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Introduction

Over 220 years of European settlement has resulted in significant changes to the structure and in some cases, the species composition of large parts of the NSW native forests estate. Aside from the impacts of forest clearing and harvesting, the changed burning regimes post European settlement have resulted in changed species composition and stand structure across much of the remaining native forest in NSW.

Some observations made by Alfred Howitt in 1890 provide important insight into this issue. (See attached paper.)

Harvesting in native forests has become increasingly regulated and prescriptive. This approach has increased compliance costs, while not necessarily providing the best environmental outcomes possible.

Comment and Recommendations

Integrated Forest Operations Approvals Restructure Pages 11 - 14

The proposal to consolidate the four IFOAs and the licence conditions, as well as a focus on outcomes is supported.

The proposal to take a landscape approach to biodiversity conservation is also supported. To ensure this approach is effective, a monitoring framework must be put in place and extend beyond the immediate harvest area to non-harvest areas and the conservation reserve system. The monitoring must extend into future decades to capture the impacts of major wildfires, predation and other issues affecting the total forest estate. Government cannot possibly effectively manage biodiversity and threatened species outcomes without adequate data.

Passive management and a "lockup" in conservation reserves approach has not brought sustainable conservation outcomes for many species. For example, substantial reserves have been created in the Eden Region to help protect the southern brown bandicoot (SBB) and long footed potoroo (LFP). Despite the additional reserves and the content of the Eden Region threatened species licence endeavouring to protect remaining populations, these populations did not immediately recover.

In the case of a number of small species, the real threat has proved to be predation. The most successful predator control program, in terms of increasing populations of small ground dwelling mammals, was commenced by FCNSW staff in southeast NSW six years ago. A similar program has been in place in East Gippsland for over 10 years. Monitoring has found significant population increases in rarer species such as LFP, SBB and the long nosed potoroo (LNP) and more common species such as the long nosed bandicoot (LNB).

It is ironic that FCNSW has been required to leave areas of forest undisturbed for LFP protection, while in Victoria, this threatened species can be found in regenerating forest as young as 2 years of age.

<u>Current IFOA Focus on Process</u>

An example of the focus on process mixed with flawed interpretation relates to the issue of incorrectly mapped streams and drainage features. The current Threatened Species Licence defines a Stream - *"means any stream or watercourse shown on the relevant topographic map(s) for the compartment from a 1:25,000 topographic map sheet produced by the Land Information Centre ....."*

It would appear that the author of the clause made the assumption that these maps are accurate or common sense would otherwise prevail. Unfortunately, the maps are not totally accurate and a "common sense" interpretation of the licence has not been applied. For the past 15 years, the State forest managers and contractors operating under this licence have had to implement Stream Exclusion Zones (SEZ) in areas of forest where no stream or drainage features exist, for fear of breaching the licence conditions. Thankfully, SEZs are applied to the actual steams and any unmapped drainage features.

Recommendation 1

Where Light Detection and Ranging (LIDAR) data is available base maps must be updated to improve planning efficiency. Where mapping errors are found, conditions must only be applied to real features in the field.

<u>Reduce Costs and Improve Clarity and Enforceability</u>

The above example is just one area where planning and field marking costs can be reduced. The use of technology such as Global Positioning Systems (GPS) and laser range finders can also potentially reduce the cost of marking various boundaries and exclusion zones. If these tasks are passed to trained harvesting contractors, it must be recognised that some of the forest managers costs and responsibilities will fall to the contractor, so some of the savings will need to be shared, to offset increased contractor costs.

Recommendation 2

Where it is most efficient for trained harvesting contractors to take on field marking, selection and other tasks, the additional costs must be funded out of some of the savings made through the transfer of responsibilities.

Minimum Competencies and Strengthen Penalties Page 16

The requirement for minimum competencies is supported and will become more important if harvesting contractors take on additional responsibilities, as stated in the discussion paper. The competency requirements must also extend to the FCNSW field staff and EPA audit staff.

One issue with compliance has been different interpretations by different individuals and organisations. Interpretation of the revised enforceable regulations must be consistent between FCNSW and EPA. Individual staff members must not be allowed to set rules in the field that are inconsistent with the agreed regulatory framework.

Defining what constitutes a rocky outcrop has been one area where there has been inconsistent interpretation between FCNSW & EPA. This issue must be addressed, given the increased focus on penalties and enforcement. It will not be fair to contractors, if inconsistencies in interpretation result in contractors being penalised.

Recommendation 3

Competency training for each contractor or forest worker, FCNSW and EPA audit staff must be consistent and relevant to the range of tasks undertaken by the individual. Regulations must have a consistent interpretation.

Approval Under Planning Legislation Page 18

The discussion paper states "*FCNSW may be required seek (sic) approval under planning legislation, if the environment impact of the activity is significant.*" This requirement is in the context of "*compartments where FCNSW is not logging or has not recently completed logging.*" This proposal has great potential to unnecessarily increase the cost of FCNSW doing business.

This potential requirement might apply to most compartments, as time between harvesting events can range from 5 to 40 or more years, therefore meeting the "recent" threshold. The FCNSW broad scale and ongoing predator control programs has resulted in a number of species listed under the Environment Protection and Biodiversity Conservation Act 1999 returning to wider areas of forest than they have occupied in the past 50 to 100 years.

Disturbance of these species may be viewed as a "significant" environmental impact, despite evidence showing predation, not harvesting, is the key threatening process. Current regulation continues to focus on stopping harvesting as the key regulatory tool to "protect" biodiversity. If forests have been shown to recover after harvesting, it should not be necessary to go though a development approval process to undertake ongoing harvesting operations.

Recommendation 4

A landscape biodiversity monitoring framework be established to put individual harvesting operations into a broader conservation perspective and to ensure other obvious and insidious threatening processes are properly managed outside the increasingly limited areas available for timber production.

Weaknesses in the Current Approach to Managing Impacts on Threatened species and Communities

Any reading of early accounts of the structure of Australian forests and aboriginal fire management reveals the structure and in some cases, the species composition of the once open forests, has changed greatly. These changes have also led to insidious, but over time, significant changes to the key habitat for many species.

In some cases, maintaining the current forest structure by excluding harvesting, while ignoring other threatening processes such as increasingly frequent wildfires and predation will condemn some species to certain extinction, whether or not harvesting continues.

The attached paper by Jurskis and Underwood relates to the Sydney sandstones. However, it does highlight some particular ecological management issues that have arisen over the past 200 years. Due to the more insidious effects of changed fire regimes, a number of once relatively common flora species are becoming rare.

"Dense and homogeneous stands of trees or woody shrubs created by post-European management have been studied as if they were natural ecosystems, and some fire management guidelines have been devised to maintain these artificial assemblies and structures. Unnatural processes have been described as if they were natural."

The above extract from the paper is relevant to the broader forest environment in much of the NSW crown land estate.

Recommendation 5

Parallel to the remake of the IFOA, government agencies monitor areas reserved from harvesting to ensure that the ecological values that were meant to be maintained through reservation are actually maintained or restored. Where threatened ecological communities or threatened flora or fauna species are not being maintained or increased, that adaptive management strategies be implemented ensure non-harvest threats are managed appropriately.

No Net Change to Wood Supply Page 4

Every review of environmental frameworks relating to harvesting of diminishing areas of forest in State forest tenure has promised "no net change to wood supply." Whilst these words sound reassuring, people working in the native forest sector know that these words have proved in the past to be wrong.

Specific wording in the discussion paper that foreshadow further impacts on potential wood supply include:

- "multi-scale protection of important habitat resources will not address all species, particularly those with limited geographic ranges such as many threatened plants."
- "The licence will include minimum required thresholds of areas protected from forestry operations at the local scale and maximum thresholds for harvesting disturbance at the local scale over both time and space."

- "Landscape connectivity will be catered for in the general landscape conditions by maintaining a network of forest areas excluded from logging operations that extend across the State forest estate."
- "All threatened species and or populations will be evaluated by an expert panel to determine is they are adequately covered by the new licence conditions."

The challenge to those rewriting the rule book will be to ensure that environmental values are maintained in the medium to long term, while understanding that many biodiversity and other values do not need a "total exclusion" approach to ensure the values are protected.

Harvesting will have to be considered along with all other threatening processes to ensure any regulatory or management changes address the true cause of any change in long term ecological values of the total forest estate.

Recommendation 6

The prescriptions relating to the protection of threatened species be modified if the results of landscape monitoring programs show that harvesting is not a threat to the maintenance of species currently requiring specific management plans.

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THE

EUCALYPTS OF VICTORIA

BY A. W. HOWITT, F.G.S., F.L.S.

REPRINTED FROM THE TRANSACTIONS OF THE ROYAL SOCIETY OF VICTORIA FOR 1890.

Influence of Settlement on the Eucalyptus Forests.

The influence of settlement upon the Eucalyptus forests has not been confined to the settlements upon lands devoted now to agriculture or pasturage, or by the earlier occupation by a mining population.

It dates from the very day when the first hardy pioneers drove their flocks and herds down the mountains from New South Wales into the rich pastures of Gippsland.

Before this time the gramminivorous marsupials had been so few in comparative number, that they could not materially affect the annual crop of grass which covered the country, and which was more or less burnt off by the aborigines, either accidentally or intentionally, when travelling, or for the purpose of hunting game.

These annual bush fires tended to keep the forests open, and to prevent the open country from being overgrown, for they not only consumed much of the standing or fallen timber, but in a great measure destroyed the seedlings which had sprung up since former conflagrations.

The influence of these bush fires acted, however, in another direction, namely, as a check upon insect life, destroying, among others, those insects which prey upon the Eucalypts.

Granted these premises, it is easy to conclude that any cause which would lessen the force of the annual bush fires, would very materially alter the balance of nature, and thus produce new and unexpected results.

