HOTSPOTS FIRE PROJECT

Fire Frequency Guidelines and the Vegetation of the Northern Rivers Region

Draft 2, Revised on Basis of Comments

Dr Penny Watson

Project Ecologist

January 2006

Nature Conservation Council of NSW
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This report has been complied for the Hotspots Fire Project. The information it contains reflects our understanding at the time writing. We are learning more about fire and the environment every day and anticipate that some recommendations may change as new information comes to hand.

Please note that this document is the second draft of this report. It incorporates comments received to early January 2006. Further comments will be incorporated into the next version.

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1. Background

1.1 Introduction

The Northern Rivers region of NSW hosts a wide range of plant communities, which in turn support many flora and fauna species (Flint *et al.* 2004). Plants grow rapidly in the warm, wet conditions found in this coastal, subtropical area. Fire is a feature of Northern Rivers landscapes – but how much fire is appropriate? This document seeks to address that question for some of the major vegetation types in the region.

Fire frequency guidelines for broad vegetation types have been published for the state of NSW as a whole by the Department of Environment and Conservation (DEC; Kenny *et al.* 2004), and for south-east Queensland by the SEQ Fire and Biodiversity Consortium (Watson 2001a). In 2004, Chiswell and Redpath (2004) developed guidelines for Northern Rivers vegetation types, drawing on the recommendations in both these documents. Time, however, precluded an in-depth assessment of local and recent fire ecology research literature. This document seeks to fill that gap, and to build on, localise and extend work done to this point. It is presented as a stimulus to further reading, discussion and research and does not claim to be definitive.

This review focuses primarily on the grassy woodlands and forests that cover much of the western part of the Northern Rivers region. This focus has been chosen because:

- Much of the local research concerns grassy communities;
- Grassy communities tend to occur disproportionately on private property, and the Hotspots project aims to provide relevant information for private landholders;
- Concurrence between the south-east Queensland and the NSW guidelines is lowest in grassy communities.

The review begins with a look at some of the fundamental ecological concepts that underpin understanding of the relationship between fire regimes and biological diversity. These concepts inform existing fire frequency guidelines in a manner which will be briefly outlined and discussed.

Specific vegetation formations are then considered under four headings:

- Grassy woodlands and grassy dry sclerophyll forests;
- Grassy wet sclerophyll forests;
- Shrubby wet sclerophyll forests;
- Shrubby dry sclerophyll forests and coastal heaths.

In each case, after an introduction to the vegetation type, research pertaining to the Northern Rivers region is summarised. Findings are discussed in the light of ecological concepts, other relevant literature and local observations. Existing fire regime guidelines are then outlined and discussed. Suggestions for fire regimes predicted to be compatible with the retention of the flora and fauna of each broad vegetation type are summarised, and further research proposed.

1.2 Disturbance, succession and a paradigm shift

Several basic ecological concepts and principles underlie current understanding of fire regimes. These ideas can help explain how fires have shaped the landscape in the past, and how fire management can best conserve the diversity of the bush in the future. The interaction between disturbance, succession, and growth has profound implications for fire regimes. Around the world, understanding of these factors has developed considerably in recent years.

Fire is a disturbance. A disturbance can be defined as "any relatively discrete event in time that removes organisms and opens up space which can be colonised by individuals of the same or different species" (Begon et al. 1990). The concept encompasses recurring discrete events such as storms, floods and fires, as well as on-going processes like grazing. Disturbance may stem from natural phenomena or human activities (Hobbs and Huenneke 1992), and is ubiquitous throughout the world's ecosystems (Sousa 1984).

Succession follows disturbance. This concept has been of interest to ecologists since Clements outlined what is now called 'classical succession' in 1916. In classical succession "following a disturbance, several assemblages of species progressively occupy a site, each giving way to its successor until a community finally develops which is able to reproduce itself indefinitely" (Noble and Slatyer 1980:5). Implicit in this model is the idea that only the final, 'climax' community is in equilibrium with the prevailing environment.

The cultural metaphor for this 'equilibrium paradigm' is 'the balance of nature'. Conservation practice aligned with this model focuses on objects rather than processes, concentrates on removing the natural world from human influence, and believes that desirable features will be maintained if nature is left to take its course (Pickett et al. 1992). The 'balance of nature' approach influenced attitudes to fire, both in Australia and elsewhere, for many years. For example, forester C.E. Lane-Poole argued to the Royal Commission following the 1939 fires in Victoria for total fire exclusion on the grounds that this would enable natural succession to proceed (Griffiths, 2002).

Over recent decades, however, a paradigm shift has been underway. Drivers include the realisation that multiple states are possible within the one community (Westoby et al. 1989, Bond and Archibald 2003), as are multiple successional pathways (Connell and Slatyer 1977). Most importantly from a conservation perspective, it has increasingly been recognised that periodic disturbance is often essential to maintain diversity, allowing species which might otherwise have been displaced to continue to occur in a community (Connell 1978).

This 'non-equilibrium paradigm' can be encapsulated by the phrase 'the flux of nature'. Scale is important in this paradigm: equilibrium at a landscape scale may be the product of a distribution of states or patches in flux. Implications include a legitimate – or even vital – role for people in ecosystem management, and a focus on the conservation of processes rather than objects. This does not, of course, imply that all human-generated change is okay; it does mean human beings must take responsibility for maintaining the integrity of ecosystem processes (Pickett et al. 1992). Fire fits much more comfortably into the non-equilibrium paradigm, where it takes its place as a process integral to many of the world's ecosystems.

Recent work on several continents is showing just how vital fire has been, and still is, in creating and maintaining much of the world's vegetation. South African ecologists have been at the forefront of this understanding: they have long been aware that the open savanna vegetation which supports so many grazing and browsing animals can change, in the absence of fire, into dense scrub or forest. These savanna landscapes burn regularly, and have done for millions of years (Bond et al. 2003a). Successional changes have been noted in fire exclusion experiments in plant communities around the world (Bond et al. 2003a, 2005), and are also predicted by recently-developed models of global vegetation when fire modules are 'switched off' (Bond et al. 2005).

The importance of fire in preserving native vegetation communities has also been increasingly recognised in the United States (Pickett et al. 1992) where fire exclusion is implicated in major changes that have occurred in a number of native forest types (Hessburg et al. 2000, Keane et al. 2002, Dombeck et al. 2004, Van Lear et al. 2005, Keeley et al. in preparation). For example numerous studies have documented a massive increase in stem density in ponderosa pine ecosystems in south-western states including Arizona and New Mexico (eg Cooper 1960, Covington and

Moore 1994, Moore et al. 2004, Heinlein et al. 2005 and references therein). In some places, species composition has shifted towards more shade-tolerant species such as white fir and Douglas-fir (eg Moore et al. 2004, Heinlein et al. 2005). Grassy understorey vegetation has declined beneath the thick subcanopy (Moir 1966, Covington and Moore 1994). Fire frequency before and after European settlement, which occurred towards the end of the 19th century in these forests, can be ascertained from tree rings: these studies clearly show a change, around this time, from frequent low-intensity fires of limited extent, to virtually no fire at all (Heinlein et al. 2005 and references therein). Low-intensity fires kept these forests open through killing the majority of young saplings, and helped create a shifting pattern in which tree patches alternated with open grassy glades. Established trees survived these fires, which 'pruned' their lower branches. Some saplings in open patches lived to become the trees of the future (Cooper 1960, Allen et al. 2002 and references therein). In recent years, however, changes in structure have made these forests vulnerable to high intensity crown fires which kill old-growth trees (Covington and Moore 1994, Moore et al. 2004). Ecologically-sensitive ecosystem restoration programs aim to minimise this risk through re-instating "surface fire as a keystone process" (Allen et al. 2002:1426 – this article provides a reasoned, management-oriented summary of research in this vegetation type).

1.3 Theory into thresholds

The non-equilibrium paradigm forms the basis for a number of theories and models which have been used to inform an understanding of fire regimes in Australia. These include the **vital attributes model** of Noble and Slatyer (1980). This scheme employs a small number of life history characteristics of plant species to predict successional pathways. It can also be used to define disturbance frequency domains compatible with maintenance of particular suites of species. This model was used by Kenny *et al.* (2004) in developing fire management guidelines for broad vegetation types in NSW, and is also used in Victoria (Friend *et al.* 2003).

The basic idea is that, to keep all species in a community, fire intervals should vary within an upper and a lower threshold. Lower thresholds are set to allow all species vulnerable to frequent fire to reach reproductive maturity, while upper thresholds are determined by the longevity of species vulnerable to lack of burning. 'Vital attributes' are used to group species into functional types whose populations have similar methods of persistence and re-establishment after fire (Noble and Slatyer 1980, Keith *et al.* 2002b). The vulnerability of each group, and of species within sensitive groups, can be assessed through consideration of species life history characteristics.

Functional types most sensitive to **short interfire intervals** (high fire frequency) contain obligate seeder[1] species whose seed reserves are exhausted by disturbance. Populations of these species are liable to local extinction if the interval between fires is shorter than their primary juvenile period[2] (Noble and Slatyer 1980). The minimum interfire interval to retain all species in a particular vegetation type (lower threshold) therefore needs to accommodate the taxon in this category with the longest juvenile period (DEC 2002). Obligate seeders with seeds that can persist through more than one fire are moderately sensitive to short interfire intervals. These species will decline if fires continue to occur within the juvenile period (Bradstock and Kenny 2003).

Species whose establishment is keyed to fire (Noble and Slatyer call these 'I species') are highly sensitive to **long interfire intervals** (infrequent fire): they are liable to local extinction if fire does not

[1] Obligate seeder species are killed by fire and rely on regeneration from seed.

[2] A species' primary juvenile period is the time from seed germination to reproductively mature adult.

occur within the lifespan of established plants and/or seedbanks (Noble and Slatyer 1980). The maximum interval (upper threshold) therefore needs to accommodate the taxon in this category with the shortest lifespan, seedbank included (DEC 2002, Bradstock and Kenny 2003).

Data on plant life history attributes relevant to setting **lower thresholds** – regeneration modes and juvenile periods – are reasonably easy to obtain. Predictions of shrub abundance based on these vital attributes have recently been tested through a field study of woodland vegetation in areas with known fire histories, and were supported (Watson 2005). It should be noted that when thresholds are determined for a very broad geographic area, as is the case in the Kenny *et al.* (2004) guidelines, lower thresholds may be set by species which are not found in particular local areas, and thus may be higher than if local species only were considered.

Data relevant to setting **upper thresholds** – longevity of adults and seeds – are much less readily available. Kenny *et al.* (2004) note the lack of quantitative data on these attributes, and point out that as a result, upper thresholds are "largely based on assumptions and generalisations" and are therefore surrounded by "considerable uncertainty" (Kenny *et al.* 2004:31). Work on these variables is an important task for the future.

Because of the uncertainty surrounding species longevities, upper thresholds in Kenny *et al.* (2004) for most broad vegetation types do not reflect the longevity of the shortest-lived 'most sensitive' species in summary charts. This is because these species "were critically assessed for data quality, and any data considered dubious was excluded from guideline calculations" (Kenny *et al.* 2004:25). This included estimates in forms such as "life span possibly 20-30 years." In addition, where a range of figures for lifespan was available, the *highest* figure was used (Kenny *et al.* 2004:26). Upper thresholds are thus set conservatively high.

It can also be argued that upper thresholds might be better set somewhat lower than lifespan + seedbank longevity (*y*) of species liable to be lost from a community if fire is insufficiently frequent. West Australians Burrows and Abbott (2003:446) suggest 0.75*y* may be more appropriate. Population decline, both above and below ground, may occur over a long period prior to the point of local extinction (Auld 1987). Flowering may peak in the years following the juvenile period: McFarland (1990) found flowering and seeding in south-east Queensland's wallum heath peaked at four to eight years after a burn, and dropped markedly by 11 years post-fire. A species may therefore still occur in the landscape, but its fecundity might be greatly reduced in later post-fire years (Auld and Myerscough 1986).

Finally, the potential for one or a small number of species to dominate under extended interfire intervals, and related competitive interactions, may mean that upper thresholds need to be lower than an assessment based solely on life history characteristics would suggest. This issue is explored in the next section.

1.4 Competition and productivity

The effect of dominant heathland shrubs, such as *Banksia ericifolia* and *Allocasuarina distyla*, on other species has been recognised in Sydney's sandstone country (Keith and Bradstock 1994, Keith 2002, Tozer and Bradstock 2002). When life history characteristics alone are considered, a feasible fire frequency for the conservation of both these dominant obligate seeders and understorey species appears to be 15-30 years. However at this fire frequency, the dominant species form high-density thickets which reduce the survival and fecundity of species in the understorey, an effect which carries through to the next post-fire generation. Similar dynamics have been observed in other Australian heath communities (Specht and Specht 1989, McMahon *et al.* 1996, Bond and Ladd 2001) and in South Africa's heathy fynbos (Bond 1980, Cowling and Gxaba 1990, Vlok and Yeaton 2000). An understanding of this dynamic has highlighted the need to include in heathland fire regimes some intervals only slightly above the juvenile period of the dominant species, thus reducing overstorey density for a period sufficient to allow understorey species to build up population numbers before again being overshadowed. This need is reflected in fire frequency recommendations in Bradstock *et al.* (1995).

The effect on understorey vegetation may be particularly profound where dominant shrubs resprout (Bond and Ladd 2001). Unlike the Sydney obligate seeder heath dominants, dominant resprouters will continue to exert competitive pressure immediately after a fire by drawing on soil resources, and once their cover is re-established, on light resources too. For example in the grassy woodlands of Western Sydney's Cumberland Plain, the prickly shrub *Bursaria spinosa* forms dense thickets which can dominate the landscape where fire has been excluded for several decades (Watson 2005). After a burn, this shrub resprouts and grows rapidly. Other shrub species in this vegetation type, particularly obligate seeders, are less abundant in Bursaria-dominated landscapes than in sites which have burnt once or twice a decade, an outcome which probably reflects competitive pressure from Bursaria. Ground layer species are also affected. Thus the strategy recommended to provide relief for competitively inferior species in heaths – inserting one short interval amongst longer ones (Keith 2002b) – is unlikely to work in this community. Upper thresholds need to be sufficiently low to allow for the moderately frequent fires that will allow Bursaria thickets, obligate seeder shrubs and a diverse ground layer of native grasses and herbs to co-exist long-term.

In Cumberland Plain Woodland, Bursaria – and some introduced shrubs such as African Olive – have the advantage of being able to recruit between fires. This characteristic differentiates them from almost all other shrubs in this community, which like most sclerophyllous shrub species, recruit almost exclusively after a fire (Purdie and Slatyer 1976, Auld 1987, Zammit and Westoby 1987, Cowling *et al.* 1990, Vaughton 1998, Keith *et al.* 2002a). The vital attributes model explicitly identifies species able to recruit between fires – Noble and Slatyer call them 'T species'– and their propensity to dominate in the absence of disturbance is also explicitly noted (Noble and Slatyer 1980). However to date little emphasis has been placed on the role of T species when determining fire frequency guidelines.

