore, dense young stands typically accumulate nitrogen in the soil as they develop without fire (Turner and Lambert 2005, this issue), supporting the hypothesis of eutrophication rather than depletion.

It has been proposed that there is a natural succession to rainforest on highly fertile sites, a process that can be interrupted by fire to produce a disclimax eucalypt forest; and that eucalypt decline is a natural consequence of prolonged absence of fire (e.g. Old 2000; Florence 2005 this issue; Wardell-Johnson and Lynch 2005, this issue). However, eucalypt decline does not occur on highly fertile sites with a well-developed subtropical rainforest subcanopy, whereas both 'bell miner dieback' and 'high altitude dieback' occur on poor sites that cannot support rainforest (Jurskis 2004a,c). Furthermore, Turner (1984) found differences between the soils of a rainforest site and the surrounding wet eucalypt forest. Boundaries between eucalypt forests and subtropical rainforests in northern New South Wales are usually determined by soil fertility including water availability, drainage and structure of soils. For example, eucalypt forests occur on drier aspects, slight rises, sharp spurs, lower elevations or 'rainshadows' and sedimentary soils (Jurskis *pers. obs.*). Isolated small stands of eucalypts with a subcanopy of rainforest trees occur in slightly exposed positions within extensive tracts of rainforest, and these eucalypt stands are not declining (Jurskis 2004a). Before European settlement, both vegetation and fire regimes were controlled by edaphic factors (Jurskis *et al.* 2003).

## Implications for nature conservation

Changes in fire regimes have upset the ecological balance in many eucalypt ecosystems (Attiwill 1994), and caused the health and predominance of eucalypts to decline (Jurskis 2005). Increasing populations of other species including mistletoes, shrubs, birds, possums and koalas have been seen by some ecologists as a sign of healthy ecosystems (e.g. Henderson and Keith 2002; Watson 2002; Keith 2004; Shaw *et al*. 2004; Kavanagh and Stanton 2005), and by others as a sign of ecological imbalance (e.g. Martin 1985; Neyland 1996; Jurskis 2002, 2005; Jurskis *et al.* 2003). A realistic view of ecology would recognise the imposition of unnatural fire regimes as a disturbance, and distinguish true biodiversity from an unnaturally high biomass of a few native weeds or pest animals (Jurskis 2003; Jurskis *et al.* 2003). Many ecological imbalances could be remedied at a landscape scale by reintroduction of more natural fire regimes (Jurskis 2005). Unfortunately ecologists and 'environmentalists' adhering to philosophies of 'non intervention' or passive management have supported misconceptions and confusion based on traditional concepts of disturbance and succession (Attiwill 1994), as well as the idea that populations are regulated by predators (White 1993). They have opposed any reinvigoration of prescribed burning in the landscape (Jurskis 2000, 2003, 2005; Jurskis *et al.* 2003). This, together with controversies about the recent widespread and disastrous fires resulting from 'non intervention' (e.g. Cheney 2005), will make it difficult to implement practical solutions to decline of eucalypt forests.

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