The increasing number of sheep and cattle in Gippsland, and the extended settlement of the district, lessened the annual crop of grass, and it was to the interest of the settlers to lessen and keep within bounds bush fires which might otherwise be very destructive to their improvements.

The results were twofold. Young seedlings had now a chance of life, and a severe check was removed from insect pests. The consequences of these and other co-operating causes may be traced throughout the district, and a few instances will illustrate my meaning.

The valley of the Snowy River, when the early settlers came down from Maneroo to occupy it, as for instance, from Willis downwards to Mountain Creek, was very open and free from forests. At Turnback and the Black Mountain, the mountains on the western side of the river were, in many parts, clothed with grass, and with but a few large scattered trees of E. hemiphloia.

The immediate valley was a series of grassy alluvial flats, through which the river meandered. After some years of occupation, whole tracts of country became covered with forests of young saplings of E. hemiphloia, pauciflora, viminalis, amygdalina, and stellulata, and at the present time these have so much increased, and grown so much, that it is difficult to ride over parts which one can see by the few scattered old giants were at one time open grassy country.

Within the last twenty-five years many parts of the Tambo valley, from Ensay up to Tongio, have likewise become overgrown by a young forest, principally of E. hemiphloia and macrorhyncha, which extend up the mountains on either side of the valley. This dates especially from the time when the country was fenced into large sheep paddocks, when it became very important that bush fires should be prevented as a source of danger to the fences, and even when fire occurred the shortness of the pasturage checked the spread.

Similar observations may be made in the Omeo district, namely, that young forests of various kinds of Eucalypts are growing where a quarter of a century ago the hills were open and park like. In the mountains, from Mount Wellington to Castle Hill, in which the sources of the Avon River take their rise, the increase of the Eucalyptus forests has been very marked. Since the settlement of the country, ranges, which were then only covered by an open forest, are now grown up with saplings of E. obliqua, E. sieberiana, and others, as well as dense growths of Acacia discolor, A. verniciflua, and other arborescent shrubs. These mountains were, as a whole, according to accounts given me by surviving aborigines, much more open than they are now.

In the upper valley of the Moroka River, which takes its rise at Mount Wellington, I have noticed that the forests are encroaching very greatly upon such open plains as occur in the valley. I observed one range, upon which stood scattered gigantic trees of E. sieberiana, now all dead, while a forest of young trees of the same species, all of the same approximate age, which may probably be twelve years, growing so densely that it would not be easy to force a passage through on horseback. Again, at the Caledonia River, as at the Moroka, the ranges are in many parts quite overgrown with forests not more than twenty years old. The valleys of the Wellington and Macalister Rivers also afford most instructive examples of the manner in which the Eucalyptus forests have increased in the mountains of Gippsland since the country was settled. The forest in these valleys, below 2000ft. above sea level, is principally composed of Eucalyptus polyanthema, E. macrorhyncha, with occasional examples of E. melliodora and E. stuartiana; while E. viminalis occupies the river banks and moist flats. I noticed here that E. melliodora and E. macrorhyncha formed dense forests of young trees, apparently not more than twenty-five years old. In some places, moreover, one could see that the original forest had been composed, on the lower, undulating hills and higher flats of a few very large E. melliodora, with scattered trees of E. polyanthema and E. macrorhyncha. At the present time the two latter have taken possession, almost to the exclusion of E. melliodora. In other places E. polyanthema or E. macrorhyncha predominate; but, on the whole, I think the latter will ultimately triumph over its rivals, unless the hand of man again intervenes.

Such observations may also be made in Western and Southern Gippsland, but, of course, with reference to different species of Eucalypts.

In the great forest of South Gippsland many places can be seen where there are substantially only two existing generations of trees; one of a few very large old trees, the other of very numerous trees which are, probably, not older than 30 to 40 years, and, in most cases, certainly not half that period. The older trees of this second growth do not, I suspect, date further back than the memorable "Black Thursday," when tremendous fires raged over this tract of country. It may also be inferred, from the constant discoveries during the process of clearing of blackfellows' stone tomahawks, that much of this country, now covered by a dense scrub of gum saplings, Pomaderis apetala, Aster argophylla, and other arborescent shrubs, that the country was at that time mainly an open forest.

I might go on giving many more instances of this growth of the Eucalyptus forests within the last quarter of a century, but those I have given will serve to show how widespread this re-foresting of the country has been since the time when the white man appeared in Gippsland, and dispossessed the aboriginal occupiers, to whom we owe more than is generally surmised for having unintentionally prepared it, by their annual burnings, for our occupation.

The age of the new forests does not, however, depend merely on the general observation that they have sprung up since the settlement of the country in 1840.

I have been enabled to make some direct observations, which show the size of certain trees of known age, and which will serve as comparison for the general growth of the forests.

In 1864 the discovery of auriferous quartz reefs in the Crooked River district, caused a township, which is now called Grant, to be formed on the summit of the mountains, near the sources of Good Luck Creek. In part of the Government reserve, upon which the warden's quarters and police camp stood, and which was cleared of timber, a few young E. amygdalina trees grew, and were permitted to remain. One of these was lately kindly measured for me by Mr. W. H. Morgan, M.M.B., who found it to be 56ft. high and 10ft. in girth 3ft. above the ground. This tree is an example of very many others of the same species now growing on the surrounding ranges. At Omeo, in the Government reserve, a number of young E. viminalis are now 60ft. high, which in 1863 were only small saplings under 5ft. in height. On the road from Sale to Port Albert, which was formed somewhere about 1858-59, there are numerous places where E. viminalis and E. muelleriana and other species are now growing, upon the ditches formed at the sides of the road. Those, for instance, at Lillies Leaf are on an average about 30ft. high.

These instances show how the occupation of Gippsland by the white man has absolutely caused an increased growth of the Eucalyptus forests in places. I venture, indeed, to say with a feeling of certainty, produced by long observation, that, taking Gippsland as a whole, from the Great Dividing Range to the sea, and from the boundary of Westernport to that of New South Wales, that, in spite of the clearings which have been made by selectors and others, and in spite of the destruction of Eucalypts by other means (to which I am about to refer), the forests are now more widely extended and more dense than they were when Angus M'Millan first descended from the Omeo plateau into the low country.

I have spoken just now of the destruction of Eucalypts by other means than the hand of man, for clearing his holdings, and the following are the facts I have gathered concerning the subject:—

About the year 1863-4 I observed that a belt of Red-gums which extended across the plains between Sale, Maffra, and Stratford were beginning to die. Gradually all the trees of this forest, as well as in other localities, perished. At that time my attention was not drawn to the investigation of the cause. Later, however, probably about 1878, I observed the Red-gum forests of the Mitchell River Valley to be dying, just as those at Nuntin and elsewhere had died years before. I then investigated the subject, and found the trees were infested with myriads of the larvæ of some one of the nocturnal Lepidoptera. These devoured the upper and under epidermis of the leaves, thus asphyxiating the tree. Some 75 per cent. of that forest died that year, and subsequently almost all the surviving trees died also. Since then I have observed the same larvæ at work, some of which, when kept until they had passed through their several metamorphoses to the perfected insect, were pronounced by Professor M'Coy to be examples of Urubra lugens. Whether this insect has in all cases been the agent in destroying the red-gums I cannot affirm. Probably not wholly, but I am satisfied that the greater part of the Red-gum trees which have died in Gippsland from obscure causes have been killed by its agency.

The inference may be drawn from the above observations of forests having been killed by infesting insects, that each species of Eucalypt, or at any rate each group of allied species, will have attached to it some particular insect which preys upon it rather than upon any other Eucalypt.

If this is so, we ought to find some one tree selected for destruction out of a number of species, and it is the case with the Red-gum, for it falls a victim to Urubra lugens, whilst its neighbours the White-gum (E. viminalis), the Swamp-gum (E. gunnii), and the Yellow-box (E. melliodora) are untouched and in vigorous health.*

I feel little doubt that this will explain why it is that in many parts of the country, at all elevations above sea level, certain tracts of dead forest are to be found. Twenty-five years ago I noticed that during the course of three years all the White-gums (E. viminalis) in part of the Omeo district died, whilst E. pauciflora and E. stellulata remained alive.

I have said that in my opinion the increased growth of the Eucalyptus forests since the first settlement of Gippsland has been due to the checking of bush fires year by year, and to the increase thereby of the chance of survival of the seedling Eucalypts, and to the same cause we may assign the increase of the leaf-eating insects which seem in places to threaten the very existence of the Red-gum.

Bush fires, which swept the country more or less annually, kept down the enormous multiplication of insect life, destroying myriads of grasshoppers and caterpillars, which now devastate parts of the Gippsland district, spoiling the oat crops, and eating the grass down to the ground.

The ravages of the larvae of Lepidoptera are at present greatly aided by the sickly state in which many of the Red-gum forests in Gippsland now are. The long-continued use of the country for pasturage, and the trampling of the surface of the ground by stock, has greatly hardened the soil, so that rain which formerly, in what I may call the "normal state" as regards Eucalypts, soaked in, now runs off. In the course of successive droughty seasons the soil of such places becomes thoroughly dry and hard, so that the Red-gum is deprived of much moisture which it otherwise would have in reserve. The trees are wanting in vigour, and thus unable to withstand the attacks of insect pests.

The effects produced by man's interference with the balance of nature, by settling new countries, is not only of great scientific interest, but is also of importance in showing us how and why it is that the labours of the graziers and farmers are being carried on year by year under the increasing attacks of insect pests.

The subject is a tempting one, but to pursue it further would be foreign to the subject of these Notes, which is the "Eucalypts of Gippsland."

* I have observed, however, in some localities E. melliodora and E. piperita have been slightly attacked by Urubra lugens.