Although not explicitly based on the vital attributes model, the south-east Queensland fire regimes guidelines (Watson 2001a) did take competitive interactions into account. For example, the observation than unburnt grassy woodlands around Brisbane were 'thickening' due to recruitment and growth of *Lophostemon confertus* and lantana, apparently to the detriment of once-common Pretty-face Wallabies (Kington 1997) was considered, as were other reports of shrub encroachment into grassy vegetation. Relatively low upper thresholds in the SEQ guidelines reflect these considerations.

The importance of competition between plant species, and thus the importance of disturbance to disrupt competitive exclusion, is likely to vary with **landscape productivity**. A second non-equilibrium paradigm offshoot, the **dynamic equilibrium model** (Huston 1979, 2003, 2004), considers the interaction of productivity and disturbance in mediating species diversity. In harsh environments where productivity is low, interspecific competition is unlikely to be great. Here, a-biotic factors such as low rainfall, heavy frosts and infertile soils limit the number of plant species able to grow, and also limit their growth rates. The need for disturbance to reduce competitive superiority is therefore minimal. In fact, a high disturbance frequency is predicted to reduce diversity in these ecosystems, as organisms won't be able to grow fast enough to recover between disturbances. In highly productive, resource-rich environments, however, competition is likely to be much more intense, as many species can grow in these areas, and they grow quickly. Here, diversity is predicted to decline where disturbance frequency is low, as some species will outcompete others, excluding them from the community.

Landscape productivity, as defined by increased biomass as an example, is likely to increase with:

- Rainfall
- Temperature
- Season of rainfall (where rainfall and warm temperatures coincide, there is a greater potential for plant growth)
- Soil fertility (clay soils are often more fertile than sandy soils, however they also tend to support more herbaceous, and less shrub, species (Beadle 1962, Specht 1970, Ashton 1976, Prober 1996, Clarke 2003) possibly due to structural characteristics inhibiting water movement (van Langevelde *et al.* 2003)).

Relatively frequent fire may thus be more appropriate in wet, warm, productive fire-prone systems than in those whose productivity is limited by poor soils, low rainfall or a short growing season (Stuwe 1994, Huston 2004).

A second reason why shorter interfire intervals may be appropriate in more productive systems is because shrubs may reach life history milestones more rapidly. Juvenile periods of obligate seeder shrubs may be shorter where resources are more readily available. On the New England Tablelands, where the growing season is constrained by severe frosts, shrub juvenile periods can be several years longer than those of the same species in coastal areas (Knox and Clarke 2004). Senescence, and/or overtopping of low growing shrub species, may also occur more rapidly in more productive areas (Specht and Specht 1989).

This discussion brings us back to the work of Bond *et al.* (2003a, 2005) in South Africa, and to the concept of succession. These authors divide global vegetation types into three categories:

- Climate-limited systems. These vegetation types don't change in structure with changes in fire frequency. In South Africa, these communities occur in arid environments, and also in areas nearer the coast where rainfall is moderate but occurs in winter. While fire may play a role in mediating species composition, these communities are not prone to either major structural change, nor to succeeding to another vegetation type in the absence of fire.
- Climate-limited but fire modified systems. These vegetation types do not succeed to another vegetation type in the absence of fire, but their structure may alter from grassy to shrubby. The Cumberland Plain Woodland described above fits into this category.
- Fire-limited. These vegetation types will succeed to a different community in the absence of fire. In South Africa, these communities occur in higher rainfall areas, and include both savannas and heath.

Climate-limited but fire-modified systems can occur in at least two 'states', for example grassy woodland and Bursaria-dominated shrub thicket woodland on the Cumberland Plain (Watson 2005). Fire-limited vegetation types could also be said to be able to exist in different states, although the differences between them are so great that they are rarely thought about in this way. For example, in north Queensland, *Eucalyptus grandis* grassy wet sclerophyll forest is succeeding to rainforest, probably due to a reduction in fire frequency and/or intensity (Unwin 1989, Harrington and Sanderson 1994, Russell-Smith and Stanton 2002). However rainforest and grassy wet forest are not generally considered as different states of a single vegetation type, but rather as two different types of vegetation.

These examples illustrate how dynamic vegetation can be in relation to fire. In some productive landscapes, variation in interfire intervals within thresholds, that is variation in time, may not be sufficient to maintain all ecosystem elements. Variation in space may also be needed to ensure all possible states, and the plants and animals they support, are able to persist in the landscape. Fire can mediate a landscape of different patches, whose location may change over time. "Variability in disturbance regimes allows ecosystems to fluctuate between alternative states, without reaching 'equilibrium' whereby any one group of species dominates over long periods while others decline to eventual elimination" (Keith *et al.* 2002b:410). Spatial aspects of the fire regime will be explored in more detail in a separate Hotspots review.

A third non-equilibrium paradigm derivative, Westoby's **state and transition model** (Westoby *et al.* 1989) provides a useful framework for viewing systems which can exist in more than one state. This model uses a catalogue of states, and of transitions between them, to identify land management options. While some transitions are gradual, others occur rapidly when an ecological threshold is crossed. Some transitions may be reversed with relative ease, but some will be difficult or impossible to undo, as the vegetation will have passed into a new, stable state. Examples of state and transition model-based descriptions of vegetation dynamics can be found in the literature on grazing in native ecosystems, where removal of particular grass species or of grass cover in general through overgrazing can trigger weed invasion, erosion and self-perpetuating changes in species composition (Westoby *et al.* 1989, Prober *et al.* 2002b).

1.5 The Northern Rivers region

The Northern Rivers region of New South Wales is wet and warm. The regional weather station with the lowest annual rainfall, Grafton, receives an average of around 1000mm per annum, with totals above 1600mm at several stations near the coast (Bureau of Meteorology 2005). Average maximum temperatures in January are in the high twenties or low thirties. Even in July, average maxima at most stations are above 18˚C. Frosts are uncommon, although this changes rapidly as one moves onto the New England plateau (Bureau of Meteorology 2005). The North Rivers region is thus likely to host vegetation types which top the state for productivity.

Plant taxa in the Northern Rivers region cover a wide range of life-forms. Many areas support grassy vegetation, often with scattered shrubs. In other areas, shrubs are thicker. North Rivers shrubs include many sclerophyllous species, with the hard leaves characteristic of low-nutrient heath environments. However soft-leaved (mesophyllous) species more reminiscent of rainforest also abound (Keith 2004). It is very likely that variation in fire frequency plays a role in providing habitat for this abundant variety.

While the following sections divide vegetation into four discrete categories, in practice boundaries may not be so clear (P. Redpath, D. Binns, pers. comm. 2005). In particular, the boundary between dry and wet sclerophyll forest is by no means clear-cut. Fire, or its absence, may play a role in creating the landscapes which are then considered 'wet' or 'dry'.

2 Grassy woodlands and grassy dry sclerophyll forests

2.1 Introduction

Grassy woodlands were once widespread in Eastern Australia (Sivertsen and Clarke 2000, Yates and Hobbs 2000). In NSW, grassy woodlands occurred over much of the State west of the Great Dividing Range, and also in some sub-coastal regions (Sivertsen and Clarke 2000). Relative to other vegetation types, Australia's temperate grassy woodlands are not well conserved. From the early days of European settlement, they have been subject to intensive management. Many areas were cleared for crops and towns. Woodlands grazed by domestic animals were often 'improved' through addition of exotic species and/or fertilizer. Few intact areas remain (Silvertsen 1993, Prober and Thiele 1995, Sivertsen and Clarke 2000, Yates and Hobbs 2000). Those that do thus have considerable conservation significance.

Grassy woodlands and forests support trees, shrubs, and a diverse ground layer of grasses interspersed with forbs[3] (Tremont and McIntyre 1994). Grassy woodlands and forests tend to occur on relatively nutrient-rich clay or loam soils, while a shrub-dominated understorey is more common on nutrient-poor sandy soils (Beadle 1962, Specht 1970, Ashton 1976, Prober 1996, Clarke 2003). Much of the plant diversity in grassy woodlands and forests is found in the ground layer (eg Benson and Howell 2002). In a study spanning a range of geologies south of Casino, the majority of understorey species in study plots were herbs (forbs, grasses, sedges, ferns). The extent to which shrubs contributed to species richness varied with substrate: they were a much more important component on sandstone than on mixed sediments (York 1999b).

Interspecific interactions in grassy ecosystems can occur between herbaceous and woody plants (eg Scanlan and Burrows 1990, Hobbs and Atkins 1991, Prober *et al.* 2002a) and also between dominant grasses and the smaller grasses and forbs growing between them (Stuwe 1994, Tremont and McIntyre 1994, Morgan 1998a). As discussed in the previous section, disturbance may play a role in mediating these interactions.

2.2 Keith vegetation types

Three vegetation formations described by Keith (2004) and occurring in the North Rivers region can be classified as grassy woodlands or grassy dry sclerophyll forests. These vegetation types are detailed below, along with Keith's comments about the role of fire in each.

- **Coastal Valley Grassy Woodlands**. This vegetation type covers "a suite of highly diverse plant assemblages isolated in different dry coastal valleys that occupy rainshadows among the surrounding hills" (Keith 2004:86). These valleys are low-lying, receive 700-1000mm rainfall annually, and have moderately fertile soils. In northern NSW, Coastal Valley Grassy Woodlands occur around Grafton and south of Casino near Rappville. These woodlands have a diverse ground layer of grasses and herbs, and "scattered or clumped shrubs, which are mostly sclerophyllous [hard-leaved]" (Keith 2004). Keith (2004) notes that these woodlands were settled rapidly and are now fragmented by land-clearing, however he does not comment on the history or role of fire in this vegetation type.

[3] A forb is a herbaceous plant which is not a grass, sedge or rush.

- **Clarence Dry Sclerophyll Forests**. This vegetation formation is only found in the Northern Rivers region, where it occurs on both sides of the Clarence River, south of the Gwydir Highway and between the patches of Coastal Valley Grassy Woodland described above. Keith (2004) points out the similarities between these forests and the tropical savannas further north: both have a continuous open grassy understorey with occasional mesophyllous (soft-leaved) shrubs, both are dominated by eucalypts which have recently been classified into the genus *Corymbia*, which includes bloodwoods and spotted gums. Again these forests occur in rainshadow areas on moderate fertility soils, however they receive somewhat more precipitation and occur at somewhat greater elevations than the Coastal Valley Grassy Woodlands. Keith (2004) notes that cattle grazing and associated frequent burning occur over much of the range of this vegetation type. "As a consequence the remnants generally have simplified understories, and are unlikely to now include the full range of plant communities that originally made up this class" (Keith 2004:122). He also attributes changes in understorey species composition to grazing and burning: "As a result *Imperata cylindrica* (blady grass), *Aristida ramosa* (purple wiregrass) and *Cympopogon refractus* (barbed-wire grass) dominate the ground cover" (Keith 2004:122).
- **Northern Gorge Dry Sclerophyll Forests**. This vegetation type occurs in the gorges of the New England Tablelands escarpment. Again these are rainshadow areas, hot in summer, with fine-grained, moderately fertile soils. Keith (2004:130-1) cites a study by Kitchin (2001) which documented the fire history of gorges in Guy Fawkes River National Park: "Current patterns of vegetation in the gorge were related more strongly to rainfall than to fire history, although a group of understorey shrubs was essentially restricted to sites that had intervals of at least 10-25 years between successive fires, and a similar length of time since they were last burned. These included non-sclerophyllous species, like *Trochocarpa laurina* (tree heath), *Cryptocarya rigida* (forest maple), *Notelaea* sp. A., *Elaeocarpus reticulatus* (blueberry ash) and *Persoonia media*. Sites that had experienced at least one interval between fires that was five years or less, since 1973, had slightly fewer shrub species, and these were predominantly sclerophyllous. The overall conclusion of the study was that high fire frequencies were associated with simplification of the species composition and structure of the forest" (Kitchin 2001).

2.3 Northern Rivers studies

There have been two major ecological studies into the effects of fire in dry forest vegetation types in the North Rivers region. Margaret Kitchin, whose work is referenced by Keith (2004), compared sites with differing fire histories in two vegetation types, one of which was Northern Gorge Dry Sclerophyll Forests (the other vegetation type was wet sclerophyll forest on the Northern Tablelands – see Section 3). Alan York and his colleagues studied the combined effects of grazing and associated low intensity frequent burning in dry forest types south of Casino. Also of interest is the research of Brett Stubbs and his colleagues at Southern Cross University, which draws on historical records that pertain to the local environment.

Kitchin (2001) surveyed groups of sites that had experienced differing fire sequences in Northern Gorge Dry Sclerophyll Forests. While she did uncover some differences amongst her fire regime categories, on many variables these differences were not significant.

For woody plants, Kitchin (2001) found no significant differences between fire regime categories in species richness, and no individual woody species showed a significant relationship with number of fires. As Keith (2004) notes, a group of woody plant species, including a number of mesophyllous shrubs, were indeed found only on Kitchin's "Moderate Long Long" sites. These sites had all had between two and four fires in the last 25 years (putting them in Kitchin's "moderate" fire frequency category). Inter-fire intervals, however, were all over 10 years (intervals over 10 years were classified "long"), plus these sites had not had a fire for at least 10 years (time-since-fire was also "long"). Two fires must therefore have occurred 10-15 years apart. Kitchin also identified a group of woody species found only on sites with a shortest interfire interval of 1-3 years. Few species were unique to sites which had not had a fire for 25 years.

Fire variables also failed to reach significance when woody plant floristics were assessed through multivariate analysis. There were significant differences, however, in numbers of shrubs in two height categories. Shrubs 2-10m tall were most abundant where fires had been moderately frequent and 10-15 years apart. Shrubs below 2m were most abundant where fires had been moderately frequent, and recent. Woody plant stem density in low fire frequency sites was lower than that in two of four moderate fire frequency categories (Kitchin 2001).

Kitchin (2001) presented data on herbs, but limited statistical analysis to community composition. Fire variables did not significantly influence herb floristics, although time-since-fire approached significance. Grass cover was highest where there had been 2-4 fires in 25 years, including at least one short (1-3 year) interfire interval, and declined with increasing time-since-fire and length of interfire interval. Cover of sedges and rushes was greatest where interfire intervals were relatively long. *Themeda australis*[4] (kangaroo grass) cover was high across all fire frequency categories. Neither blady grass nor bracken (*Pteridium esculentum*) was a major contributor to cover values under any fire regime.