FORUM: ISSUES, MANAGEMENT, POLICY, AND OPINIONS

HUMAN FIRES AND WILDFIRES ON SYDNEY SANDSTONES: HISTORY INFORMS MANAGEMENT

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ABSTRACT

There is a concept in fire ecology that some natural (pre-European) fire regimes were dominated by infrequent high intensity fires ignited by lightning. In Australia, some ecologists extend this to most or all ecosystems across the landscape. They regard contemporary human burning or prescribed burning as an unnatural disturbance that threatens biodiversity. Their particular concern is the potential extinction of slow maturing obligate seeders by frequent fire. However, a completely different picture emerges from study of Australia's ecological history and prehistory. There is ample evidence that Australian vegetation was shaped by thousands of years of frequent mild burning by Aborigines. Infrequent, high intensity lightning fires affected only small areas of wet forests in refuges that were physically protected from mild fires. We present a case study of ecosystems on the Sydney sandstones to demonstrate that a regime of infrequent high intensity wildfires since European settlement has caused structural changes and reduced spatial diversity. This has put many fire dependent plants at a competitive disadvantage and increased their susceptibility to disease.

RESUMEN

En ecología del fuego se plantea que algunos regímenes de fuego naturales (pre-europeos) fueron dominados por incendios poco frecuentes de alta severidad causados por rayos. En Australia, esta idea ha sido aplicada por ecólogos y ecólogas a la mayoría de los ecosistemas en el paisaje, quienes consideran que los incendios de origen humano y las quemas prescritas contemporáneas son disturbios no naturales que amenazan a la biodiversidad. Su principal preocupación es que los incendios frecuentes pueden causar la extinción de plantas semilladoras obligadas de crecimiento lento. Sin embargo, estudios ecológicos de la historia y prehistoria australiana muestran una imagen completamente diferente. Existen evidencias de que la vegetación australiana se ha formado a lo largo de miles de años de quemas frecuentes y de baja severidad iniciadas por grupos aborígenes. Los incendios de alta severidad y baja frecuencia causados por rayos han afectado solo áreas pequeñas de bosques húmedos en refugios que estuvieron físicamente protegidos de los incendios de baja severidad. Presentamos un estudio de caso de ecosistemas en las areniscas de Sidney para demostrar que los regímenes de incendios de baja frecuencia y alta severidad, a partir de la colonización Europea, han causado cambios estructurales y reducción de la diversidad espacial. Esto ha puesto a muchas plantas dependientes del fuego en desventaja competiti-

We argue that biodiversity, ecosystem health, and fire safety are threatened by lack of frequent mild fire. Ecological theory should build on ecological history. Australia is fortunate in having comprehensive historical records of Aboriginal burning against which paleoecological data can be calibrated. We emphasize the importance of using historical information to interpret ecological studies and inform fire management.

va, incrementando su susceptibilidad a enfermedades. Argumentamos que la biodiversidad, salud y resistencia de los ecosistemas se ven amenazadas por la falta de incendios de baja severidad. La teoría ecológica debe basarse en la historia ecológica. Australia tiene la fortuna de contar con registros completos de las quemas aborígenes para calibrar los datos paleoecológicos. Enfatizamos la importancia del uso de información histórica para interpretar estudios ecológicos y proveer información para manejo del fuego.

Keywords: Aborigines, biodiversity, European settlement, fire regimes, history, prehistory, sandstone, Sydney, vegetation change, wildfires

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INTRODUCTION

Many Australian ecologists have assumed that ecosystems showing little evidence of human activity (usually characterized as "disturbance") represent the natural (pre-European) state (e.g., McElhinney *et al*. 2006, Gibbons *et al*. 2008, Killey *et al*. 2010). This hypothesis portrays stands of native vegetation that have been dramatically altered as a consequence of more than a century of fire suppression as benchmarks of natural conditions. In fire ecology, the assumption has led to conclusions that prescribed burning reduces densities of woody plants and quantities of litter, fallen timber, and soil nutrients below natural levels, and that this threatens biodiversity (e.g., Morrison *et al*.1996, Henderson and Keith 2002, Tasker and Bradstock 2006, Christie and York 2009, Tasker *et al*. 2011).

This assumption implies that the natural (pre-European) fire regime was one of infrequent (at least decadal), extensive, high intensity wildfires ignited by lightning, and that the natural vegetation was mostly thickly wooded. However, prehistoric and historic records of fire regimes and vegetation contradict this. For example, Matthew Flinders (1814) described thickly wooded vegetation and evidence of infrequent high intensity lightning fires on the uninhabited Kangaroo Island in 1802. He contrasted this environment with continental Australia where human fires were prevalent.

The view of a thickly wooded Australian landscape shaped by infrequent and intense wildfires is unsustainable for two reasons. Firstly, it is totally inconsistent with historical records of Aboriginal fire regimes and vegetation (e.g., Tench 1793; Flinders 1814; Mitchell 1839, 1848; Curr 1883; Howitt 1891; Pyne 1998; Gammage 2011); secondly, it ignores the widespread woody thickening that occurred after Aboriginal culture was disrupted and frequent mild fires no longer maintained the Australian landscape (Mitchell 1848, Howitt 1891, Gammage 2011).

Dense and homogeneous stands of trees or woody shrubs created by post-European management have been studied as if they were natural ecosystems, and some fire management guidelines have been devised to maintain these artificial assemblies and structures. Unnatural processes have been described as if they were natural. For example, Cohn *et al*. (2011) described the response of unnaturally dense stands of *Callitris* (*Callitris glaucophylla* Joy Thomps. & L.A.S. Johnson) to unnaturally severe fires as though it were a natural process. In fact, these conifers were attuned to occasional low intensity fires that killed seedlings and maintained the health of scattered mature trees with thick, insulating bark that protected them from damage by quick moving fires in grassy fuels (Jurskis 2009, 2011*a*).

The argument (e.g., Mooney *et al.* 2001, 2011) that Australian Aborigines did not burn frequently and extensively because sustained high levels of biomass burning were not evident as charcoal in sediments post-dating Aboriginal occupation cannot be sustained. The prehistory of fire in Australia can only be resolved by calibrating sedimentary charcoal records against historical records. Charcoal deposition increased markedly at the time, about 40 000 years ago, that Aborigines occupied Australia (Mooney *et al*. 2011: Figure 2); after the demise of the Aboriginal population on Kangaroo Island about 2500 years ago (Singh *et al*. 1981); and after European settlers disrupted Aboriginal culture on the mainland (Howitt 1891, Mooney *et al*. 2011). Charcoal deposition was reduced after extensive prescribed burning was reintroduced by forest managers in the mid-twentieth century (Jurskis *et al.* 2003, Mooney *et al.* 2011). Increased deposition of charcoal was clearly associated with intense fires in heavy accumulations of fuel (woody biomass), whereas reduced deposition was associated with long term Aboriginal burning and broad area prescribed burning by forest managers.

The reported negative impacts of frequent mild burning (at intervals less than about ten years) have been based on comparisons of frequently burnt vegetation against infrequently burnt or long unburnt areas inappropriately designated as controls (Turner *et al*. 2008, Jurskis *et al*. 2011). Much of this work has focused on non-resprouting, bradysporous shrubs (seeds retained for long periods in aerial, woody fruits unless released by fire) on sandstone formations around Sydney (e.g., Keith *et al*. 2002: Figure 17.2a). We examine this work in the context of historical information about vegetation and fire regimes in the area.

THE FIRE HISTORY OF SYDNEY'S SANDSTONE VEGETATION

When Europeans settled at Sydney in 1788, their agricultural activities were virtually confined to the Cumberland Plain, which is encircled by large areas of Triassic sandstones. These rugged and barren areas have remained largely undeveloped and now form an extensive system of national parks including the Blue Mountains to the west, most of the land between Sydney Harbour and the Hawkesbury River to the north, and Royal National Park immediately south of Sydney. The consequently long interface between urban and wildland around Australia's largest city has led to extensive debate about the fire history, ecology, and management of Sydney's wildlands.

Detailed observations of Aboriginal culture in this region were made by Captain Lieutenant Watkin Tench (1793) during the first four years of European settlement at Sydney Cove (1788–1791). Tench was an officer in the second rank of the new colony's military department. He reported that Aboriginal people carried fire wherever they went, noting that "they always, if possible, carry a lighted stick with them, whether in their canoes or moving from place to place on land." He saw Aborigines "perpetually setting fire to the grass and bushes" and noted that "it is a very common custom" for "the Indians in their hunting parties" to "set fire to the surrounding country". Aborigines used fire for warmth, cooking, hunting, signaling, lighting their way, managing vegetation and fauna, and in celebration as well as in conflict (e.g., Tench 1793; Flinders 1814; Mitchell 1839, 1848; Curr 1883; Howitt 1891; Gammage 2011). Fire was integral to the mental and material existence of Australian Aborigines (Pyne 1998).

On 11 April 1791, Tench left Rose Hill (now Parramatta) with a party of exploration. Each member of the party except Governor Phillip carried about twenty kilograms of bulky equipment and provisions. Once they reached the sandstone country (at what is now known as North Rocks), the terrain became, "very bad, being full of steep barren rocks, over which we were compelled to clamber for seven miles". However, the only references by Tench to difficulties occasioned by vegetation were along the Hawkesbury River where they were "plagued and entangled … stung … with nettles and ridicule," (by their Aboriginal guides) "and shaken nigh to death" by tripping over obstacles.

Once more in rocky sandstone country with "nothing but trees growing on precipices", Tench "saw a tree on fire here and several other vestiges of the natives." Scrambling to the top of a sandstone mountain "with infinite toil and difficulty", Tench had an extensive view "in almost every direction, for many miles." Governor Phillip named this "pile of desolation" Tench's Prospect Mount (Tench 1793).

The "infinite toil and difficulty" faced by Governor Phillip's party in scrambling up Tench's Prospect Mount was as nothing compared to the task that would confront them in the current dense vegetation (Figure 1). Furthermore, the toil would be wasted because the party's objective—Richmond Hill (now Enfield Hill)—is no longer visible due to the thick growth.

Gregory Blaxland (1823) led the first European crossing of the Blue Mountains in 1813. He described thickets of "brushwood" that impeded the packhorses. However, in unknown territory, a few men were able to clear and blaze a track through this tall shrubland for four heavily laden packhorses at the rate of one mile (1.6 km) per hour, suggesting that the shrubs were not very dense, and certainly not as dense as they are today.

Surveyor General Thomas Mitchell (1839) observed that "no vegetable soil is formed" on sandstone in New South Wales because "conflagrations take place so frequently and extensively … as to leave very little vegetable matter to return to earth." Travelling the Great Northern Road, Mitchell described the country between Parramatta and the Hawkesbury River thus:

Figure 1. Dense undergrowth on the approach to the summit of Tench's Prospect Mount. Note large dead banksia in left foreground. No large live banksias were present.

> *… no objects met the eye except barren sandstone rocks, and stunted trees. With the* banksia [Banksia *spp.*] *and* xanthorhaea [Xanthorrhoea *spp.*] *always in sight … The horizon is flat ...*

Mitchell had surveyed the continuation of the road through the sandstone country north of the river, and recounted that:

> *… the whole face of the country is composed of sandstone rock, and but partially covered with vegetation. ... on many a dark night … I have proceeded on horseback amongst these steep and rocky ranges, my path being guided by two young boys belonging to the tribe who ran cheerfully before my horse, alternately tearing off the stringy bark which served for torches, and setting fire to the grass trees (*xanthorhaea*) to light my way.*

Today, Mitchell's Aboriginal assistants would not be able to run "cheerfully before" his horse, lighting grasstrees because the vegetation is too thick and fully grown grasstrees are rare as are large banksia trees. In fact, anyone would have great difficulty riding a horse through the current vegetation, even in broad daylight (Figure 2).

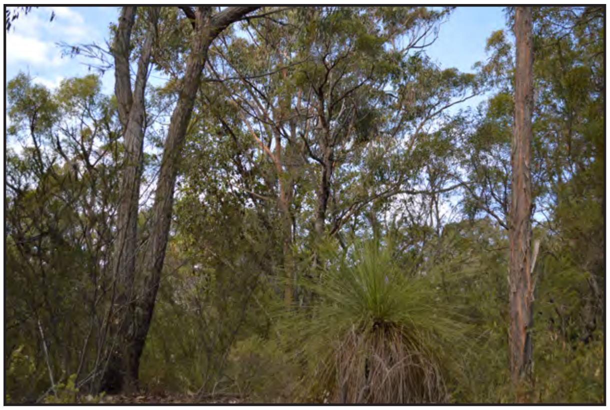

Figure 2. This is the forest type and locality that Mitchell traversed on horseback in the dark of night and described in daylight as follows: "no objects met the eye except barren sandstone rocks, and stunted trees. With the banksia and xanthorhaea always in sight … the whole face of the country is composed of sandstone rock, and but partially covered with vegetation".

When Charles Darwin travelled the road blazed across the Blue Mountains by Blaxland's party, he described "scrubby trees of the never-failing Eucalyptus family". Clearly the patches of shrubland made little impression. When he descended to the granite country of the central tablelands he noted "the trees were both finer and stood farther apart; and the pasture between them was a little greener and more plentiful" (Darwin 1845).

Though the sandstone country was not generally thickly wooded, thickets occurred in some rocky or sheltered sites. Mitchell noted that after European settlers occupied their kangaroo grounds, the displaced Aborigines:

> *… were compelled to seek a precarious shelter amidst the close thickets and rocky fastnesses which afforded them a temporary home, but scarcely a subsistence … I knew this unhappy tribe, and had frequently met them in their haunts. In the prosecution of my surveys I was enabled to explore the wildest recesses of these deep mountainous ravines, guided occasionally by one or two of their number*.

Tench and Judge Advocate David Collins recorded the first European observations of fire behavior under drought and extreme weather conditions at Sydney. Aboriginal fires were burning in bushland northwest of Rose Hill (Parramatta) on 10 and 11 February 1791 under extreme temperatures (>40 ^{o}C) and searing northwesterly winds, conditions that caused fruit-eating bats and parrots to drop dead from the sky. However, the fires did not affect the settlement (Tench 1793, Collins 1798). There was another "blow up day" (a day when high temperatures, low humidities, and strong winds can cause extreme fire behavior) on 5 December 1792 when a grass fire at Sydney burnt one house and several fences before being controlled (Collins 1798). Extensive fires at Parramatta and Toongabbie on the same day also had relatively minor impacts. They were thought to be controlled until a firebrand from the crown of a tree ignited a spotfire on a thatched roof, leading to the destruction of a hut, outbuildings, and a stack of wheat (Collins 1798). The minimal impact of these fires, burning under extreme conditions, demonstrates that they were generally burning in light, discontinuous fuels, and thus did not attain high intensity (e.g., Jurskis *et al*. 2003).

MODERN HISTORY AND ECOLOGY OF SYDNEY SANDSTONE VEGETATION

After disastrous fires around the mid-twentieth century, Australian foresters introduced broad area prescribed burning, including aerial ignition, as a major facet of fire management (Jurskis *et al.* 2003). Ecologists began to raise concerns about the potential environmental impacts of prescribed burning, and in 1976 the Scientific Committee on Problems of the Environment initiated an international fire ecology project (Gill *et al*. 1981). In this project, Gill (1981) reviewed responses to fire of Australian plants. He suggested that plants be classified as sprouters or seeders and their life cycles analysed in the context of fire regimes to assess their likely persistence. This suggestion was enthusiastically adopted by many ecologists, particularly in regard to non-resprouting bradysporous shrubs, which form a major component of Sydney's sandstone vegetation.

The nub of their concern was that burning at intervals shorter than the time taken for these shrubs to develop from seedlings to sexual maturity would eliminate them, reducing biodiversity (e.g., Benson 1985, Bradstock and O'Connell 1988, Cary and Morrison 1995, Keith 1996, Keith *et al*. 2002). Dangerous fuel loads were found to accumulate within two to four years after fire, leading Morrison *et al*. (1996) to suggest that fuel reduction burning was incompatible with conservation of biodiversity. Keith *et al.* (2002) claimed that Siddiqi *et al.* (1976) had "demonstrated" local extinctions by frequent fires. However, Siddiqi *et al.* (1976) actually reported that a "fierce" wildfire eliminated some plants from a few small plots where they had been present as seedlings before the fire, whilst the same species regenerated close by, within the fire perimeter, in a more sheltered plot where they had been present as mature plants. Thus the purported extinctions (Keith *et al*. 2002) occurred at a minutely small scale and could be more aptly described as reinstatement of the natural species pattern.

Another study found that obligate seeders produced more seeds under a regime of short fire intervals (three or four years) than under longer intervals between fire, whilst resprouting shrubs showed the opposite response, and resprouting trees were unaffected (Knox and Morrison 2005). Knox and Morrison (2005) speculated that there may be rapid selection for early maturity of obligate seeders in fire prone environments.

A number of studies demonstrated that short intervals between fires disadvantaged large shrubs and favoured smaller shrubs or herbs (e.g., Siddiqi *et al.*1976, Cary and Morrison 1995, Morrison *et al*. 1995, Bradstock *et al*. 1997) and grasstrees (*Xanthorrhoea resinosa* Pers.; syn. *X. resinifera* Sol. ex C.Kite E.C.Nelson & D.J.Bedford) (e.g., Tozer and Bradstock 2002, Tozer and Keith 2012). Not surprisingly, plants' responses to fire varied with growth stage (e.g., Siddiqi *et al.* 1976) as well as with fire intensity (Bradstock and Myerscough 1988). It also emerged that mediation of interspecific competition by fire regimes was equally or more important than individual species responses to direct physical impacts of fire (e.g., Bradstock *et al*. 1997, Tozer and Bradstock 2002, Tozer and Keith 2012).

It is indisputable that the time between fires can influence the abundance of particular species and consequently the floristic composition of the vegetation (e.g., Bradstock and O'Connell 1988; Cary and Morrison 1995; Morrison *et al.* 1995, 1996; Bradstock *et al*. 1997). Bradstock and O'Connell (1988) predicted that densities of large shrubs on Sydney's sandstones would increase if fires occurred at fifteen to thirty year intervals, and their prediction was found to be correct by retrospective studies (e.g., Conroy 1996). There was no evidence that a reduction in density of some species by frequent prescribed burning would lead to local extinctions and reduced biodiversity. Cary and Morrison (1995) reported that frequent, intense fires (intervals less than ten years, understory completely destroyed across at least five hectares) reduced species richness, whereas Morrison *et al*. (1995) found that this regime favoured ten small plants and disadvantaged six large shrubs. Morrison *et al*. (1996) found that, of seven plants whose abundance was affected by fire frequency, the least abundant across all sites were two plants favoured by frequent fires (less than seven years), and one of these species was not found on sites with longer fire intervals (Morrison *et al*. 1996: Table 2).

Bradstock *et al*. (1997) concluded that frequency of fires affected floristic composition but not species richness. Frequent fires at short intervals (one or two years) reduced the density of seven shrubs and increased the density of one grass. The most common shrub in the area was the most reduced. Bradstock *et al*. (1997) emphasized the highly heterogeneous nature of site effects on fire regimes and vegetation, and that it was difficult to extrapolate conclusions from fine scale studies to the landscape scale.