York (1997, 1998, 1999b) investigated the effects of grazing in some North Coast State Forests[5]. This study focused on dry sclerophyll forests types, and covered a range of geologies. The intention was to illuminate the effects of the frequent fire reputedly associated with grazing leases, however fire history information proved difficult to obtain. Sites were allocated to treatments on the basis of grazing indicators (specifically presence of cow pats). The study, which focused on plants and invertebrates, found few significant differences between grazed and ungrazed sites in either the abundance, richness or composition of any group of organisms. The notable exception concerned shrubs, whose species richness was reduced in grazed areas. This effect was particularly pronounced on sandstone, which hosted more shrubby vegetation than the other two geologies, and thus falls outside the grassy woodland/dry sclerophyll forest category under discussion here. On mixed sediments differences in shrub species richness were slight; shrub richness averaged 2.9 species per 0.1ha in grazed sites, and 3.1 in ungrazed areas; shrubs were a minor component of the vegetation on this substrate, irrespective of grazing. There was some indication that beetle species composition had shifted with increased grazing intensity, however neither beetle abundance nor beetle species richness was affected by grazing, in fact both were

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[4] In some Australian states, this grass species is called *Themeda triandra,* name which recognizes the close affiliation between the African and Australian forms of the species

[5] Some of these forests are now under NPWS management. Although a small number of exotic plant species were recorded during this study, the species complement was mostly indigenous.

higher in grazed sites, though not significantly so.

Further analysis by York and Tarnawski (2004) of a subset of the data from this study confirmed that neither invertebrate abundance – overall, or in any of the 16 groups with sufficient numbers for statistical testing – invertebrate ordinal richness, nor invertebrate community composition was significantly affected by grazing and burning in these dry forests. Harris *et al.* (2003) also failed to identify any significant differences between the two treatments in an in-depth analysis of the data for spiders.

Boyd *et al.* (1999) and **Stubbs** (2001) have approached the topic of woodland management from a very different perspective. These authors are environmental historians who use historical records to gain an understanding of vegetation formations in times past. Their papers document the existence of grassy patches, known to early European settlers as 'grasses', within the margins of the Big Scrub rainforest. Boyd *et al.* (1999) used sediment cores and carbon dating to ascertain that a grass near Lismore was indeed of pre-European origin. Stubbs (2001), through a search of 19th century surveyors' plans, identified 56 'grasses'. Most were near the western and northern boundaries of where the Big Scrub is believed to have been. They ranged from less than 10 to over 200 ha in size, and were found in two positions in the landscape: on creek and river flats, and on the high ground of hilltops, ridges and spurs. Most appear to have had some tree cover (eucalypts, casuarinas) over a grassy understorey.

As Stubbs (2001) points out, similar areas are found in south-east Queensland's Bunya Mountains (known as 'balds') and in north Queensland's Atherton Tablelands ('pockets'). Although little is known about Aboriginal use of the northern NSW grasses, both the balds and the pockets are known to have been frequented by Aboriginal people. Stubbs (2001) speculates that these areas may have been relictual habitats from the last ice-age. The fact that they did not join the surrounding rainforest vegetation might be attributable to environmental factors such as soil type, but might also owe something to human activity.

Stubbs (2001) also used historical records to ascertain grass composition in the northern rivers area in the early years of European settlement. He concludes that swamp foxtail (*Pennisetum alopecuroides*) dominated floodplain grassy areas. Kangaroo grass (*Themeda australis*) "was plentiful in many places in coastal districts" (Stubbs 2001:12), and probably dominated the understorey of the upland 'grasses'. Blady grass (*Imperata cylindrica*) was also common in the area. Nineteenth century sources indicate that annual burning was employed to render grasses palatable to domestic stock.

2.4 Discussion of studies

In this section local studies and Keith's comments on fire in local vegetation types are discussed and contextualised. Fire ecology studies in Australian temperate and subtropical grassy woodlands are in their infancy: we are fortunate that two of the small number that do exist have been carried out in Northern NSW. 'Context' therefore draws on studies in similar vegetation elsewhere, as well as on the observations of ecologists and land managers. The discussion initially focuses on shrubs, then moves to herbs.

Kitchin and York present pictures of relatively stable plant and animal communities. York's study, in particular, found remarkably few differences between areas which were believed to have experienced very frequent burning, and areas where fire was assumed to have been infrequent. It is possible that differences in fire frequency between York's categories were not so great as anticipated. As noted above, grazing indicators, rather than fire history, were used to distinguish grazed-and-burnt from ungrazed-and-unburnt areas. Mean litter depth did not differ between grazed and ungrazed sites (York

1998), suggesting that the use of fire might not have been dissimilar in the two treatments. If this were indeed the case, either grazing-related fires had not occurred at as high a frequency as initially believed, or a high frequency of fires was common throughout the area. Either way, a diverse flora and fauna was supported irrespective of management. For example an average of 36 and 34 beetle species per 0.1 ha was found in grazed and ungrazed plots, respectively (York 1999b).

Kitchin, too, found relatively few significant differences between her treatments, which this time directly reflected fire history. Keith's account of Kitchin's work could be interpreted as suggesting that burning in gorge forests, unless very infrequent, is likely to be harmful. However Kitchin's data do not, in my opinion, support that interpretation. Her findings for woody plants suggest, if anything, that *moderate* interfire intervals (2-4 fires in 25 years) may be associated with the greatest abundance of shrubs. Longer intervals tended to favour a number of woody species, particularly soft-leaved shrubs, as well sedges and rushes. However some shrub species were only found where a very short interval had occurred, and grasses were most abundant under these circumstances. Note that Kitchin's fire regime categories were based on *mapped* fires, while "field observations suggested that the absolute value of fires for the study period per area was an underestimate" (Kitchin 2001:79). This point reinforces the argument that moderately frequent fire is unlikely to be detrimental to shrubs in gorge forests.

Kitchin's findings in relation to shrubs have common ground with those of a recent study into the effects of fire frequency in Cumberland Plain Woodland (Watson 2005). Cumberland Plain Woodland, which once dominated rain-shadow areas between Sydney's coastal sandstone plateaux and the Blue Mountains, forms part of the Coastal Valley Grassy Woodland formation (Keith 2004) under discussion here. Species richness and abundance of fire-cued, sclerophyllous shrubs on the Cumberland Plain were greater where fires had occurred once or twice a decade, than in either very frequently burnt areas (intervals mostly 1-3 years) or where the last interfire interval exceeded 20 years. The T-species *Bursaria spinosa*, however, was considerably more abundant where fire frequency had been low. It is likely that T-species also form part of the non-eucalypt woody plant flora in Northern Rivers grassy woodlands and forests. Logically, one would not expect establishment of species with rainforest or vine scrub affinities to be cued to fire, and a south-east Queensland study across rainforest/eucalypt forest ecotones confirmed that seeds in the rainforest did not, in general, respond to smoke or heat cues (Tang *et al.* 2003). Thus soft-leafed shrubs in eucalypt forests and woodlands may well have the ability to establish between fires. This is indeed the case, according to the NSW Flora Fire Response Database (DEC 2002), for at least two species found only on Kitchin's "Moderate Long Long" plots: *Trochocarpa laurina* and *Elaeocarpus reticulatus*. Like Bursaria, these T-species probably benefit from long periods without fire, although their propensity to dominate the landscape may not be as great.

One T-species of concern in the Northern Rivers context is the exotic shrub *Lantana camara*. Local DEC ecologist John Hunter reports that lantana is moving into dry forests in the NPWS estate at an alarming rate. From observation of the effects of unplanned fires, John believes that fire may have a role to play in limiting the spread of lantana. This species may operate like African Olive, a major woody weed of woodlands around Sydney. Olive seedlings germinate between fires from bird-dispersed seeds. Once established, they resprout after a fire, however small plants are killed. Relatively frequent fire has the potential to reduce Olive incursion, although some hand removal might still be needed (von Richter *et al.* in press). Local ecologist and bush regenerator Tein McDonald (pers. comm. 2005) also believes fire can play a role in lantana control. She has successfully used a combination of fire followed by other weed control techniques to remove Lantana from

North Coast sites. In one situation, fire killed many plants, particularly in areas without rocks. Seed was stimulated to germinate, providing an opportunity to reduce the lantana seedbank through eliminating seedlings. Land managers around Brisbane also report success in using fire, particularly relatively intense fire, to retard lantana (Paul Donatiu, David Kington, pers. comm. 2005). Few Australian studies have assessed the effects of a sequence of fires on lantana, or any weed species, for that matter. One exception is a study by Russell and Roberts (1996) in Blackbutt forest in south-east Queensland. These researchers assessed the effects of four low-intensity fires in a 14 year period against an unburnt control. Lantana density increased more rapidly in the unburnt area, although this trend was not significant.

Neither Kitchin nor York provide a detailed analysis of herb dynamics, although Kitchin notes a shift from grasses to sedges with decreasing fire frequency. Although Watson (2005) found no differences in native herb species richness between sites with differing fire histories, herb species composition was significantly affected by overstorey cover: open areas supported a somewhat different suite of ground layer species than patches around trees or under Bursaria bushes. Fire frequency therefore indirectly affected ground layer floristics through its influence on the shrub layer.

The work of McIntyre and Martin (2001) in south-east Queensland's Brisbane River Valley confirms that plant diversity in grassy vegetation can be high in regularly burnt areas. These woodlands, which are burnt for green pick, have considerably higher native species richness than Tablelands sites. Fire frequency is one of several factors which may help explain these findings (McIntyre and Martin 2001).

It is sometimes suggested that bracken and blady grass increase with frequent burning at the expense of tussock grasses. As noted above, Keith (2004) mentions the propensity of blady grass, and two additional grass species, *Aristida ramosa* and *Cympopogon refractus*, to dominate under a regime of frequent fire and grazing. However empirical support for the role of fire in this scenario, at least in dry forests, is not easy to find. York (1999b) gives abundance figures for individual species in an Appendix to his study. On mixed sediments, blady grass occurred in seven of the eight plots in each treatment; average abundance was slightly higher in ungrazed/unburnt areas. Blady grass was also more abundant on ungrazed plots, on average, on sandstones and carbonate sediments. *Aristida ramosa* was only found on 6 of 64 plots (there were 32 plots in each treatment), three of which were ungrazed. *Cymbopogon refractus* occurred on 17 ungrazed, and 13 grazed plots. Bracken was also found on 17 ungrazed plots, but only on 12 grazed ones. In a study in dry sclerophyll woodland/forest on the nearby Tablelands, neither bracken nor blady grass showed a significant association with either time-since-fire or fire frequency (Watson and Wardell-Johnson 2004). Both species were in fact found in a lower percentage of plots burnt at least twice in the nine years prior to the most recent fire, than in plots whose last interfire interval had been at least a nine years (Watson 1999). In Cumberland Plain Woodland, percent dominance of *Aristida* species was not related to fire frequency (Watson 2005). However greater cover of both blady grass and bracken in more, relative to less, frequently burnt areas was recorded in *wet* sclerophyll forest on the Northern Tablelands by Tasker (2002), although the tussock grass *Poa sieberiana* still dominated the ground layer in frequently burnt sites. The findings of Tasker's study are explored in more detail in Section 3.3.

Grass dynamics in relation to fire have been studied experimentally in South Africa. Fynn *et al.* (2004) report a 50 year experiment in savanna country located at approximately the same latitude as northern NSW, in a summer-rainfall area with mild winters. Precipitation is slightly lower (700mm per annum) than in the Northern Rivers grassy forests and woodlands under discussion here, however *Themeda triandra/australis* is an important species in both communities. Plant dynamics are thus likely to be similar in the two environments. This study, which included burning treatments at 1, 2 and 3 year intervals, as well as mowing, concluded that some form of disturbance was needed to maintain grass species richness, which dropped dramatically in undisturbed sites. Forb richness was similar across disturbance regimes, though forb composition in frequently burnt areas was quite different to that in plots where fire had been excluded. Uys *et al.* (2004), in a survey of the same plots, confirmed that unburnt and burnt plots supported different suites of species. This pattern was also found in two other grassland/savanna environments in South Africa. Uys *et al.* (2004) found that the cover of bunch grasses, particularly *Themeda*, was high where fire was frequent, including after many years of annual burning. Cover of sod-forming grasses was higher where fire had been excluded or where fire frequency was low.

Themeda australis is of particular interest because it may be one of a small number of temperate woodland understorey species able to compete successfully against exotics (Cole and Lunt 2005). Recent work in White Box woodlands suggests that *Themeda* may regulate nitrogen to the advantage of native perennials over exotic annuals (Prober *et al.* 2002b, 2004). Watson (2005) found a significant negative correlation between *Themeda* abundance and species richness of exotic herbs in Cumberland Plain woodland, while Morgan (1998d) reported similar findings for Victorian grassland. *Themeda* apparently dominated large areas of temperate and subtropical Australia prior to European settlement (Prober and Theile 1993, Nadolny *et al.* 2003, Prober and Theile 2004); Stubbs' findings (Stubbs 2001) confirm its importance in the Northern Rivers region.

Several Australian studies have documented a decline in abundance and vigour of *Themeda australis* with increasing time-since-fire (Robertson 1985, Morgan and Lunt 1999, S. Clarke 2003), again suggesting that relatively frequent fire benefits this species. On the Cumberland Plain, *Themeda* dominated high and moderate, but not low, fire frequency sites (Watson 2005).

In the dry forests of north-east NSW, *Themeda* appears to tolerate a fairly wide range of conditions: it was found on 22 of 32 grazed/burnt plots in York's study (York 1999b), and 16 of 32 ungrazed/unburnt ones. In Kitchin's study, *Themeda* cover was high across all fire frequency categories (Kitchin 2001). These findings, together with those above, strongly suggest that this species is not adverse to frequent burning – and equally, that it does not rapidly disappear when fire frequency drops. It is possible, however, that an extreme regime of annual burning may disadvantage this species in eastern Australian woodlands, although this in not the case in South Africa. Studies in Australia have found that *Themeda* flowers somewhat later than many other ground layer species (Lunt and Morgan 2002, Watson 2005), suggesting that seedset might be precluded by annual burns.

If annual burning did indeed disadvantage *Themeda* in the Northern Rivers, blady grass might become more prominent, explaining the observations noted above. Alternatively, blady grass may dominate where kangaroo grass has been grazed out, giving the impression of a fire effect.

The dominance of kangaroo grass and the lack of shrubs in Stubbs and Boyd's 'grasses' suggest that these areas may have been burnt quite frequently under Aboriginal management. Fensham and Fairfax (1996) analysed a range of possible causative factors for the Bunya Mountains 'balds', which they found had been shinking in size due to forest encroachment. They found little support for the hypothesis that balds were maintained by intrinsic physical conditions, and concluded that firing by Aboriginal people was likely to have been the major influence.

The relative stability of Northern Rivers grassy forests and coastal grassy woodland suggests they can be classified as 'climate limited but fire modified' (Bond *et al.* 2003, 2005; see Section 1.4). Abundance of both shrubs and grasses seems to vary with fire frequency, however wholesale succession to a more mesic vegetation type has not been documented in Northern NSW[6]. Most plants and animals maintain their presence in the community over a range of fire regimes. Some life-forms and species do particularly well when fire frequency is high, others where it is low.

2.5 Existing fire regime guidelines

The south-east Queensland guidelines group woodlands and dry sclerophyll forests together, then distinguish between grass and shrub understorey (Watson 2001a). The guideline reads:

> "Appropriate fire frequency for dry sclerophyll forests and woodlands depends on the nature of the understorey. Fires at a range of intervals between 3 and 6 years are suggested for areas which support a grassy understorey. Fires at a range of intervals between 7 and 25 years are suggested for areas which support a shrubby understorey. The variable fire intensity and season which is likely to result from a mix of planned burns and wildfire should be appropriate for maintaining biodiversity in this forest type" (Watson 2001a:25).

The south-east Queensland guidelines were developed through synthesis of information from published and unpublished ecological research, both local and pertaining to similar vegetation elsewhere in eastern Australia, and through consultation with local ecologists and land managers (Watson 2001b).

The DEC guidelines distinguish "sclerophyll grassy woodland" from "dry sclerophyll shrub/grass forest." Suggested thresholds for vegetation in the first category are 5 and 40 years, with the proviso that "occasional intervals greater than 15 years may be desirable." For dry sclerophyll shrub/grass forests, thresholds are 5 and 50 years, and "occasional intervals greater than 25 years may be desirable" (Kenny *et al.* 2004:34).

In their guidelines for North Coast vegetation types, Chiswell and Redpath (2004:6-7) suggest thresholds of 3 and 6 years for sclerophyll grassy woodland, noting that "fires at these intervals should maintain a grassy understorey." An interval range between 3 and 25 years is recommended for "dry sclerophyll shrub/grass forest." Chiswell and Redpath (2004:7) include a spatial component in their guideline: "to maintain a shrub/grass understorey, it will be necessary to promote a fire regime where there is a mosaic of areas, with burns in the 3 – 6 year range and other areas closer to the 25 year fire interval."

There is thus considerable variation in recommendations, particularly with respect to grassy woodlands[7].

2.6 Discussion of fire regime guidelines

In the text accompanying their recommendation for grassy woodlands, Kenny *et al.* (2004:40) note that differences of opinion exist over fire management in grassy woodland vegetation. They present a number of arguments for the long intervals they advocate, and note that management issues are similar in dry sclerophyll shrub/grass forests (Kenny *et al.* 2004:42).

Kenny *et al.* (2004:40) first dismiss the need to consider ground layer dynamics on the basis that tree canopies reduce the competitive advantage of dominant grasses,

[6] See, however, Cromer and Pryor (1942) for a description of rainforest encroachment into *Eucalyptus maculata* woodland near Gympie in south-east Queensland.

[7] Note that both the NSW and south-east Queensland fire frequency recommendations are intended to be read in the context of additional guidelines, for example about variation of inter-fire intervals in space.

allowing forb species richness to remain high. They cite Prober *et al.* (2002a), who did indeed find increased herb species richness under trees in Box woodlands on the NSW Western Slopes. However recent work suggests that this may not be the case in subcoastal grassy woodlands, at least in Western Sydney. Watson (2005) found no significant difference between microhabitats in native herb species richness; this variable was in fact somewhat lower under trees. Similarly, no significant differences between microhabitats were detected when the species richness of the two major subgroups of ground layer plants – native forbs, and native grasses and graminoids[8] – was examined. In particular, patches round trees showed no trend towards either a higher richness of forbs, or a lower richness of grasses and graminoids. Mean forb species richness was in fact highest in open patches. Abundance measures also failed to detect a difference between microhabitats. 'Under tree' microhabitats did differ from open patches, however, in having a significantly greater amount of leaf litter. In the early post-fire years, the bare ground necessary for herb establishment was thus more common beyond canopies. Thus 'under tree' habitats do not appear to provide a haven for forbs in at least one coastal grassy woodland variant.

In addition, research into woodland microhabitats suggests that forbs under trees may not be the same ones at risk of being outcompeted by tussock grasses. In Watson's study, herb composition varied between microhabitats, a finding echoed by researchers elsewhere (Chilcott *et al.* 1997, Gibbs *et al.* 1999, Facelli and Temby 2002). *Themeda* tends to be more abundant in open patches than under trees (Robertson 1985, Prober *et al.* 2002a, Watson 2005), as are a number of native lilies (Gleadow and Ashton 1981, Costello *et al.* 2000, Watson 2005). It may be that fire plays a somewhat different role in mediating ground layer diversity in open woodland patches than it does under trees. In open areas, grass/forb interactions may be similar to those in grasslands; under trees, the mulching effects of litter may be more of an issue for herb growth and reproduction. Somewhat different suites of species may be involved in each environment.

Kenny *et al.* (2004) also argue that recurrent short intervals do not allow new cohorts of canopy and shrub species to reach maturity. With respect to trees, Watson (2005) found no significant differences between fire frequency categories in tree density or basal area, nor in the abundance of juveniles or saplings. Trends suggested that both frequent fire, and intense fire (which may tend to occur where fire has been excluded and fuel has built up) reduce the number of juveniles 'getting away' into the canopy. However as eucalypts are long-lived, replacement of canopy trees does not need to occur very often. Adult tree density on the Cumberland Plain appeared to be limited by soil factors, not fire. Savanna eucalypts are also unaffected by frequent low intensity fire (Liedloff *et al.* 2001, Russell-Smith *et al.* 2003, Woinarski *et al.* 2004). With respect to shrubs, there is indeed evidence that recurrent short intervals will reduce shrub density. It is, however, important to define 'short'. In Kitchin's study, sites with 2-4 fires in 25 years supported a good shrub flora. In Watson's study, while 1-3 year intervals were associated with reduced shrub abundance, shrubs were most diverse and abundant on sites which had burnt once or twice a decade (Watson 2005).

Finally, Kenny *et al.* (2004) contend that "While intermediate fire intervals may allow a shrub layer to 'invade', longer fire intervals can see senescence of these shrubs returning the system to a predominantly grassy one." While short-lived, fire-cued shrubs may indeed die out after many years without fire, longer lived species and those that can recruit between fires, such as Lantana and Bursaria, are unlikely to disappear. In the Cumberland Plain Woodland study, the site with the longest interfire interval (approximately 50 years) had by far the highest abundance of Bursaria (Watson 2005); this shrub dominated the entire landscape, leaving few

[8] Graminoids are grass-like plants, generally sedges and rushes.

open patches. Studies in woodland ecosystems elsewhere in eastern Australia have also found the density of 'invasive' T-species continuing to increase with time-since-fire (Lunt 1998a,b; Emeny 2005). Even if shrubs did die out after a very long period of fire exclusion, by this time the ground layer would likely be greatly changed. For example in the long unburnt site mentioned above, *Themeda* abundance was very low. And relative to frequently burnt sites, herbaceous exotics were common (Watson 2005).

In setting the upper threshold at 40 years, Kenny *et al.* (2004) bypassed species in their 'most sensitive' category with lifespans of 10, 20, 30 and 35 years, because these estimates were considered dubious (Section 1.3). Although lifespan data do have a high degree of uncertainty, the longevity chart presented by Kenny *et al.* (2004) suggests some species may decline considerably in the face of inter-fire intervals well below 40 years. Watson's findings indicate this may be the case for short-lived obligate seeder shrubs in Western Sydney's grassy woodlands (Watson 2005), while the long-term South African experiments described above identified herbaceous species which did not survive where fire was excluded.

In summary, although there are valid reasons for ensuring very short intervals are not constantly employed in woodlands and dry forests, the case for extremely long intervals in dry grassy vegetation is considerably less convincing. Rather, there are good arguments and evidence to suggest that a frequency of one or two fires a decade is compatible with retention of a diverse and abundant shrub flora. There are also arguments and evidence to suggest that long intervals may change ground layer composition, increase weeds and risk the capture of resources by one or a small number of T-species.

The south-east Queensland guideline for grassy woodlands and forests (variable intervals between 3 and 6 years) was based on the literature available at the time. As little research into the effects of fire in Australian subtropical or temperate grassy woodlands had been published at that point, Watson (2001a) drew on work from Victorian grasslands and, to a lesser extent, on savanna research. More directly relevant information is now available, in the form of the studies discussed above.

This recent research suggests that some interfire intervals greater than six years in **woodlands** are unlikely to have a deleterious effect on ground layer plant species or dry forest fauna, and will probably benefit shrubs.

On the other hand, some woodland fauna species may depend on resources available as a result of frequent burning (eg abundant and flowering grasses, open areas for foraging). Short intervals may also be important to prevent woody weeds such as Lantana and Olive from establishing or expanding, and may even have the potential to reduce their abundance. Tein McDonald (pers. comm. 2005) believes some short intervals (eg 3 years) may also be beneficial on grassy ridges in sandstone country near the coast to reduce the density of wattles which germinate in large numbers when a fire occurs after a long period. This would help maintain some parts of the landscape as open habitat, and also break up the fuel load making it less likely that bushfires will burn right through refuge areas. Some longer intervals in this ridgetop grassy forest would ensure wattles were maintained in the landscape.

On the basis of her findings in Cumberland Plain Woodland, Watson (2005) suggested that fires at 4 to 12 year intervals should allow fire-cued shrubs, a diverse range of forbs and some Bursaria thickets to co-exist long term. In the warmer, wetter environment of the Northern Rivers, thresholds to achieve a similar outcome should probably be somewhat lower, as plant growth will occur more rapidly. Variable intervals between 3 and 10 years are suggested for Northern Rivers Coastal Valley Grassy Woodlands.

In **grassy dry forests**, some longer intervals are probably appropriate, to provide opportunities for mesic shrubs and late successional fauna. Again, however, the need to ensure habitat for early successional species, and to limit woody weeds, must be considered. Chiswell and Redpath (2004) have wisely suggested that it may not be possible to maintain the wide range of habitat needed only through varying intervals in time. Rather, their guidelines recommend implementing regimes which favour open grassy areas in different parts of the landscape to regimes favourable to shrubs. This approach is supported, as it recognises the shifts in species composition typical of climate-limited but fire-influenced communities (eg Vanderwoude *et al.* 1997a, Hannah *et al.* 1998[9]). Similar recommendations have recently been made for grassy woodland/savanna vegetation elsewhere (Uys *et al.* 2004, Woinarski *et al.* 2004).

Where the aim is to retain an open grassy understorey, 3-6 year intervals seem appropriate. However local research suggests that intervals conducive to a diverse native shrub flora in dry forests may be nearer to 6-15, than to 25, years. Intervals above 15 years may have their place in limited parts of the landscape, as they will provide particularly dense habitat for late successional fauna (though areas managed on moderate 6 to 15 year intervals should also do that). However long unburnt areas may be particularly prone to invasion by lantana, and should be monitored. In times past, dense habitat may have been concentrated in wetter gullies rather than being scattered throughout the landscape. Modern fire management would also do well to consider topography, slope and aspect when deciding which dry forest areas to burn frequently, and which to manage on longer intervals. Ridges, north-facing slopes and wide valleys may be the 'natural' place for open areas, while gullies and south-facing slopes may tend to support the more mesic plant species which will benefit from longer intervals between fires.

A similar 'spatial' approach may also be appropriate in grassy woodlands. Areas managed on short intervals (3-6 years) may play an important role in providing habitat for some fauna species. Longer intervals (6-10 years) should benefit shrubs and late-successional fauna.

2.7 Summary recommendations

Northern Rivers sclerophyll grassy woodlands: An interval range between 3 and 10 years is recommended. Some areas should be managed on short intervals (3-6 years) while others are managed with variable intervals including some towards the top of the range.

Northern Rivers dry sclerophyll shrub/grass forests: An interval range between 3 and 25 years is recommended. It is suggested that some areas (eg ridges, wide valleys, north-facing slopes) be managed on short intervals (3-6 years) to retain an open grassy understorey and to break up fuel loads to protect refuge areas from being burnt out in wildfires. Other parts of the landscape (eg gullies, south-facing slopes) should be managed for a higher density of shrubs. Intervals between 7 and 25 years, with an emphasis on 7 to 15 years, are suggested.

The recommendation that more than one vegetation 'state' should be maintained within a vegetation type raises questions as to the proportion of each state that may be desirable in the landscape. Effects of fragmentation may be relevant here. These questions are beyond the scope of this review. Hotspots hopes to address them, so far as it is possible to do so given what's known – and not known – in a later review of the spatial aspects of fire in the landscape.

2.8 Further research

Research questions whose answers would help refine fire regime guidelines for grassy woodlands and dry forests in the Northern Rivers region include:

- Does the Northern Rivers variety of Coastal Valley Grassy Woodlands

[9] These are fauna studies from a long-term experiment in spotted gum forest at Bauple in south-east Queensland.

react to fire exclusion in the same manner as its Western Sydney counterpart? In particular, does *Bursaria spinosa*, lantana or some other T-species shrub dominate the landscape in the absence of fire?

- More generally, can trends in the fire-related dynamics of the State's woodland and dry forest ecosystems be systematically related to productivity, and to gradients in substrate and climate? To what degree is the shrub/grass balance a function of fire frequency vis-à-vis substrate?

- Can a series of short interfire intervals retard or reverse lantana encroachment? Different numbers of fires (eg 1 to 4 fires) could be experimentally tested, along with several different short intervals (eg 1, 3 and 5 year intervals). How are native flora and fauna affected? Can one or two longer intervals reverse any negative effects? Can post-fire herbicide treatment play a useful and practical role in reducing lantana? Do effects differ with vegetation type? Do effects differ with fire intensity?

- What mammals and birds are associated with different vegetation states in Northern Rivers grassy dry sclerophyll forests? Can these states be adequately sustained in the landscape through varying interfire intervals in time, or is conscious variation of fire frequency across space also necessary?

3 Grassy wet sclerophyll forests

3.1 Introduction

Grassy wet sclerophyll forests are "Tall forests dominated by straight-trunked eucalypts, with mixed grassy understories and sparse occurrences of shrubs with broad soft leaves" (RFS 2003). Sometimes called semi-mesic grassy forests, or wet sclerophyll forest (grassy subformation), they typically occur in coastal areas where rainfall is high and soils are moderately fertile.

These forests are thus similar in structure to the grassy dry forests discussed in the last section, however their shrubs are more likely be mesophyllous. Huston's Dynamic Equilibrium Model suggests that competitive interactions will be an important feature of these forests. High rainfall and fertile soils mean grassy wet sclerophyll forests are likely to be even more productive than dry sclerophyll forests and woodlands. Plants will grow more quickly, and competition dynamics are likely to come into play earlier. The tendency for grassy wet forests to succeed to rainforest in North Queensland (Unwin 1989, Harrington and Sanderson 1994, Russell-Smith and Stanton 2002) indicates that major changes can occur in at least some parts of the range of this broad forest type.