Grasstrees were a prominent component of Sydney's sandstone vegetation at the time of European settlement (Mitchell 1839), and although still common, are suffering decline as a consequence of modern fire regimes, competition from large shrubs, and disease associated with infection by *Phytophthora cinnamomi* Rand (Tozer and Bradstock 2002, Regan *et al*. 2011, Tozer and Keith 2012). Tozer and Bradstock (2002) found that fully grown live grasstrees were virtually absent from patches of large shrubs, although there were many dead stems, "consistent with suppression by overstorey species".

Regan *et al*. (2011) sampled the demographics of grasstrees and *Phytophthora* under the recent wildfire regime. They considered that grasstrees were threatened by an adverse fire regime as well as by the fungal pathogen. Simulated populations of grasstrees declined in the long term under all fire management scenarios (burning at 5 yr, 12 yr, 20 yr, and 30 yr intervals with and without wildfires and total fire exclusion), even in the absence of disease (Regan *et al*. 2011). Tozer and Keith (2012) reported a local extinction of grasstrees after a 17 year interval between fires. They found higher mortality of grasstrees with less frequent fire because of competition from large shrubs, and they considered that presence of *Phytophthora* would exacerbate the effects of competition.

The endangered broad-headed snake (*Hoplocephalus bungaroides* Wagler), is thought to be extinct in sandstone vegetation north of Sydney (Pringle *et al*. 2009). Remotely sensed chronosequences in sandstone woodlands to the south revealed that its habitat of bare exfoliated sandstone, critical for thermoregulation, was substantially reduced between 1941 and 2006 as a consequence of shading by encroaching shrubs under a wildfire regime (Pringle *et al*. 2009).

The aforementioned ecological studies have assessed the role of recent fire history in shaping ecosystems, but they have largely neglected to assess changes in fire regimes and biota consequent to European settlement. However, records of charcoal deposition in a lagoon within Royal National Park were used to infer long term fire history. Mooney *et al*. (2001) found evidence of many fires during the previous seven decades but of only one "conflagration" during the 1600 years before European settlement. This led them to suggest that either Aborigines did not burn much or they burnt in a way that delivered little charcoal. Mooney *et al*. (2001) concluded that "the idea of the ubiquitous use of fire by Aboriginal people should be further, and critically, analysed".

In contrast, Clark and McLoughlin (1986) presented historical evidence that Aborigines burnt Sydney's sandstone vegetation frequently and that less frequent fire after European settlement caused woody thickening and upslope expansion of gully vegetation at the expense of groundcover plants. Conroy (1996) analysed the fire history of Ku-ring-gai Chase National Park between 1943 and 1994. He concluded that wildfires were more frequent and less intense prior to 1970, after which strategic burning and fire suppression were introduced. After 1970, reduced frequency and increased intensity of fire resulted in increased cover of woody shrubs that impedes bushwalkers, shades out some attractive small flowering plants, and reinforces a regime of high intensity fires (Conroy 1996).

The significance of the change in fire regimes and vegetation over the longer term can be appreciated by comparing the situation on blow up days under Aboriginal management against the current situation. Fires on blow up days in 1791 and 1792 caused little damage to settlements at Parramatta and Sydney, and were easily controlled (Tench 1793, Collins 1798). In contrast, fires under similar conditions in January 1994 (Speer *et al*. 1996: Figure 3) were mostly uncontrollable, burning more than thirty thousand hectares around Sydney, claiming hundreds of houses and three lives despite the efforts of a well-equipped army of firefighters (NSW Rural Fire Service 1998).

The difference in 1994 was that firestorms developed in the dense, three dimensionally continuous fuels produced by modern mismanagement of the native vegetation on sandstone surrounding Sydney (e.g., Figure 1). The fire storms caused showers of embers and long distance spotting of fires. For example, a run of fire that claimed human lives spotted 800 metres across a major watercourse (Hurditch and Hurditch 1994). However, Conroy (1996) listed four localities where runs of these fires under extreme weather conditions were effectively contained as a result of prior hazard reduction burning.

DISCUSSION

It is clear that Aboriginal burning maintained Sydney sandstone vegetation in a generally very open condition. Tench, Mitchell, Darwin, and others described vastly different vegetation to that currently occurring on sandstone around Sydney. Explorers systematically and meticulously recorded impediments to travel and visibility because it was a large part of their 'job' (e.g., Jurskis 2009, 2011*a*). Where they made no such records, there were clearly no such impediments to be recorded.

Mooney *et al*. (2001) used paleological data on charcoal accumulation to question the historical record. Physical records such as charcoal deposits (e.g., Mooney *et al*. 2001, 2011) or fire scars on trees (e.g., Banks 1989, von Platen *et al.* 2011) have often been misinterpreted as providing a complete prehistory of fire when, in fact, mild fires in open vegetation burn relatively low quantities of mostly fine and herbaceous fuels, leaving little charcoal or scarring (e.g., Burrows *et al*. 1995 , Mooney *et al*. 2011, Jurskis and Underwood 2012). Aboriginal burning was ubiquitous and prehistory shows that, after the period when the continent was initially occupied, subsequent burning delivered little charcoal (e.g., Mooney *et al*. 2011: Figure 2). Interpretation of charcoal in sediment cores should be informed by historical observations. Taken together, paleological and historical records indicate that Aborigines altered vegetation pattern and structure using high intensity fires when they originally occupied Australia, after which they maintained the new pattern using frequent mild burning. Following the initial peak in biomass burning, there was a sustained reduction (e.g., Mooney *et al*. 2011: Figure 2) as dense woody vegetation was restricted to physical refugia (e.g., Singh *et al*. 1981, Kershaw *et al*. 2002).

McLoughlin (1998) inferred the Sydney region's early European fire history using only individual records that identified the date. She found 31 records between 1788 and 1845 (an average of one fire somewhere in the region every two years). The more general observations of explorers and settlers indicate that fires were very common, so that specific fires were unremarkable unless they were damaging or had been set maliciously. There were certainly many more fires than those listed by McLoughlin (1998) (e.g., Tench 1793, Mitchell 1839).

Since the 1970s, a plethora of ecological studies has purported to examine the impacts of frequent fires on Sydney sandstone vegetation. However, the results of these studies have not been interpreted in the context of Aboriginal fire regimes and the historical, ecological consequences of their disruption including woody thickening and outbreaks of pests, parasites, diseases, and megafires (e.g., Mitchell 1848; Howitt 1891; Jurskis 2002, 2009, 2011*a*, *b*; Jurskis *et al*. 2003, 2011). Furthermore, these studies examined wildfire regimes or mixed fire regimes dominated by intense wildfires, whilst the abundance and richness of species have been measured at a fine scale so the conclusions have little relevance to consideration of the effects of frequent, mild, and patchy burning (e.g., Penman *et al*. 2007) on the natural (pre-European) composition and structure of the vegetation across the landscape (Jurskis *et al*. 2003, Bradstock *et al*. 1997, Jurskis 2011*b*).

The theory of extinctions of plant species (loss of biodiversity) as a result of frequent fire (e.g., Benson 1985 , Keith 1996, Keith *et al*. 2002) relies on the untenable assumption that the current vegetation in national parks represents the natural (pre-European) condition. It also relies on the unlikely assumption that frequent prescribed burns are sufficiently hot and uniform to kill or substantially damage most plants irrespective of life form or growth stage but not sufficiently hot and uniform to stimulate their reproduction or establishment (Jurskis *et al*. 2003, Jurskis 2011*b*). Another implicit assumption is that direct impacts of fire are the major influence on plant demography. Competitive interactions between species have been neglected (Bradstock *et al*. 1997). This is particularly apparent in the case of grasstrees on Sydney's sandstones, which are declining as a result of damage by high intensity fires, competition from thickening woody vegetation, and a disease that is favoured by infrequent, high intensity fires (that is, by modern fire regimes) (e.g., Tozer and Bradstock 2002, Jurskis 2005, Regan *et al*. 2011, Tozer and Keith 2012).

Tozer and Keith (2012) recognized that a focus on minimum allowable intervals between fires would not ensure the persistence of grasstrees, but they suggested that further studies are required to establish what patterns of shrub densities will promote the coexistence of contrasting species. However, there is no need for further studies because the landscape pattern established by thousands of years of frequent burning by Aborigines allowed grasstrees and shrubs to coexist. Shrubs occurred in much lower densities on most sites.

Fire suppression can promote *Phytophthora* root-rot by increasing topsoil moisture levels and changing soil chemistry, with adverse impacts on roots and direct benefits to the pathogen (Jurskis 2005). Increasing fuel loads promote high intensity fires that can raise water tables by interrupting transpiration and further benefit the pathogen (e.g., Fagg *et al*. 1986, Davison 1997, Jurskis 2005). Thus the inoculum level and extent of the *Phytophthora* has probably increased compared to natural levels (e.g., Pratt and Heather 1973, Jurskis 2005). It is likely that the health of grasstrees on Sydney's sandstone is generally reduced and that current mortality rates used in modeling by Regan *et al*. (2011) are unnaturally high. There is strong evidence that *Phytophthora* is indigenous to eastern Australia and that natural vegetation patterns reflected genetic susceptibility of plants as well as suitable soil conditions for the pathogen (Pratt and Heather 1973, Jurskis 2005). The history of grasstrees at Sydney strongly suggests that modern fire regimes disrupted these natural patterns.