3.2 Keith vegetation types

Keith (2004) divides NSW wet sclerophyll forests into two subgroups according to the nature of the understorey. Two vegetation types in the 'grassy subformation of wet sclerophyll forests' occurring in the Northern Rivers region are described below. Both have been the subject of considerable research over recent years.

- **Northern Hinterland Wet Sclerophyll Forest**. This formation occurs below 600m where rainfall exceeds 1000mm per annum. Soils are moderately fertile loams on slopes and ridges (Keith 2004). These forests have "a prominent grassy ground cover below an open layer of both mesophyllous and sclerophyllous shrubs," and a history of seasonal grazing and burning. Keith contends that "There is ecological evidence that frequent burning and grazing has led to a simplification of the understorey in the grassy wet sclerophyll forests, and some of the dry sclerophyll forests that have been managed in a similar fashion (Birk and Bridges 1989; York 1999[a]). In particular, the frequent removal of plant shoots seems to favour species with rhizomes, such as *Imperata cylindrica* var. *major* (blady grass) and *Pteridium esculentum* (bracken), which occur in high densities possibly to the exclusion of smaller herbaceous species. Conversely, livestock may impose heavy losses on the palatable seedlings of shrubs that germinate after each fire. The short interval between successive fires also limits the amount of seed that can be produced by shrubs, which take longer to mature than grasses and herbs. When these pressures are maintained over several fire cycles, loss of plant diversity and simplification of the understorey structure seem to be inevitable (Birk and Bridges 1989), and in turn have cascading effects on communities of forest birds and invertebrates (Woinarski 1999; York 1999[a])." (Keith 2004:70).

- **Northern Tableland Wet Sclerophyll Forests** occur on the Tablelands above 800m. Here, "shrubs are conspicuously sparse, but where present include some sclerophyllous species. The ground flora includes a high diversity of grasses and herbs, which form an almost continuous cover." Seasonal burning and grazing also occur in this formation. Keith (2004:74) cites Kitchin (2001), Henderson and Keith (2002[a]), and Tasker (2002): "sites exposed to heavier grazing and/or more frequent fire generally have a lower diversity of shrub species, lower abundance of individual shrubs, and a more open understorey structure than less disturbed sites."

3.3 Northern Rivers studies

Keith (2004) cites Birk and Bridges (1989) and York (1999a) to support the argument that frequent burning in grassy Hinterland WSF is detrimental. On the Tablelands, he notes the work of Kitchin, and that of Meredith Henderson and Elizabeth Tasker. These studies are outlined below, along with additional work which complements that of York (1999a).

Hinterland forests

Birk and Bridges (1989) studied plots allocated to one of three fire regime treatments – a burn every 2 years, a burn every 4 years, or fire exclusion – over a 20 year period. These authors report differences in structure between burnt and unburnt plots: with burning, "the tall woody shrubs such as *Allocasuarina* and *Lantana* [were] replaced by grasses." This assessment is based on observation not data: Birk and Bridges (1989) did not survey vegetation, as their study focused on fuel accumulation.

York (1999a) did measure vegetation structure, on experimental plots burnt every three years for 20 years, and on plots unburnt during that time, in blackbutt forest at Bulls Ground near Port Macquarie. Sampling on burnt plots took place two years post-fire. Cover assessments were based on vegetation height classes, not plant life-forms. "Cover of ground herbs" (vegetation 0-20cm tall), "small shrubs" (vegetation 20-50cm) and "mid-sized shrubs" (50-100cm) were all greater in burnt plots, but not significantly so. The "tall shrub layer" (100-150cm), and the "very tall shrub layer" (150-200cm) returned considerably higher readings in unburnt plots; these differences were significant (York 1999a).

York's study was primarily concerned with terrestrial invertebrates. His report (York 1999a) presents a detailed and rigorous analysis of the effects of the two fire regimes described above on invertebrate abundance, species richness and community composition. Analysis focused primarily on five groups: ants, beetles, spiders, bugs and flies. Overall 'morphospecies' richness[10] was identical in the two treatments (279 morphospecies were collected from each), and mean subplot richness was very similar (46.5 on burnt plots, 48.2 on unburnt plots). However individual groups showed a variety of responses to the two treatments, as did subsets of species within them. At subplot level, there were less fly and beetle morphospecies where burning had occurred, but numbers of bug, spider and ant morphospecies were higher. These results were significant for flies, beetles and ants. Community composition also varied within groups depending on fire treatment, with large numbers of species appearing only, or mostly, in one treatment or the other. In some cases differences in species composition could be linked to habitat features characteristic of the two fire regimes. For example plant-eating bugs, flies and beetles were considerably more abundant on burnt plots, reflecting the dense ground-layer vegetation in these areas, while flies and ants known to feed in the litter layer were more common on unburnt plots. On the other hand, litter-feeding spiders were mostly found on burnt plots.

A second report of findings from Bulls Ground (York 2000) focuses on ants. This article covers both the results for ants of the study reported in York (1999a), which used

[10] Morphospecies are groups of organisms that belong to at least the same taxonomic class and order, and that look very similar.

pitfall traps, and further work on the same plots carried out several years later – but also two years post-fire in frequently burnt plots – based on litter samples. Litter was more abundant on the unburnt plots, and it contained more ant species than the burnt plot litter, though differences were not significant. Groups of species unique to each habitat were identified in each study, as was a substantial group that occurred on both burnt and unburnt sites. York (2000) concluded that a variety of management strategies, from fire exclusion to frequent burning, would be needed in the forests of the region to maintain the full complement of ant species.

Andrew *et al.* (2000) also studied ants at Bulls Ground. This investigation, two years after the study reported in York (2000), surveyed leaf litter near and away from logs. Burnt plots were four years post-fire[11]. This time, slightly fewer ant species were found in the unburnt plots (33 species) than on the burnt ones (36 species), however there were no statistical differences between the two burn treatments in either the abundance or the species richness of the ant fauna. Community composition did not differ greatly between habitats; open areas in burnt sites had the most distinctive ant assemblages. Habitats were not, in general, distinguished by differences in the abundance of the various ant functional groups, with one exception: subdominant ant species were only found in the burnt area. The authors concluded that, four years post-fire, no adverse effects of burning on ant diversity could be discerned, that management should aim to maintain a range of burn frequencies, and that retained logs in frequently burnt areas could contribute to invertebrate conservation.

York (1999a) did not assess the abundance or species richness of plants, and no detailed analysis of above-ground vegetation at Bulls Ground has yet been published. However some indication of the effects of the two burning regimes on plant species can be gathered from a study by Ben Stewart, carried out when the burnt plots were seven years post-fire. Stewart (1999) focused primarily on soil seed banks, though he also reports some information on above-ground vegetation. The seeds of two plant groups, graminoids (sedges and rushes) and shrubs, were significantly more abundant in the long-unburnt plots. Seedbank shrub species richness was also significantly higher under this treatment, although overall seedbank richness was identical in the two treatments, with 44 species found in the seedbanks of each. Herbs and grasses were less abundant but more species rich in frequently burnt sites, however these findings were not statistically significant.

While no statistical analysis is given, Stewart (1999:75) reports that the species richness of the above-ground vegetation was higher in frequently burnt plots. Species found in each treatment are listed: 66 species were found in both treatment areas, 21 only where fire had been excluded, and 36 only in frequently burnt plots. Six of these 36 species emerged from the unburnt soil, leaving 30 plant species which had apparently disappeared from both the above and below-ground vegetation in infrequently-burnt plots. Species found only in unburnt plots included several graminoids, and broad-leafed shrubs and trees. Species found only in burnt plots included grasses, forbs and shrubs whose germination is cued to fire. Recent as yet unpublished work on the Bulls Ground plots confirms this pattern. Doug Binns (pers. comm. 2005) reports that where fire has been excluded, a thick subcanopy of *Syncarpia glomulifera* now exists, particularly in wetter areas. Unlike the burnt sites, unburnt sites have very little grass; Doug speculates this may be due as much to shading and increased competition for moisture between the dense shrub/small tree layer, and grasses, as to the direct effect of fire exclusion.

[11] Burning of the Bulls Ground 'burnt' plots ceased after 1992 but has since recommenced (Doug Binns, pers. comm. 2005).

Tableland forests

We move now to Tablelands studies. Kitchin's work in the second of her two Guy Fawkes River National Park environments is relevant here (Kitchin 2001). Woody plant species richness was lower in Tablelands sites which had experienced six or more fires in a 25 year period, or where at least one interfire interval of 1-2 years had occurred, than in either long unburnt sites or in vegetation exposed to moderately frequent fire (2-4 fires in 25 years) and relatively long interfire intervals. These differences were statistically significant. However only one of 18 species tested (*Pimelea linifolia*) had a statistically significant relationship with interfire interval, and that relationship was positive – ie more fires, more *Pimelea*. Two shrubs (*Polyscias sambuccafolia* and *Olearia oppositifolia*) decreased in abundance as the shortest interfire interval decreased, while another (*Hibbertia obtusifolia*) increased. Multivariate analysis of the shrub data indicated significant effects on community composition for number of fires, length of shortest interfire interval, and time since fire. Total woody plant abundance differed significantly with fire regime category: it was considerably higher in recently-burnt sites which had experienced 2-4 fires in 25 years, with no short interfire intervals, than in either long-unburnt sites, or where interfire intervals had been short. This pattern held for shrubs 2-10m, and for shrubs under 2m. Very frequently burnt sites had very few shrubs.

Kitchin's Tablelands survey sites had a high diversity of ground layer species. Again, data are presented but statistical analysis limited to community composition. Multivariate analysis revealed a cluster of herbaceous species associated with the mid-range on most variables but with a tendency towards higher number of fires. Length of shortest interfire interval had a significant association with herb species composition. Grass cover was greatest where fire frequency was high, and/or where at least one very short interfire interval had occurred, and grass species richness was highest in very frequently burnt sites. Sedges and rushes were more abundant where fire had not occurred for a long time and where interfire intervals were relatively long. Tussock grasses *Themeda australis, Poa sieberiana* and *Sorghum leiocladum* dominated high fire frequency sites.

Henderson and Keith (2002a) also researched the effects of disturbance in grassy Tablelands forests in Guy Fawkes River National Park. They limited their study to 'dells'; flat areas near headwater creeks. Only the shrub component of the vegetation was assessed. While number of fires was used as a variable in multivariate analyses, scarcity of records limited the authors' confidence in its accuracy. Site selection was based on a composite index of grazing indicators (eg presence of cow pats, dams, fences): sites were classified as 'more' or 'less' disturbed depending on how many grazing indicators they possessed. Multivariate analysis indicated that disturbance alone accounted for 15% of the variation in adult shrubs, although this figure rose to 45% when variance shared with other variables was included. Grazing indicators accounted for much of the disturbance-related variance. When fire frequency was entered as a separate variable, it accounted for 2.5% of total shrub variation. 'More' disturbed sites had significantly fewer shrub species per 20x20m quadrat (mean values were 4.2 and 5.9), and shrub density was considerably lower, averaging 37 plants per 400m^2 in 'more' disturbed, and 98 plants in 'less' disturbed quadrats.

As well as surveying areas with differing numbers of grazing indicators, Henderson and Keith (2002b) established experimental plots to examine effects of fire and grazing, singly and in combination, in several 'dells'. Changes over time in species richness and abundance were monitored, though again only for woody species. Ten months post-fire, no significant differences between treatments could be discerned. Plant density, and numbers of woody plant recruits, were highest in plots which had been burnt but not grazed. These differences, however, were not significant.

Tasker (2002) studied plants, small mammals and invertebrates in Northern Tableland WSF south and east of Armidale. Some of her work involved a survey of a large number of sites (58) across a 1000km^2 area. More detailed survey work was conducted in 12 sites. Six of these 12 sites had been grazed and burnt in low-intensity 'green pick' fires at approximately 1-5 year intervals, while six were in ungrazed areas which had remained unburnt for at least 15 years.

Tasker (2002) found big differences in vegetation structure between sites in each grazing-cum-burning treatment: shrubs and small trees dominated the understorey in ungrazed sites (in general), while grasses dominated in grazed areas. This pattern held across both surveys. Analysis of the strength of the relationship between understorey structure and a range of environmental and disturbance variables in the 58-site study revealed that grazing practices, including burning, were having by far the greatest effect (Tasker and Bradstock submitted). Sites on a grazing lease where burning had occurred every 1-2 years had particularly low vegetation complexity scores.

However although grazed sites had a simplified structure, plant species richness was higher in the six grazed and burnt sites than in the equivalent unburnt areas in Tasker's 12-site study, at both quadrat and site scale (Tasker 2002). Species composition also differed considerably between the two treatments. Herbaceous species were particularly well-represented in the burnt plots, with many herbs found in these areas absent, or much reduced in abundance, in unburnt areas. On the other hand ungrazed/unburnt areas supported many more fern, climber, and small tree species than their frequently burnt counterparts. Many species in these groups were found only, or almost exclusively, in unburnt plots, and many of them had rainforest affinities.

Results for small mammals, from survey work on the 12 intensively-studied sites, are reported in Tasker and Dickman (2004). These authors found no difference in species richness in the two areas, though there were big differences in species composition. Bush rats (*Rattus fuscipes*) occurred in much greater abundance in the ungrazed and unburnt areas, and Brown Antechinus (*Antechinus stuartii*) also tended to favour these sites. However three species were caught only on the grazed and frequently burnt sites, and another mostly there – and these were rarer species, including the New Holland mouse (*Pseudomys novaehollandiae*) and the Hastings River mouse (*Pseudomys oralis*). Swamp Rats (*Rattus lutreolus*) were also more numerous on burnt sites.

Some of Tasker's invertebrate findings, again from the 12 intensively-studied sites, are briefly reported in Bickel and Tasker (2004). Again, community composition differed between grazed/burnt and ungrazed/unburnt areas, although there were no significant differences in the overall diversity of invertebrates caught in sticky traps placed on tree trunks. Invertebrates other than flies (Diptera) were significantly more abundant in grazed and burnt sites.

3.4 Discussion of studies

In the last few years, studies relating to the effects of fire in grassy wet sclerophyll forests have moved understanding forward considerably. We are fortunate, in the context of this review, that much of this work has occurred in the Northern Rivers region.

The studies described above present a coherent picture of a vegetation type strongly affected by fire. The picture is not, however, simply one of detrimental effects from frequent burning, and unmitigated benefits from long interfire intervals. While some groups of plants and animals do indeed appear to decrease in richness and abundance when burning is frequent, others increase in this situation – and decrease when fire is infrequent or excluded. This picture is familiar from the discussion of 'states' in previous sections. In this wetter, more productive vegetation type, differences between fire frequency categories are more pronounced than in the drier grassy forests and woodlands discussed in Section 2.