The ecological studies have shown that interactions between fire regime and interspecific competition are important (e.g., Bradstock *et al.*1997) because absence of fire favours larger plant species over smaller species (Clark and McLoughlin 1986, Cary and Morrison 1995, Morrison *et al*. 1995, Morrison *et al*. 1996, Conroy 1996, Bradstock *et al*. 1997, Tozer and Bradstock 2002, Tozer and Keith 2012) and other fire studies in dry eucalypt forests have confirmed that many small groundcover plants decline rapidly after fire as larger shrubs develop (Jurskis 2011*b*). Thus biodiversity is likely to decline with less frequent fire because many smaller species are shaded out by fewer larger species and spatial heterogeneity due to site factors (e.g., Siddiqi *et al*. 1976, Bradstock *et al*. 1997, Keith *et al*. 2002) is obliterated (e.g., Siddiqi *et al*. 1976, Clark and McLoughlin 1986, Conroy 1996, Jurskis *et al*. 2003, Jurskis 2011*b*). Fire regimes also mediate intraspecific competition. Frequent mild fire regimes favoured mature plants over juveniles irrespective of species, whilst a regime of fire suppression can have the reverse effect, causing loss of mature trees and shrubs, and initiating changes in species composition (Jurskis 2009, 2011*a*).

Some proponents of the theory that prescribed burning threatens biodiversity have used a circular argument around species that are long lived obligate seeders (e.g., Benson and Redpath 1997, Enright *et al*. 2005). They claim that persistence of these species in the landscape is evidence that Aborigines did not burn frequently because burning at shorter intervals than their maturation period would eliminate them. Clark and McLoughlin (1986) recognized the historical evidence for frequent burning by Aborigines, but used the same circular argument to overestimate intervals between Aboriginal burning at seven to fifteen years. The persistence of the slow maturing obligate seeders on Sydney sandstone and of naturally rare plants (e.g., Keith *et al*. 2002) despite thousands of years of frequent Aboriginal burning provides clear evidence that both the theory and the circular argument should be discarded. It is apparent that slow maturing obligate seeders, once mature, are very tolerant of frequent mild fires (e.g., Jurskis 2009, 2011*a*) and that fire sensitive obligate seeders mature rapidly (e.g., Knox and Morrison 2005). Aboriginal burning over thousands of years undoubtedly selected genotypes attuned to frequent low intensity fire. Genotypes that were not so attuned, that is fire sensitive species, persisted in limited areas that were physically inaccessible to mild fires. A small number of plants on Sydney's sandstones are associated with wetter soils or dense shrub cover (Tozer and Bradstock 2002). Disruption of natural fire regimes has allowed these fire sensitive species to escape their refuges and interfere with fire management across the landscape (Clark and McLoughlin 1986, Conroy 1996, Jurskis *et al*. 2003).

The results of recent ecological studies are entirely consistent with the recorded history of Sydney's sandstone vegetation, but the way that these results have been interpreted to influence fire management is not, because the historical context has not been appreciated. For example, Morrison *et al*. (1996) claimed that there is "a clear conflict in south-eastern Australia between fire management practices based solely on prescribed burning for hazard reduction and the fire management practices necessary to maintain ecosystem biodiversity". However, this proposal fails to recognize that the current high fuel accumulation rates and extreme fire behavior during severe weather are products of changed vegetation structure and composition consequent to less frequent and more intense fire regimes. For example, Cary and Morrison (1995) studied sites where the understorey had been completely destroyed across at least five hectares by severe fires. Their finding that short intervals between these fires reduced species richness has no relevance to low intensity prescribed burning. Post-European fire management in national parks around Sydney has initiated a vicious circle that threatens biodiversity and human socioeconomy. The historical evidence indicates that Aboriginal burning favoured biodiversity over biomass and that there is no conflict between the socioeconomic and environmental objectives of low intensity prescribed burning.

Keith *et al*. (2002) acknowledged that the current Australian biota persisted through Aboriginal fire regimes for tens of thousands of years, but argued against reinstating those regimes because:

- they are difficult to specify precisely;
- they may have different consequences today because of habitat fragmentation and introduction of exotic biota;
- they were implemented to provide food whereas conservation has "*very different goals*" such as protecting rare plants, which may have had no value to Aboriginal people and may have been disadvantaged by their burning;
- they may be too expensive to apply across the landscape because of their fine scale.

However, the concept that frequent mild fire regimes would need to be defined precisely before they could be successfully implemented is not valid. These fires are inherently patchy (e.g., Penman *et al.* 2007) and fire behavior varies with site factors at a fine scale (e.g., Bradstock *et al.* 1997). Habitat fragmentation is irrelevant to the discussion for the same reasons. Invasion by exotic biota can be minimized under natural fire regimes (e.g., Jurskis 2012). Exotic plant invasions on Sydney's sandstones depend on unnatural nutrient enrichment (Lake and Leishman 2004), whereas frequent burning at intervals around five years can maintain stable nutrient cycles on such low nutrient sites (Turner *et al*. 2008).

There is no doubt that Aboriginal burning was economically and culturally motivated (e.g., Pyne 1998, Gammage 2011) and it is clear that the best way to conserve ecosystems shaped by about forty thousand years of Aboriginal burning would be to continue in a similar vein. Infrequent burning obliterates fine scale environmental variation (e.g., Clark and McLoughlin 1986, Conroy 1996), whereas frequent mild burning enhances it and facilitates low input and low cost management (Jurskis *et al*. 2003).

Kenny *et al*. (2004) reviewed the fire ecology of Sydney sandstone vegetation and concluded that the "domain of acceptable fire intervals" was 7 yr to 30 yr and that some intervals greater than 20 yr were "desirable." Clearly, the guideline is intended to maintain the status quo, and this will perpetuate the accumulation of woody vegetation, dangerous fuel loads, and pathogenic inoculum at the expense of understory diversity and healthy soil conditions. The guideline is apparently based on a philosophy of minimizing human "interference" rather than on any historical or ecological foundation.

CONCLUSIONS

Contrary to the views of many modern fire ecologists, human ignitions were the dominant cause of fire in most Australian ecosystems for thousands of years (Pyne 1998; Kershaw *et al*. 2002; Gammage 2011; Jurskis 2011*a*, *b*). Patchy Aboriginal burning undoubtedly limited recruitment of woody plants by killing seedlings on sandstone around Sydney as it did elsewhere (Mitchell 1848, Howitt 1891, Noble 1997, Jurskis 2009). Frequent, mild, and patchy fires in sparsely shrubbed vegetation leave many established woody plants unscathed (e.g., Jurskis *et al.* 2003, Penman *et al*. 2008). Thus, recruitment after such fires is not a conservation issue as has often been suggested.

Studies of prescribed burning have confirmed that most obligate seeders are favored by frequent mild fire whilst a few common large shrubs are disadvantaged (Jurskis *et al*. 2003; Penman *et al*. 2008, 2009; Jurskis 2011*b*). In the absence of frequent burning, these few shrubs have commenced to shade out many smaller and less common species within three or four years, reducing diversity (Penman *et al*. 2008, 2009; Jurskis 2011*b*).

Other studies of fuel accumulation (Birk and Bridges 1989), fire risk (Boer *et al*. 2009) nutrient cycling, and tree health (Turner *et al*. 2008) in dry eucalypt systems have shown that burning at three to six year intervals can maintain dynamic stability and ecological resilience in these systems (Jurskis 2011*b*). Physical records (e.g., Singh *et al*. 1981, Burrows *et al*. 1995, Ward *et al*. 2001, Hassell and Dodson 2003, Mooney *et al*. 2011: Figure 2) and historical records (Mitchell 1848, Curr 1883, Howitt 1891, Abbott 2003, Gammage 2011) support these studies of ecological processes pointing to ecosystems shaped by extensive, frequent Aboriginal burning.

Australia is fortunate in having good historical records of Aboriginal fire regimes and vegetation before they were impacted by European settlement (e.g., Pyne 1998, Gammage 2011). These show that prehistoric physical evidence cannot provide a reliable record of mild fire regimes. Even though historical records may be scant, such records should guide interpretation of physical evidence as well as interpretation of ecological studies.

Human fires can support biodiversity by restoring and maintaining natural, open conditions that favour ancient trees, small understorey plants, and bare ground as well as the rare species that depend on them (Jurskis 2009, 2011*a*, *b*). In eastern Australia, these include Hastings River mouse (*Pseudomys oralis*) (Tasker and Dickman 2004), the orchid *Prasophyllum correctum* (Coates *et al*. 2006), superb parrot (*Polytelis swainsonii*) (Manning *et al*. 2006), eastern brown treecreeper (*Climacteris picumnis victoriae*) (Ford *et al*. 2009), and broad-headed snake (Pringle *et al*. 2009). Informed application of human fires could also reverse declines in common species such as grasstrees.

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LITERATURE CITED

Abbott, I. 2003. Aboriginal fire regimes in south-west Western Australia: evidence from historical documents. Pages 119–146 in: I. Abbott and N. Burrows, editors. Fire in ecosystems of south-west Western Australia: impacts and management. Backhuys Publishers, Leiden, The Netherlands.

Banks, J.C.G. 1989. A history of forest fire in the Australian Alps. Pages 265–280 in: R. Good, editor. The scientific significance of the Australian Alps. The proceedings of the first Fenner conference on the environment. September 1988, Canberra, Australia. Australian Alps National Parks Liaison Committee and Australian Academy of Science, Canberra, Australia.

Benson, D.H. 1985. Maturation periods for fire-sensitive shrub species in Hawkesbury sandstone vegetation. Cunninghamia 1: 339–349.

Benson, J.S., and P.A. Redpath. 1997. The nature of pre-European native vegetation in south-eastern Australia: a critique of Ryan, D.G., Ryan, J.R., Starr, B.J. (1995) the Australian landscape—observations of explorers and early settlers. Cunninghamia 5: 285–328.

Birk, E.M., and R.G. Bridges. 1989. Recurrent fires and fuel accumulation in even-aged blackbutt (*Eucalyptus pilularis*) forests. Forest Ecology and Management 29: 59–79. doi: 10.1016/0378-1127(89)90056-X

Blaxland, G. 1823. The journal of Gregory Blaxland, 1813 incorporating the journal of a tour of discovery across the Blue Mountains, New South Wales, in the year 1813. A Project Gutenberg of Australia ebook. <http://gutenberg.net.au/ebooks02/0200411.txt>. Accessed 16 Jun 2013.