Results from Bulls Ground (Stewart 1999, York 1999a, 2000, Andrew *et al.* 2000) are particularly valuable in the current context, as this well-replicated experiment is local, and focuses directly on fire frequency without the complication of grazing which appears to have been unavoidable in a number of retrospective studies. Unusually, we know more about the effects of the two fairly extreme fire regime treatments at Bulls Ground on fauna, than we do about their effects on flora. The results for invertebrates clearly indicate that both very frequently burnt areas (3 year fire cycles), and long unburnt areas (20 years of fire exclusion), support an extremely diverse invertebrate fauna. These faunas differ substantially in composition but are similar in richness.

With respect to vegetation structure, York (1991a) found that unburnt plots had significantly higher cover values for shrubs over 100cm. Given that the fire-treated plots had burnt just two years previously, this result is unsurprising. Burnt plots, on the other hand, had greater cover in the three vegetation classes below 100cm. Thus by two years post fire, these plots were by no means devoid of cover. This cover, together with flowering and fruiting grasses, herbs and resprouting shrubs, appears to provide suitable habitat for many invertebrate species.

While we know less about plants than about invertebrates at Bulls Ground, what we do know suggests a pattern similar to that for invertebrates: both treatments support many species, but composition differs. While Stewart's soil seedbank findings are of interest, they need to be seen in context: only about a quarter of the plant species found in the above-ground vegetation were found in the seedbank (Stewart 1999). This finding is typical of grassy vegetation, as many herb and grass species do not have a permanent store of seeds in the soil (Lunt 1997c, Morgan 1998b, Odgers 1999, Hill and French 2003). Adding Stewart's findings to the little we know about the above-ground species complement suggests that plant diversity may be higher where burning has been frequent; that some species, particularly graminoids and soft-leaved shrubs do best where fire has been excluded; and that other species, particularly grasses, forbs and I-species shrubs, may be more diverse and abundant under a regime of fairly frequent fire.

These findings are consistent with both the vital attributes and the dynamic equilibrium models. Dominance of large, long-lived, T-species (the soft-leaved species which have increased in abundance over the years of fire exclusion in unburnt plots must be able to recruit between fires) in the absence of disturbance is predicted by Noble and Slatyer's (1980) model. A concomitant reduction in abundance of small, short-lived, light-loving species in the absence of disturbance is consistent with both models, while Binns' observation that grasses and forbs are affected by shading from thickening shrubs and small trees also points to the existence of competition in the absence of disturbance.

Research into fire in Tablelands wet grassy forests reinforces the picture presented by the Bulls Ground findings. Rainfall in Tablelands wet sclerophyll forests is similar to that in their Hinterland counterparts, however temperatures would be lower. Productivity may therefore be somewhat lower, particularly as winter frosts on the Tablelands will reduce the length of the growing season.

Looking first at plants: generally, frequent fire on the Tablelands was associated with a diverse grassy understorey, while areas subject to long interfire intervals or long periods without fire tended to carry more multilayered vegetation with a strong mesic/rainforest component. These differences were most apparent in Tasker's work (Tasker 2002), which highlighted both the high diversity of grasses and herbs in sites burnt every 1-5 years, and the relative dearth in these sites of the climbers, ferns and small trees which dominated unburnt areas. Henderson and Keith (2000a) found considerably fewer individual shrubs and fewer shrub species in less disturbed sites, although grazing contributed here as well as fire. Kitchin found fire impacts on composition of both shrubs and herbs, with greater numbers of shrubs – which in her study included various sclerophyllous species – in sites which had experienced some fire than in either long unburnt or very frequently burnt sites. Sites exposed to a high fire frequency were dominated by native tussock grasses, and length of shortest interfire interval influenced herb species composition. NPWS ecologist John Hunter (pers. comm. 2005) also studied the effects of fire frequency on herbs in upland forests [check], although findings are yet to be written up. He too found that herbs declined in long-unburnt grassy forest areas, and considers that both shading by shrubs, and a heavy litter layer, may be responsible.

In relation to animals, Tasker's results for both small mammals and invertebrates echo those for Bulls Ground invertebrates. Both frequently burnt and long unburnt areas supported particular suites of species, though species richness was similar. Tasker and Dickman (2004) point out that this finding "contradicts the prediction of Catling and Burt (1995) that eucalypt forest with fewer understorey shrubs would have fewer species of small mammals. In this study, moderately frequent disturbance appear[ed] to result in habitat suitable for early-mid successional species" (Tasker and Dickman 2004:733). In their discussion, Tasker and Dickman (2004) point out that the distribution of the two native mouse species found only in grazed and burnt sites corresponds with that of grazing leases, and that these species forage amongst the diverse herbaceous layer promoted by moderately frequent fire. Although not specifically focussed on fire, a local study of *P. oralis* (Townley 2000) also reported that this species was generally found in sites with a predominantly grassy understorey, that grasses and herbs were important food sources, and that plant diversity at a small scale was linked to trap success. This species also appears to need access to dense, low cover (Townley 2000). Tasker and Dickman (2004:737) conclude that "Management of former grazing leases incorporated into National Park for the conservation of *P. oralis* in our view will require sufficiently frequent fire disturbance to maintain an open and floristically diverse ground cover while still maintaining adequate shelter cover for the species."

Some years previously, Christensen (1998) also argued, on the basis of a review of the literature, that retention of frequent low-intensity fire in the grassy forest landscapes of Northern NSW would be the precautionary approach towards conservation of medium-sized mammals. A number of Australian taxa in this size range use the early post-fire environment and/or grassy areas which are maintained by frequent fire. Vegetation which provides dense cover is also important for species of this size, and fire regimes which promote the juxtaposition of grassy and shrubby patches may be vital. The vulnerable Parma Wallaby (*Macropus parma*) is an example here (Maynes 1977, NPWS 2002).

It appears clear, from the range of studies outlined above, that relatively frequent fire in grassy wet sclerophyll forests creates an open landscape in which tussock grasses, forbs and some shrubs thrive, creating habitat which is preferentially utilized by many animals. Vegetation which has not been burnt for some time, or where fire frequency has been low favours some shrub and non-eucalypt tree species, particularly those able to recruit between fires. This thicker vegetation has a deep litter layer and is associated with habitat features which are important for a different suite of animal species.

Grassy wet sclerophyll forests in the Northern Rivers region can thus exist in at least two 'states.' The dynamic nature of these forests suggests they would fall into either Bond's 'climate limited but fire modified' or his 'fire limited' category (Bond *et al.* 2003, 2005; see Section 1.4). The extent of successional change in the absence of fire remains to be determined. However as Doug Binns (pers. comm. 2005) points out, the considerable differences between burnt and unburnt plots at Bulls Ground have occurred in a relatively short time-span (20-30 years), emphasising the lability of this vegetation type.

3.5 Existing fire regime guidelines

The south-east Queensland guidelines do not clearly distinguish between different forms of wet sclerophyll forest. The WSF guideline reads, in part:

> "a. High intensity fire catalyses regeneration in eucalypt-dominated wet sclerophyll forests. Wildfire in its natural season should adequately fulfil this role in most cases. Intervals are likely to range between 20 and 100+ years.
>
> "b. Less intense understorey fires may also play a role in some tall eucalypt forests (eg those with an understorey of sclerophyllous shrubs), along with occasional 'stand replacing' wildfires. Research to determine where and when this may be the case is urgently needed. Intervals below 6 years for grassy systems…are not recommended (Watson 2001a:20).

DEC, on the other hand, includes a guideline explicitly for this vegetation type. Suggested thresholds are 10 and 50 years, with the proviso that "Occasional intervals greater than 15 years may be desirable. Crown fires should be avoided in the lower end of the interval range" Kenny *et al.* (2004:34).

Chiswell and Redpath's guideline for grassy wet sclerophyll forests duplicates that of Kenny *et al.* (2004).

3.6 Discussion of fire regime guidelines

One regime or two?

Both the south-east Queensland (SEQ) and the NSW guidelines for this vegetation type cover a wide range of intervals. Both refer to fire intensity. Is it possible that both occasional high intensity fire, and more frequent lower intensity burns, play a role in conserving diversity in grassy wet sclerophyll forests?

In Victoria, 'tree killing' fires in *Eucalyptus regnans* forests may be interspersed with less intense sub-canopy fires, which regenerate the *Pomaderris aspera* understorey (Ashton 1976, McCarthy *et al.* 1999). Similar dynamics have been recognised in North American pine and mixed conifer forests. Prior to European settlement frequent but patchy low intensity fires kept tree densities low and variable, and ground fuels light and patchy (Heinlein *et al.* 2005). Crown fires still occurred but were of much more limited extent than they have been in recent years (Swetnam and Betancourt 1998 [check], Swetnam *et al.* 1999, Swetnam and Baisan nd and references therein). The interplay between different sorts of fires and landscape features created a shifting mosaic of vegetation structure and composition which provided a wide variety of habitat and helped limit forest susceptibility to large-scale insect-related disturbance events (Hessberg *et al.* 2000, Keane *et al.* 2002, Hessburg *et al.* 2005). [I've got more references coming, will refine this section.]

The relationship between fire and eucalypt species in wet sclerophyll forests is not the same in all wet sclerophyll forest (WSF) types (Florence 1996). While the concept of occasional stand-replacing fires fits well for obligate seeder eucalypt species such as *E. regnans* and *E. delegatensis* (the latter species occurs in southern NSW), the relationship between high intensity fire and resprouter WSF eucalypts is less clear. Keith (2004) lists dominant tree species in each of his vegetation formations, while the NSW Fire Response Database (DEC 2002) summarises what is known about the regeneration mode of individual species. No tree species listed by Keith for Northern Rivers wet sclerophyll types is unequivocally classed as an obligate seeder, although several act in this manner under certain circumstances. Two grassy subformation eucalypts, *Eucalyptus* *pilularis* and *Eucalyptus obliqua*, resprout in the drier part of their range, but not in wetter areas (DEC 2002). Thus most if not all Northern Rivers grassy WSF eucalypts are unlikely to die en masse in a fire, and are also unlikely to exhibit the 'wheatfield germination' of their obligate seeder counterparts (Florence 1996). Florence (1996) suggests that high intensity fires in 'fire-tolerant' WSF may kill individual trees or groups of trees only where they are senescent or weak, creating small patches of even-aged regrowth dispersed though the forest. There is an implication here that intense fire plays a role in providing conditions needed for eucalypt regeneration, however I am not aware of studies addressing this topic directly.

Low to moderate intensity fires may have little effect on the WSF overstorey, however they may play an important role in understorey dynamics.

It is possible that both the DEC and the SEQ guidelines pertaining to the forest type under discussion represent something of an uneasy compromise between the fire requirements of overstorey and understorey. This compromise position could fail to deliver either sufficiently frequent low intensity fire to maintain a range of understorey habitats, nor sufficiently infrequent high intensity fire for eucalypt regeneration. The concept of a 'two tier' regime is proposed as a way out of this dilemma.

Uneasy compromises may also be inevitable in any state-wide guideline for grassy wet sclerophyll forests. As noted above, there are likely to be major differences across NSW in the nature of the relationship between WSF trees and fire. Understorey dynamics may also differ considerably, reflecting differences in climate from the subtropical north to the subalpine south. These differences highlight the benefits of tailoring regimes for smaller geographic areas.

The upper threshold of 50 years proposed by Kenny *et al.* (2004) may in part reflect the authors' desire to ensure a reasonable life-span for obligate seeder eucalypts, which they note may occur in this vegetation type. This figure was obtained by bypassing 'most sensitive' plant species with lifespans of 20, 30 and 35 years (Kenny *et al.* 2004:38). In fact, 50 years would be a very short life-span for obligate seeder eucalypts: for example *Eucalyptus regnans* lives for 350-500 years (McCarthy *et al.* 1990) and only starts producing the tree hollows used by arboreal mammals when it reaches about 120 years of age (Lindenmayer *et al.* 1997); *E. delegatensis,* which occurs in similar habitat, may develop over a similar timeframe. Mackowski (1984) found that hollows in blackbutt trees near Coffs Harbour did not start to form until trees were over 100 years old.

On the other hand, a 50 year interfire interval may be too high for many Northern Rivers understorey plants and animals. Again, although the bypassed figures may be anecdotal, they suggest that some species in this forest type may fail to persist under intervals well below 50 years. That this is indeed the case in the Northern Rivers area is attested by the Bulls Ground research, where many invertebrates and plant species found in frequently burnt areas were not found where fire had been excluded for 20 - 30 years (Stewart 1999, York 1999a, York 2000, Andrew *et al.* 2000).

It is suggested that by reframing wet sclerophyll fire regimes as having two tiers, and acknowledging the major differences between forest types in the north and south of the State, this paradox can be resolved.

Interval domains for understorey diversity

High intensity fires will occur when weather conditions are extreme, whatever the regime at other times. Of more concern for vegetation managers is the nature of the 'second tier' regime. Here, a range of intervals across both time and space may be desirable.

We know that quite frequent fire – fire at 1 to 5 year intervals – is associated with diverse ground layer vegetation (Stewart

1999, Tasker 2002) and a high abundance of many invertebrate species (York 1999a, York 2000, Andrew *et al.* 2000, Bickel and Tasker 2004). This regime also provides habitat for a number of rare small mammals (Tasker and Dickman 2004). However burning at very short intervals will limit the extent to which vegetation progresses down the path towards shrubbiness and high litter levels (Birk and Bridges 1989, York 1999a, Henderson and Keith 2002a), features which are important for conservation of another component of forest diversity (Catling *et al.* 2000, York 2000, Tasker 2002, Tasker and Dickman 2004).

The existence of two understorey 'states' supporting distinct suites of species in the grassy wet forests of Northern NSW implies the need for a fire regime which supports the existence of each state somewhere in the landscape. In some places, fire needs to happen often enough to maintain open, grassy forest environments rich in grasses and herbs, where early-successional animal species can thrive. Other places need to support good-sized patches of thicker vegetation where mesophyll shrubs and late-successional fauna can flourish.

This proposal is in line with the recommendations of Bulls Ground researchers York (2000) and Andrew *et al.* (2000). It would also provide the shrubby vegetation advocated by Henderson and Keith (2002a), and the "open and diverse ground cover" recommended by Tasker and Dickman (2004:737), albeit in different parts of the landscape. Both Tasker and Dickman (2004) and Christensen (1998) also point out that some animals need access to both open areas and denser cover; a mosaic of open and shrubby patches should fulfill that requirement.

What will it take to retain significant open areas (State 1) in the grassy mesic forest landscape? Dynamic equilibrium theory implies that these productive landscapes may need more frequent disturbance than their drier counterparts. This reasoning suggests intervals in the 2 to 5 year range. While it is possible that a wider range of intervals (eg 2-7 years) may also produce the habitat needed by the suite of species that uses open grassy vegetation, this possibility has not yet been investigated. Two to five years encompasses the regime in the Bulls Ground burnt plots, approximates that in Tasker's burnt/grazed areas, and would allow time for dense grassy vegetation to develop in the later post-fire years.

What regimes might provide habitat for both sclerophyll and mesic shrubs, and mid to late successional fauna (State 2), without setting in train irreversible successional processes? Again dynamic equilibrium theory would suggest the need for relatively frequent disturbance in wetter forests. Intervals in the six to 15 year range, with occasional intervals up to 20 years, would be in line with this thinking. This range is similar to that encountered by Kitchin in her moderate fire frequency sites, and probably encompasses a proportion of Tasker's unburnt areas. It would not allow succession to proceed beyond the level encountered on the unburnt sites at Bulls Ground in the early 1990s, and in Birk and Bridges' unburnt treatment (Birk and Bridges 1989).

In the cooler Tablelands environment, slightly longer intervals would probably be appropriate – see summary guidelines below.

The rider to the DEC guideline – "occasional intervals greater than 15 years may be desirable" – can be read as a recommendation that *most* intervals fall within the 10-15 year range. This brings the guideline closer to the secondary regime recommendation in SEQ (6+ years), and to the State 2 regime proposed above. It is worth noting that Kenny *et al.* (2004:38) identify only two 'most sensitive' species in grassy subformation wet sclerophyll forest with a minimum time to maturity of greater than one year. This suggests that although the short intervals recommended to maintain State 1 will undoubtedly disadvantage some plant species, the number disadvantaged may not be high. Slow-maturing species should find a place in parts of the landscape managed for State 2.

The SEQ six year minimum for the 'secondary' regime was set this high for two reasons. The first was to ensure young eucalypts had time to reach fire tolerance, either through lignotuber development or through escaping out of the flame zone. The second was a fear that frequent fires would deplete soil nutrient levels, a concern based on a study by Guinto *et al.* (1998) which found that unburnt plots in a south-east Queensland forestry experiment had 40% more topsoil organic carbon and total nitrogen than plots burnt every second year, and 10% more than plots burnt on a four year cycle. Watson (2001a) interpreted these findings on nutrient levels as an indication that frequent fires were problematic. However as discussed in Section 2.4, in Western Slopes woodlands low nutrient levels favour native ground layer species over exotics (Prober *et al.* 2004), while high nutrient levels are linked with degradation (Prober *et al.* 2002b). The relationship between nutrient levels, fire and diversity in grassy WSF requires clarification. Perhaps nutrient levels vary naturally between states.

The need to limit the abundance of lantana and other exotic invaders may have a bearing on the percentage of the landscape which can be maintained on State 2 intervals, and/or on the length of those intervals themselves. Birk and Bridges (1989) reported an increase in lantana on their 20-year unburnt plots, and anecdotal evidence suggests this shrub is a major problem in some long unburnt Northern Rivers forests (Wardell-Johnson and Lynch 2005). The possibility of a link between eucalypt dieback and fire exclusion has also been suggested, although researchers are a long way from untangling the web of factors involved (Wardell-Johnson and Lynch 2005). Recent work in the Richmond Range has confirmed an association between dieback severity, bell miner density, shrub cover, lantana abundance, and soil ammonium levels (Stone, submitted). Logging and grazing practices may also be implicated (Wardell-Johnson and Lynch 2005).

The two-tier fire regime concept calls into question how the two regimes might interact in relation to overstorey recruitment. If occasional intense wildfires do indeed play a major role in eucalypt recruitment, would secondary regimes, particularly the frequent burning associated with state 1, need to be suspended for a while to allow seedlings to reach the point where they can survive low intensity fires? Or might continued low intensity burning play a positive role in thinning young eucalypt regrowth? Might a hiatus in burning result in more intense fire, and more damage to young trees, when the secondary regime is eventually reinstated? Does the nature of the understorey affect eucalypt recruitment? Might either the thick grass encouraged by State 1 fire regimes, or the thick shrubs of State 2, pose difficulties for young eucalypts? Might these competitive interactions, if they exist, help regulate sapling density appropriately? So far as I am aware, we do not have answers to these questions at present.

The concept of a mosaic of states also raises questions. One concerns the scale of the mosaic – should we aim to have large patches in each state, or a fine-scale mosaic of grassy and shrubby areas? Literature on fauna habitat needs and dispersal distances may throw some light on this issue, and may be explored later in the Hotspots project (see comment in Section 2.7). It seems, *a priori*, that a sensible approach may be to build on what already exists, taking into account landscape features. In areas that have been managed on short intervals in the past, it may be appropriate to maintain much of the landscape in an open state, but increase habitat diversity through reducing fire frequency in gullies and in other more mesic areas. Areas where fire has been less frequent and shrubs are thicker could be managed primarily for State 2, with more open areas being introduced into the matrix through more frequent burning in strategic patches. In places where one state or the other dominates most of the landscape, it may be desirable to establish a more equitable distribution of states through greater or lesser use of fire.

3.7 Summary recommendations

Northern Hinterland Wet Sclerophyll Forest: An interval range between 2 and 20 years is recommended. Some areas should be managed to retain an open, grassy environment: patchy low intensity fires at 2-5 year intervals are suggested. Other areas should be managed for a multilayered understorey: variable intervals between 5 and 20 years are suggested here. Occasional high intensity fire may be important for eucalypt regeneration.

Northern Tableland Wet Sclerophyll Forest: An interval range between 2 and 25 years is recommended. Some areas should be managed to retain an open, grassy environment: patchy low intensity fires at 2-7 year intervals are suggested. Other areas should be managed for a multilayered understorey: variable intervals between 8 and 25 years are suggested here. Occasional high intensity fire may be important for eucalypt regeneration.

3.8 Further research

Research questions whose answers would help refine fire regime guidelines for grassy wet sclerophyll forests in Northern NSW include:

- At what point, if ever, is succession to rainforest inevitable? Does this vary with rainfall, slope, aspect, geology or soil type? Experimental studies generally test short intervals against a no-burn treatment. It would be informative to experimentally test some longer intervals, eg 7, 14, 21, 28, 35 years.
- Do invertebrates found only on frequently burnt plots at Bulls Ground also utilise the early stages of regeneration after a fire in Stage 2 vegetation? At what stage post-fire do they drop out? The answer to this question would help refine Stage 1 interval guidelines. It would also help us understand the degree to which variability in interfire intervals needs to happen across space, as well as across time. The same question could be asked for small mammals on the Tablelands.
- At what point post-fire do the invertebrates found only in the unburnt plots at Bulls Ground join the vegetation? The answer to this question would help refine State 2 interval guidelines, and increase understanding of the need for variability across time and space.
- Which medium-sized and large mammals use which states and/or stages of post-fire regeneration in this vegetation type?
- Which bird, reptile and amphibian species use which states and/or stages of post-fire regeneration in this vegetation type?
- Does a substantial suite of fauna species need resources from both states? The answer to this question might help determine how fine-scale the mosaic of states in the landscape would ideally be.
- How and when, in relation to fires of different intensities, do Northern Rivers WSF eucalypts recruit? Is there a 'suppressed seedling' pool for all or some species?
- Is eucalypt recruitment after a wildfire inhibited by either regenerating grasses or regenerating shrubs? Is inhibition problematic, given that only occasional recruitment will be needed to replace adult trees?

4 Shrubby wet sclerophyll forests

4.1 Introduction

Shrubby subformation Wet Sclerophyll Forests are: "Tall forests dominated by straight-trunked eucalypts with dense understories of shrubs with broad soft leaves, ferns and herbs" (RFS 2003). They occur in high rainfall areas near the coast on relatively fertile soils, and have a multilayered understorey of mesic shrubs. These are productive environments where growth is rapid.

Some consider these forests to be a successional stage between open forest and rainforest (Kenny *et al.* 2004), although others believe a stable understorey community can be kept in check by an intact eucalypt canopy (Florence 1996).

4.2 Keith vegetation types

Keith (2004) identifies two vegetation formations in the "shrubby subformation of wet sclerophyll forests" that occur in the Northern Rivers region.

- **North Coast Wet Sclerophyll Forests**. These forests occur along the coast, mostly below 500m elevation, where rainfall exceeds 1000mm. They grow on relatively fertile soils of the coastal ranges, hills and creek flats. They have a multi-layered understorey of mesic shrubs and a ground layer of herbs and ferns. Vines are common (Keith 2004). "With increasing shelter, moisture or soil fertility, the North Coast Wet Sclerophyll Forests grade into Subtropical or Warm Temperate Rainforests, and many of the mesophyllous shrubs and vines of the sclerophyll forests have strong rainforest affinities. Stands that are intermediate are probably transient, given the different requirements for regeneration of the sclerophyll and rainforest components. However, these changes are not obvious, as they occur over time scales of decades or centuries" (Keith 2004:62). Keith (2004:63) mentions several disturbances that occur in this forest type: "As well as changes in vegetation structure resulting from logging… the North Coast Wet Sclerophyll Forests have also been modified by regular burning and livestock grazing in some areas. These activities change the species composition, and simplify the structure of the understorey, reducing the diversity of habitats available to some groups of animals (Woinaski 1999; York 1999)."
- **Northern Escarpment Wet Sclerophyll Forests**. These forests occur on the coastal escarpment between 600 and 1400m above sea level. Soils are fertile loams, and rainfall ranges from 1000 to 2000mm per annum. Mesophyllous shrubs, ferns and herbs again make up the understorey. The T-species *Trochocarpa laurina* is common. These forests too grade into rainforest, a dynamic balance which Keith (2004) considers mediated by fire. To the west with declining rainfall these forests grade into the grassy Tablelands wet sclerophyll forests described in Section 3.2. "This distinction is blurred, however, by livestock grazing and associated grazier burning, which encourages the growth of grasses and herbs at the expense of woody species in the understorey" (Keith 2004:66). Keith speculates that frequent burning in these forests may set in train long-term changes.

4.3 Northern Rivers studies

Northern Rivers shrubby subformation wet sclerophyll forests have not been the subject of fire ecology research in recent years. Some studies from earlier decades do exist, and are described below. In 2004 a study in the Richmond Range explored the correlates of eucalypt dieback. As it has been suggested that dieback and fire may be related, this study is also described.

In the 1960s and 70s, Alex Floyd conducted some of the earliest fire ecology experiments in Australia in wet forest near Coffs Harbour. One study (Floyd 1966) sought to understand the germination of shrub species which compete with eucalypt seedlings attempting to establish after logging. 'Weeds' considered particularly problematic were the fire-cued native shrubs *Dodonaea triquetra*, *Indigofera australis*, *Kennedia rubicunda*, *Acacia binervata* and *Acacia irrorata*. All these species germinated in greater abundance when heated.

In a later field study in *E. pilularis/E. grandis* forest, Floyd (1976) found less seed of two common rainforest pioneer species (*Callicoma serratifolia* and *Piptocalyx moorei*) in a site which had had two fires at approximately 15 year intervals, than in a matched site which had burned after 30 years without fire. The short-lived, shade-intolerant species *Acacia binervata* had more seed in the more frequently burnt site; in fact no seed of this species was found in the soil from the long unburnt site.

Smith and Guyer (1983) surveyed a rainforest/WSF ecotone in Giraud State Forest east of Tenterfield, using a series of 100m transects. Soil profiles were similar in both vegetation types. Charcoal was present in the upper layers of the eucalypt forest soils, but not in the rainforest. Charred logs, stumps and fire-damaged trees were also limited to eucalypt and ecotone areas. Large, old eucalypts (*E. saligna*, *E. microcorys*) penetrated furthest through the ecotone towards rainforest, while small eucalypts were comparatively rare. Conversely, the smallest rainforest trees penetrated furthest towards the eucalypt forest. From this study and a companion one at Barrington Tops, Smith and Guyer (1983) concluded that the rainforest was advancing, and the eucalypt forest retreating, across the ecotone in these sites, and that fire delineated the boundary. While several fires had occurred in the vicinity over past decades, the exact extent and frequency of fires at survey sites was not known.

Turner (1984) used carbon dating to study the frequency of 'severe fires' in a coastal valley in Whian Whian State Forest. He counted layers of charcoal in the soil of three vegetation types: gully rainforest, adjacent *Lophostemon confertus*-dominated wet sclerophyll forest, and blackbutt forest on the slopes above the brush box. Estimated average fire return intervals were: rainforest, 1100 years; brush box, 325-380 years; blackbutt, 280 years. It was not possible to tell whether the fires detected in this study were interspersed with fires of lower intensity which did not show up in the charcoal record.

Stone (submitted) reports the results of a recent survey of 24 sites in the Richmond Range, covering a range of levels of eucalypt dieback, and various eucalypt associations. Eucalypt crown condition had highly significant negative correlations with bell miner density, shrub cover and soil ammonium content. Healthy trees were more likely to be found where *Corymbia variegata* was abundant, while "poorer tree crown condition and higher bell miner density tended to be associated with the mesic plots" (Stone, submitted:2). However no significant association with overall plant species composition was detected.

4.4 Discussion of studies

Research into the role of fire in wet sclerophyll forest with a mesic shrub understorey has been sparse in the subtropics. As noted in the previous section, work from Victoria's Mountain Ash (*Eucalyptus regnans*) forests is not necessarily relevant. These Victorian studies, along with those from North Queensland, are reviewed by Watson (2001a), who concludes that there is still much to be understood in relation to this forest type, and cautions that suggested fire regimes for WSF may well need modification as research findings come to hand. This situation has not changed.

Floyd's first study (Floyd 1966) documented the now well-established effect of heat on legume germination. It is interesting that these fire-cued species had soil-stored seed in a forest type that is generally considered to have a mesophyllous understorey: a comparison of tree species placed this site in Keith's North Coast Wet Sclerophyll Forest category. Floyd's second study (Floyd 1976) showed a shift in the seedbank away from early-maturing, shade-intolerant species toward species that are slow to mature but tolerant of shade. Presumably this is succession in action. The lack of *any Acacia binervata* seed in the site unburnt for 30 years suggests this species needs intervals well below this level to persist in the community.

Smith and Guyer (1983) also document succession in action. It is interesting that the rainforest advance was occurring despite some fire in the ecotone at both study sites, and despite the high altitude in Barrington Tops (1340m): it suggests that succession can proceed not only where fire is excluded, but also where it is infrequent. Unfortunately, we do not know the fire history of Smith and Guyer's sites.

Turner's estimated fire return interval for blackbutt forest – 280 years (Turner 1984) – implies either that fires were extremely far apart prior to European settlement, or that if fires were more frequent, they were generally not intense. I tend to the latter explanation. It seems unlikely that wildfires in landscape-wide old fuels would be so far apart, given the fire-prone nature of Australia's eucalypt forests. This suggests that these forests had some protection through reduction of fuel in low intensity understorey fires. Also, the studies discussed above, together with those detailed in the section on grassy WSF, strongly suggest that eucalypt forest would succeed to rainforest during a 280 year interfire interval – although whether and how fast this would actually occur at any particular site is unknown.