Boer, M.M., R.J. Sadler, R.S. Wittkuhn, L. McCaw, and P.F. Grierson. 2009. Long-term impacts of prescribed burning on regional extent and incidence of wildfires—evidence from 50 years of active fire management in SW Australian forests. Forest Ecology and Management 259: 132–142. doi: 10.1016/j.foreco.2009.10.005

Bradstock, R.A., and P.J. Myerscough. 1988. The survival and population response to frequent fires of two woody resprouters *Banksia serrata* and *Isopogon anemifolius*. Australian Journal of Botany 36: 415–431. doi: 10.1071/BT9880415

Bradstock, R.A., and M.A. O'Connell. 1988. Demography of woody plants in relation to fire: *Banksia ericifolia* L.f. and *Petrophile pulchella* (Schrad) R.Br. Australian Journal of Ecology 13: 505–518. doi: 10.1111/j.1442-9993.1988.tb00999.x

Bradstock, R.A., M.G. Tozer, and D.A. Keith. 1997. Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney. Australian Journal of Botany 45: 641–655. doi: 10.1071/BT96083

Burrows, N.D., B. Ward, and A.D. Robinson. 1995. Jarrah forest fire history from stem analysis and anthropological evidence. Australian Forestry 58: 7–16. doi: 10.1080/00049158.1995.10674636

Cary, G.J., and D.A. Morrison. 1995. Effects of fire frequencies on plant species composition of sandstone communities in the Sydney region: combinations of inter-fire intervals. Australian Journal of Ecology 20: 418–426. doi: 10.1111/j.1442-9993.1995.tb00558.x

Christie, F.J., and A. York. 2009. No detectable impacts of frequent burning on foliar C and N or insect herbivory in an Australian eucalypt forest. Applied Vegetation Science 12: 376–384. doi: 10.1111/j.1654-109X.2009.01033.x

Clark, S.S., and L.C. McLoughlin. 1986. Historical and biological evidence for fire regimes in the Sydney region prior to the arrival of Europeans: implications for future bushland management. Australian Geographer 17: 101–112. doi: 10.1080/00049188608702909

Coates, F., I.D. Lunt, and R.L. Tremblay. 2006. Effects of disturbance on population dynamics of the threatened orchid *Prasophyllum correctum* D.L. Jones and implications for grassland management in south-eastern Australia. Biological Conservation 129: 59–69. doi: 10.1016/j.biocon.2005.06.037

Cohn, J.S., I.D. Lunt, K.S. Ross, and R.A. Bradstock. 2011. How do slow-growing, fire-sensitive conifers survive in flammable eucalypt woodlands? Journal of Vegetation Science 22: 425–435. doi: 10.1111/j.1654-1103.2011.01280.x

Collins, D. 1798. An account of the English colony in New South Wales, vol. 1 with remarks on the dispositions, customs, manners etc. of the native inhabitants of that country. To which are added some particulars of New Zealand; compiled, by permission, from the mss of Lieutenant-Governor King. Project Gutenburg Ebook. <http://www.gutenberg.org/files/12565/12565-h/12565-h.htm#chapter8>. Accessed 16 Jun 2013.

Conroy, R.J. 1996. To burn or not to burn? A description of the history nature and management of bushfires within Ku-ring-gai Chase National Park. Proceedings of the Linnean Society of New South Wales 116: 79–95.

Curr, E.M. 1883. Recollections of squatting in Victoria, then called the Port Phillip District, from 1841 to 1851. Australiana facsimile edition 103, 1968. Libraries Board of South Australia, Adelaide.

Darwin, C. 1845. The voyage of the Beagle. <http://www.literature.org/authors/darwin-charles/the-voyageof-the-beagle/>. Accessed 16 Jun 2013.

Davison, E.M. 1997. Are jarrah (*Eucalyptus marginata*) trees killed by *Phytophthora cinnamomi* or waterlogging? Australian Forestry 60: 116–124. doi: 10.1080/00049158.1997.10674706

Enright, N.J., B.B. Lamont, and B.P. Miller. 2005. Anomalies in grasstree fire history reconstructions for south-western Australian vegetation. Austral Ecology 30: 668–673. doi: 10.1111/j.1442-9993.2005.01509.x

Fagg, P.C., B.K. Ward, and G.R. Featherstone. 1986. Eucalypt dieback associated with *Phytophthora cinnamomi* following logging, wildfire and favourable rainfall. Australian Forestry 49: 36–43. doi: 10.1080/00049158.1986.10674461

Flinders, M. 1814. A voyage to Terra Australis; undertaken for the purpose of completing the discovery of that vast country, and prosecuted in the years 1801, 1802, and 1803, in His Majesty's ship the Investigator, and subsequently in the armed vessel Porpoise and Cumberland schooner. With an account of the shipwreck of the Porpoise, arrival of the Cumberland at Mauritius and imprisonment of the commander during six years and a half in that island. G. and W. Nicol, Pall-Mall. Facsimile edition, 1966. Project Gutenberg Australia Ebook. <http://gutenberg.net.au/ebooks/e00049.html#chapter1-7>. Accessed 16 Jun 2013.

Ford, H.A., J.R. Walters, C.B. Cooper, S.J. Debus, and V.A.J. Doerr. 2009. Extinction debt or habitat change?—ongoing loss of woodland birds in north-eastern New South Wales, Australia. Biological Conservation 142: 3182–3190. doi: 10.1016/j.biocon.2009.08.022

Gammage, B. 2011. The biggest estate on earth: how Aborigines made Australia. Allen & Unwin, Sydney, Australia.

Gibbons, P., S.V. Briggs, D.A. Ayers, S. Doyle, J. Seddon, C. McElhinny, M. Jones, R. Sims, and J.S. Doody. 2008. Rapidly quantifying reference conditions in modified landscapes. Biological Conservation 141: 2483–2493. doi: 10.1016/j.biocon.2008.07.009

Gill, A.M. 1981. Adaptive responses of Australian vascular plant species to fires. Pages 243−272 in: A.M. Gill, R.H. Groves, and I.R. Noble, editors. Fire and the Australian Biota. Australian Academy of Science, Canberra, Australia.

Gill, A.M., R.H. Groves, and I.R. Noble. 1981. Preface. Pages iii−iv in: A.M. Gill, R.H. Groves, and I.R. Noble, editors. Fire and the Australian biota. Australian Academy of Science, Canberra, Australia.

Hassell, C.W., and J.R. Dodson. 2003. The fire history of south-west Western Australia prior to European settlement in 1826–1829. Pages 71–86 in: I. Abbott and N. Burrows, editors. Fire in ecosystems of South-west Western Australia: impacts and management. Backhuys, Leiden, The Netherlands.

Henderson, M.K., and D.A. Keith. 2002. Correlation of burning and grazing indicators with composition of woody understorey flora of dells in a temperate eucalypt forest. Austral Ecology 27: 121–131. doi: 10.1046/j.1442-9993.2002.01162.x

Howitt, A.W. 1891. The eucalypts of Gippsland. Transactions of the Royal Society of Victoria II: 81–120.

Hurditch, W.E., and W.J. Hurditch. 1994. The politics of bushfires: can we learn from past mistakes? Pages 37−50 in: P.M. Attiwill, editor. The burning continent. Forest ecosystems and fire management in Australia. Institute of Public Affairs, West Perth, Western Australia.

Jurskis, V. 2002. Restoring the prepastoral condition. Austral Ecology 27: 689–690. doi: 10.1046/j.1442-9993.2002.01244.x

Jurskis, V. 2005. Eucalypt decline in Australia, and a general concept of tree decline and dieback. Forest Ecology and Management 215: 1–20. doi: 10.1016/j.foreco.2005.04.026

Jurskis, V. 2009. River red gum and white cypress forests in south-western New South Wales, Australia: ecological history and implications for conservation of grassy woodlands. Forest Ecology and Management 258: 2593–2601. doi: 10.1016/j.foreco.2009.09.017

Jurskis, V. 2011*a*. Benchmarks of fallen timber and man's role in nature: some evidence from temperate eucalypt woodlands in southeastern Australia. Forest Ecology and Management 261: 2149–2156. doi: 10.1016/j.foreco.2011.03.012

Jurskis, V. 2011*b*. Human fire maintains a balance of nature. Pages 129−138 in: R.P. Thorton, editor. Proceedings of Bushfire CRC & AFAC 2011 Conference Science Day. 1 September 2011, Sydney Australia. Bushfire Cooperative Research Centre, Melbourne, Australia. <http://www.bushfirecrc.com/resources/pages-129-138-human-fire-maintains-balance-nature>. Accessed 16 Jun 2013.

Jurskis, V. 2012. Plant invasions: symptoms and contributors rather than causes of environmental degradation. Forests 3: 896–902. doi: 10.3390/f3040896

Jurskis, V., B. Bridges, and P. de Mar. 2003. Fire management in Australia: the lessons of 200 years. Pages 353–368 in: E.G. Mason and C.J. Perley, editors. Joint Australia and New Zealand Institute of Forestry Conference Proceedings. 27 April–1 May 2003, Queenstown, New Zealand. Ministry of Agriculture and Forestry, Wellington, New Zealand.

Jurskis, V., J. Turner, M. Lambert, and H. Bi. 2011. Fire and N cycling: getting the perspective right. Applied Vegetation Science 14: 433–434. doi: 10.1111/j.1654-109X.2011.01130.x

Jurskis, V., and R. Underwood. 2012. Letters to the editor. Fire frequency in south-eastern Tasmania. Australian Forestry 75: 65–66. doi: 10.1080/00049158.2012.10676387

Keith, D.A. 1996. Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. Proceedings of the Linnean Society of New South Wales 116: 37–78.

Keith, D.A., J.E. Williams, and J.C.Z. Woinarski. 2002. Fire management and biodiversity conservation: key approaches and principles. Pages 401–428 in: R.A. Bradstock, J.E. Williams, and A.M. Gill, editors. Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, United Kingdom.

Kenny, B., E. Sutherland, and R. Bradstock. 2004. Guidelines for ecologically sustainable fire management. NSW Biodiversity Strategy July 2004. New South Wales National Parks and Wildlife Service, Hurstville, Australia. <http://www.environment.nsw.gov.au/resources/biodiversity/FireGuidelinesReport.pdf>. Accessed 16 Jun 2013

Kershaw, A.P., J.S. Clark, A.M. Gill, and D.M. D'Costa. 2002. A history of fire in Australia. Pages 3–25 in: R.A. Bradstock, J.E. Williams, and A.M. Gill, editors. Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, United Kingdom.

Killey, P., C. McElhinny, I. Rayner, and J. Wood. 2010. Modelling fallen branch volumes in a temperate eucalypt woodland: implications for large senescent trees and benchmark loads of coarse woody debris. Austral Ecology 35: 956–968. doi: 10.1111/j.1442-9993.2010.02107.x

Knox, K.J.E., and D.A. Morrison. 2005. Effects of inter-fire intervals on the reproductive output of resprouters and obligate seeders in the Proteaceae. Austral Ecology 30: 407–413. doi: 10.1111/j.1442-9993.2005.01482.x

Lake, J.C., and M.R. Leishman. 2004. Invasion success of exotic plants in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. Biological Conservation 117: 215–226. doi: 10.1016/S0006-3207(03)00294-5

Manning, A.D., D.B. Lindenmayer, S.C. Barry, and H.A. Nix. 2006. Multiscale-scale site and landscape effects on the vulnerable superb parrot of south-eastern Australia during the breeding season. Landscape Ecology 21: 1119–1133. doi: 10.1007/s10980-006-7248-6

McElhinney, C., P. Gibbons, and C. Brack. 2006. An objective and quantitative methodology for constructing an index of stand structural complexity. Forest Ecology and Management 235: 54–71. doi: 10.1016/j.foreco.2006.07.024

McLoughlin, L.C. 1998. Season of burning in the Sydney region: the historical records compared with recent prescribed burning. Australian Journal of Ecology 23: 393–404. doi: 10.1111/j.1442-9993.1998.tb00744.x

Mitchell, T.L. 1839. Three expeditions into the interior of eastern Australia; with descriptions of the recently explored region of Australia Felix and of the present colony of New South Wales. Second edition. Facsimile edition 2006. Rediscovery Books, Uckfield, England.

Mitchell, T.L. 1848. Journal of an expedition into the interior of tropical Australia in search of a route from Sydney to the Gulf of Carpentaria. Longman, Brown, Green and Longmans, London, facsimile edition 2007. Archive CD Books Australia, Ridgehaven, South Australia, Australia.

Mooney, S.D., K.L. Radford, and G. Hancock. 2001. Clues to the 'burning question': pre-European fire in the Sydney coastal region from sedimentary charcoal and palynology. Ecological Management and Restoration 2: 203–212. doi: 10.1046/j.1442-8903.2001.00085.x

Mooney, S.D., S.P. Harrison, P.J. Bartlein, A.-L. Daniau, J. Stevenson, K.C. Brownlie, S. Buckman, M. Cupper, J. Luly, M. Black, E. Colhoun, D. D'Costa, J. Dodson, S. Haberle, G.S. Hope, P. Kershaw, C. Kenyon, M. McKenzie, and N. Williams. 2011. Late quaternary fire regimes of Australia. Quaternary Science Review 30: 28–46. doi: 10.1016/j.quascirev.2010.10.010

Morrison, D.A., G.J. Cary, S.M. Pengelly, D.G. Ross, B.J. Mullins, C.R. Thomas, and T.S. Anderson. 1995. Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: inter-fire interval and time-since-fire. Australian Journal of Ecology 20: 239–247. doi: 10.1111/j.1442-9993.1995.tb00535.x

Morrison, D.A., R.T. Buckney, B.J. Bewick, and G.J. Cary. 1996. Conservation conflicts over burning bush in south-eastern Australia. Biological Conservation 76: 167–175. doi: 10.1016/0006-3207(95)00098-4

Noble, J.C. 1997. The delicate and noxious scrub: CSIRO studies on native tree and shrub proliferation in the semi-arid woodlands of eastern Australia. CSIRO Division of Wildlife and Ecology, Lyneham, Australian Capital Territory, Australia.

NSW Rural Fire Service. 1998. A state ablaze. The January 1994 fires. <http://www.rfs.nsw.gov.au/file_system/attachments/State/Attachment_20050308_DFF87D81.pdf>. Accessed 2 Oct 2013.

Penman, T.D., R.P. Kavanagh, D.L. Binns, D.R. Melick. 2007. Patchiness of prescribed burns in dry sclerophyll eucalypt forests in south-eastern Australia. Forest Ecology and Management 252: 24–32. doi: 10.1016/j.foreco.2007.06.004

Penman, T.D., D.L. Binns, R.J. Shiels, R.M. Allen, and R.P. Kavanagh. 2008. Changes in understorey plant species richness following logging and prescribed burning in shrubby dry sclerophyll forests of south-eastern Australia. Austral Ecology 33: 197–210. doi: 10.1111/j.1442-9993.2007.01809.x

Penman, T.D., D.L. Binns, T.E. Brassil, R.J. Shiels, R.M. Allen. 2009. Long-term changes in understorey vegetation in the absence of wildfire in south-east dry sclerophyll forests. Australian Journal of Botany 57: 533–-540. doi: 10.1071/BT09079

Pratt, B.H., and W.A. Heather. 1973. The origin and distribution of *Phytophthora cinnamomi* Rands in Australian native plant communities and the significance of its association with particular plant species. Australian Journal of Biological Science 26: 559–573.

Pringle, R.M., M. Syfert, J.K. Webb, and R. Shine. 2009. Quantifying historical changes in habitat availability for endangered species: use of pixel- and object-based remote sensing. Journal of Applied Ecology 46: 544–553. doi: 10.1111/j.1365-2664.2009.01637.x

Pyne, S.J. 1998. Burning bush. A fire history of Australia. University of Washington Press, Seattle, USA.

Regan, H.M., D.A. Keith, T.J. Regan, M.G. Tozer, and N. Tootle. 2011. Fire management to combat disease: turning interaction between threats into conservation management. Oecologia 167: 873–882. doi: 10.1007/s00442-011-2029-6

Siddiqi, M.Y., R.C. Carolin, and P.J. Myerscough. 1976. Studies in the ecology of coastal heath in NSW. III. Regrowth of vegetation after fire. Proceedings of the Linnean Society of New South Wales 101: 53–63.

Singh, G., A.P. Kershaw, and R. Clark. 1981. Quaternary vegetation and fire history in Australia. Pages 23–54 in: A.M. Gill, R.H. Groves, and I.R. Noble, editors. Fire and the Australian biota. Australian Academy of Science, Canberra, Australia.

Speer, M.S., L.M. Leslie, J.R. Colquhoun, and E. Mitchell. 1996. The Sydney Australia wildfires of January 1994—meteorological conditions and high resolution modeling experiments. International Journal of Wildland Fire 6: 145–154. doi: 10.1071/WF9960145

Tasker, E.M., and R.A. Bradstock. 2006. Influence of cattle grazing practices on forest understorey structure in north-eastern New South Wales. Austral Ecology 31: 490–502. doi: 10.1111/j.1442-9993.2006.01597.x

Tasker, E.M., A.J. Denham, J.E. Taylor, and T.C. Strevens. 2011. Post-fire seed predation: does distance to unburnt vegetation matter? Austral Ecology 36: 755–766. doi: 10.1111/j.1442-9993.2010.02214.x

Tasker, E.M., and C.R. Dickman. 2004. Small mammal community composition in relation to cattle grazing and associated burning in eucalypt forests of the Northern Tablelands of New South Wales. Pages 721–740 in: D. Lunney, editor. Conservation of Australia's forest fauna. Second edition. Royal Zoological Society of New South Wales, Mosman, Australia.

Tench, W. 1793. A complete account of the settlement at Port Jackson including an accurate description of the situation of the colony; of the natives; and of its natural productions. G. Nichol and J. Sewel, London, England. <http://adc.library.usyd.edu.au/data-2/p00044.pdf>. Accessed 16 Jun 2013.

Tozer, M.G., and R.A. Bradstock. 2002. Fire-mediated effects of overstorey on plant species diversity and abundance in an eastern Australian heath. Plant Ecology 164: 213–232. doi: 10.1023/A:1021387210745

Tozer, M.G., and D.A. Keith. 2012. Population dynamics of *Xanthorrhoea resinosa* Pers. over two decades: implications for fire management. Proceedings of the Linnean Society of New South Wales 134: B249–B266.

Turner, J., M. Lambert, V. Jurskis, and H. Bi. 2008. Long term accumulation of nitrogen in soils of dry mixed eucalypt forest in the absence of fire. Forest Ecology and Management 256: 1133–1142. doi: 10.1016/j.foreco.2008.06.021

Von Platen, J., J.B. Kirkpatrick, and K.J. Allen. 2011. Fire frequency variation in south-eastern Tasmanian dry eucalypt forest 1740–2004 from fire scars. Australian Forestry 74: 180–189. doi: 10.1080/00049158.2011.10676361

Ward, D.J., B.B. Lamont, and C.L. Burrows. 2001. Grasstrees reveal contrasting fire regimes in eucalypt forest before and after European settlement of southwestern Australia. Forest Ecology and Management 150: 323–329. doi: 10.1016/S0378-1127(00)00584-3