The recent study reported by Stone (submitted) documents a correlation between shrub cover, soil ammonium levels, and eucalypt dieback. In her discussion, Stone links bell miner behaviour and the high nutrient content of leaf flushes as trees attempt to recover to high densities of, and damage from, herbivorous insects. Bell Miners need dense shrub cover 2-5m in height, for nesting. Although this article does not address the role of fire in the BMAD (bell miner associated dieback) scenario, the tendency for frequent fire to reduce the cover and abundance of mesic shrub species has been noted many times in this review. The possibility of a link between fire exclusion and nutrient build-up has also been mentioned (Guinto *et al.* 1998). The BMAD Working Group [correct name?] has recently received funding to further study the causes and cures of dieback, and is planning an exploration of fire frequency effects. At this point, we have a hypothesis that frequent burning may help limit dieback, but this hypothesis is untested.

4.5 Existing fire regime guidelines

As previously noted, the south-east Queensland guidelines do not clearly distinguish between wet sclerophyll forest subformations. The relevant part of the guideline reads:

> "a. High intensity fire catalyses regeneration in eucalypt-dominated wet sclerophyll forests. Wildfire in its natural season should adequately fulfil this role in most cases. Intervals are likely to range between 20 and 100+ years.
>
> "b. Less intense understorey fires may also play a role in some tall

> eucalypt forests… Intervals below ….12 years for shrubby systems, are not recommended.
>
> "c. *Lophostemon confertus* (brush box) dominated forests are probably adapted to very long interfire intervals, and may not need fire at all." (Watson 2001a:20).

Kenny *et al.* (2004:34) recommend intervals between 25 to 60 years, with the proviso that "Crown fires should be avoided in the lower end of the interval range."

Chiswell and Redpath (2004:6) give an interval range of 20 to 100+ years. Notes state "No crown fire in the lower end of range. Intervals below 6 years for grassy wet sclerophyll formations and below 12 years for shrubby wet sclerophyll formations are not recommended."

4.6 Discussion of fire regime guidelines

One regime or two?

This question is also relevant for this vegetation type, as is much of the discussion on this topic in Section 3.6. Shrubby formation wet sclerophyll forests may be more likely to host obligate seeder eucalypts than their grassy counterparts; *Eucalyptus grandis* is a candidate. This species lacks a lignotuber but may coppice, according to the NSW Flora Fire Response database (DEC 2002). Kenny *et al.* (2004) note that dominant WSF eucalypts may be obligate seeders, do not have soil-stored seed, and thus will be vulnerable to local extinction in the face of a single short inter-fire interval.

Again, current guidelines may represent an uneasy compromise between the occasional high intensity fire needed to ensure successful generational change in eucalypts, and a regime appropriate for the understorey. Kenny *et al.* (2004) bypassed lifespan figures for 'most sensitive' species of 15, 20, 30, 35, 40 and 50 years before settling on a maximum threshold of 60 years. These lower figures may represent more than inaccuracies; they may flag the need for a secondary regime of understorey fires. And again, even a 60 year interfire interval would be extremely short for an obligate seeder eucalypt.

Turner's findings, although limited to a single site, imply that the time between intense wildfires in the past, may have been very long indeed. An average interval of 280 years is, however, compatible with what we know about the lifespan of obligate seeder eucalypts.

I believe the concept of a 'two-tiered' regime is appropriate for this vegetation type.

Interval domains for understorey diversity

The lack of long-term experiments, or retrospective studies of areas with different fire frequencies in sub-tropical shrubby wet sclerophyll forests means we have considerably less information to guide the development of interval domains for understorey diversity in this forest type than in those discussed so far.

The vital attributes analysis provided in Kenny *et al.* (2004:37) provides some clues, but its usefulness is limited both by the inclusion of species from across NSW, and by the acknowledged lack of data.

The minimum interval in the DEC guideline was set by a single 'most sensitive' species with a 25 year time to maturity. This species may or may not occur in Northern Rivers forests. The most sensitive species with the next longest time to maturity had a juvenile period of 10 years. Taking this figure and the second-lowest figure in the lifespan chart would give a range of 10 – 20 years. This range would be compatible with retention of *Acacia binervata*. It might also limit the density of the shrub layer, and thus nest sites for bell miners. These intervals might also, however, encourage fire-cued shrubs at the expense of T-species and thus maintain a thick shrub layer, albeit of somewhat different composition.

Dynamic equilibrium theory would predict that the effects of competition in this productive environment would be considerable, and thus that fairly frequent disturbance might be important to maintain diversity. These forests probably fall into Bond's 'fire-limited' category, implying the potential for at least two states to exist at any one site. Kenny *et al.* (2004:36) discuss this possibility explicitly: "Wet sclerophyll forests are considered to be a successional stage between open forest and rainforest, leading to differences of opinion regarding management. Frequent fires (c.15-20 years) will favour the sclerophyllous species over the rainforest elements, with the forest tending towards dry sclerophyll forest or even scrub. Conversely, long fire intervals (c. 100 years) allow encroachment of more rainforest species while suppressing establishment of sclerophyll species, resulting in 'expansion' of rainforest into wet sclerophyll forests (Ashton 1981)." The implication here is that possible states may include not only rainforest and WSF with a range of understorey types, but also other sclerophyll vegetation formations. Of course, this statement and the figures in it are a generalization covering a diverse range of forests across the state. Transitions from sclerophyll to mesic vegetation are likely to occur faster in the warm, wet climate of the Northern Rivers than in forests to the south. Juvenile periods of obligate seeders may also be shorter in warmer areas (Knox and Clarke 2004).

4.7 Summary recommendations and further research

The primary recommendation for this forest type is that basic research into the effects of fire frequency is needed. The following hypothesis is proposed for testing:

> That the Northern Rivers shrubby subformation wet sclerophyll forest understorey can exist in three states whose maintenance is mediated by the frequency of understorey fires.
>
> - **State 1**. Understorey dominated by grasses, herbs and ferns with occasional, mostly I-species shrubs. It is hypothesized that this state is maintained by fires at approximately 2-6 year intervals.
> - **State 2**. Understorey dominated by I-species shrubs. T-species shrubs present in low to moderate abundance. Grasses, herbs and ferns present but in lower abundance than in State 1. It is hypothesized that this state is maintained by fires at variable intervals between 7 and 20 years.
> - **State 3**. Understorey dominated by T-species shrubs, and vines. It is hypothesized that this state develops in the absence of fire and is not reversed by fires at intervals above 20 years. If fire continues to be excluded this state transitions to rainforest.

This hypothesis draws on an understanding of the vital attributes and dynamic equilibrium models, extrapolation from vegetation dynamics in other vegetation types, and the limited local research literature.

Ideally, fire frequency effects would be assessed through a replicated, landscape-scale experimental study. Such studies are, however, expensive and difficult to maintain over the very long time-frame that would be needed to assess the effects of moderate and low fire frequencies. An alternative is to attempt to locate replicated areas containing eucalypts generally associated with shrubby subformation wet sclerophyll forests in the Northern Rivers which have been exposed to particular disturbance regimes. Areas subject to high (2-6 year), moderate (7-20 year) and low (20-50 year) frequency fires, together with areas from which fire had been excluded for over 50 years could be assessed for:

- Species richness, composition and cover of grasses, herbs, ferns, I-species shrubs, T-species shrubs, sclerophyll trees, mesophyll trees; abundance data could be collected for selected taxa eg rare and threatened species
- Species richness, composition and abundance of animals (eg birds, mammals, invertebrates)
- Vegetation structure
- Extent of eucalypt recruitment after and between wildfires
- Canopy condition
- Species richness and cover of exotic plant species, particularly lantana

Site selection would need to attempt to either control for, or randomize out, variation due to other disturbances, particularly logging and grazing.

Again, there may be questions as to the desirable distribution of WSF states in the landscape. In addition, if shrubby wet sclerophyll forest does indeed succeed to rainforest in the absence of disturbance, the desirable distribution of rainforest relative to WSF may need to form part of management deliberations.

5 Shrubby dry sclerophyll forests and coastal heaths

5.1 Introduction

Shrubby dry sclerophyll forests are distinguished by an understorey of diverse sclerophyllous shrubs, while coastal heaths are either treeless, or support only low-growing trees. These vegetation types generally occur on sandy low-nutrient soils. In the Northern Rivers region warmth and moisture encourage growth in these communities, although nutrients are limiting.

5.2 Keith vegetation types

Two vegetation types in the shrubby subformation of dry sclerophyll forests, and occurring in the Northern Rivers region are identified by Keith (2004), as are two heathland vegetation types. Keith provides virtually no commentary on the fire ecology of these communities.

- **North Coast Dry Sclerophyll Forests.** These forests occur on the low fertility soils of the coastal sand plains, and on sandstone hills and plateaus. Keith (2004) does not comment on the role of fire in this vegetation type, but notes its similarities to the Sydney sandstone flora.
- **Northern Escarpment Dry Sclerophyll Forests**. These forests occur on low-nutrient sandy soils weathered from leucogranite at altitudes of 800-1400m where rainfall exceeds 850mm per year, for example in the Gibraltar Range. Keith (2004) notes their flammability relative to rainforest, and their affinities with Sydney's sandstone flora.
- **Wallum Sand Heaths** grow on the very infertile soils of old sand dunes along the coast where rainfall is high (Bureau of Meteorology 2005). *Banksia aemula*, the wallum banksia, occurs in these heaths; eucalypt species, where they occur at all, are stunted. Sandmining has introduced the weed bitou bush to this community. This vegetation type once occurred in Sydney, and is also found in south-east Queensland (Keith 2004).
- **Coastal Headland Heaths** have a scattered occurrence on exposed headlands and plateaus "within the sea spray zone" (Keith 2004:174), and include dense scrubs, open sedge-heaths, and *Themeda* grasslands with scattered shrubs. Soils are generally loams and clays, though some are more sandy; substrate affects vegetation composition.

5.3 Northern Rivers studies

Two local studies provide some insight into the fire ecology of these vegetation types. Benwell (1998) studied post-fire recruitment in heathland near Evans Head. York (1997, 1998, 1999b) included some sandstone sites in the study of fire and grazing reported in Section 2.3.

Benwell (1998) monitored the density, survival and growth rate of seedlings in wet, dry, moist and headland heaths, and linked these factors to species regeneration modes. Seedling numbers peaked around 12 months post-fire; density ranged from an average of 239 seedlings per m^2 in moist heath to 40-105 per m^2 in dry heath. A small number of species including *Xanthorrhoaea johnsonii* began seedling recruitment in the second post-fire year. Seedling survival was primarily a function of cover of vegetative regrowth; this factor explained 72% of variation in seedling survival rates. Obligate seeders made up

30-40% of species in each heathland type. Obligate seeders tended to produce many more seedlings than resprouters, and both seedling survival and growth rates were higher for obligate seeders. By three years post-fire, wet and moist heath had developed a closed crown cover, while dry heath, and particularly headland heath, were still open.

York's study of the effects of grazing and associated fire regimes in dry sclerophyll forest types south of Casino has already been described (Section 2.3). Few differences between grazed and ungrazed sites were found in either the abundance, richness or composition of any group of organisms (York 1998, 1999b, York and Tarnawski 2004). However species richness of shrubs was considerably lower in grazed sites on sandstone (7.8 species per 0.1ha), than in ungrazed sites (13.5 species) on this geology (York 1999b). Despite this difference, total plant species richness on sandstone was almost identical in the two treatments; grasses and sedges made up the difference in grazed/burnt sites.

5.4 Discussion of studies

Benwell's study (Benwell 1998) illustrates the very close link between fire and plant species reproduction in local heaths. This link is found in all Australian coastal heath communities, where typically the vast majority of species recruit after a fire (Keith *et al.* 2002a). Benwell's careful and community-wide documentation of links between regeneration mode and seedling production and development also confirms and extends findings elsewhere. Purdie and Slatyer 1976, Wark *et al.* (1987) and Enright and Goldblum (1999) also recorded higher seedling densities amongst obligate seeders than resprouters, while Bell and Pate (1996), Enright and Goldblum (1999) and Bell (2001) found slower growth rates in resprouters.

This study also provides stark evidence of the effects of competition in coastal heaths. Seedling survival was strongly linked to cover of resprouter regrowth: the thicker the regrowth, the lower the percentage of seedlings that survived. This picture mirrors that described in Section 1.4 in heaths around Sydney, where high density thickets of overstorey shrubs reduce the survival and fecundity of understorey plants. The rapid recovery of full canopy cover in wet and moist heath attests to the small window of opportunity for regeneration afforded by fire, and to the rapid rate of plant growth, particularly where moisture is readily available.

The finding that *Xanthorrhoea johnsonii* recruited heavily in the second year after fire (Benwell 1998) is interesting. This species flowers rapidly after fire (DEC 2002), presumably creating the seed which then germinates in Year 2 while gaps in the shrub canopy are still available.

York's study has already been discussed (Section 2.4). While these findings probably reflect the effects of grazing more than those of fire, a decrease in shrub species richness with high fire frequency is consistent with studies elsewhere (Henderson and Keith 2002, Watson 2005).

5.5 Existing fire regime guidelines

The south-east Queensland guideline for coastal heath reads:

> "In coastal treeless heath and *Banksia aemula* woodlands, fires at a range of intervals between 7 and 20 years, with an emphasis on intervals in the 8-12 year range, are recommended to maintain overall biodiversity. Planned burns in wet heaths should be conducted when the substrate is wet, to avoid the risk of peat fire" (Watson 2001a:30).

The SEQ guideline for shrubby dry sclerophyll forests has already been quoted in Section 2.5; variable intervals between 7 and 25 years are suggested (Watson 2001a).

Thresholds in the DEC guideline for heathland are 7 and 30 years, with the proviso that "Occasional intervals greater than 20 years may be desirable" (Kenny *et al.* 2004:34). DEC thresholds for dry sclerophyll shrub forest are also 7 and 30 years, and "Occasional intervals greater than 25 years may be desirable" (Kenny *et al.* 2004:34).

Chiswell and Redpath (2004:7) recommend intervals between 7-20 years for coastal heath in the Northern Rivers region, with the rider: "Recommended there be an emphasis on the 8-12 year range to maintain biodiversity." Intervals for dry sclerophyll shrub forests are 7 to 30 years: "Maintenance of the shrub understorey will require burning at not less than 7 years over most of the area being maintained" (Chiswell and Redpath 2004:7).

There is thus considerable agreement on appropriate interfire intervals in these vegetation formations.

5.6 Discussion of fire regime guidelines

As Kenny *et al.* (2004) point out, the fire ecology of shrubby forests and heaths has been extensively studied around Sydney, as it has, from another perspective, in south-east Queensland. The agreement between the different guidelines with respect to these vegetation types probably partly reflects the depth of the knowledge base: while there is still room for discussion on detail, the basic facts about the role of fire in these sclerophyllous shrub-dominated communities are clear. Relevant literature is reviewed in Watson (2001a).

The seven year minimum recommended for heath should provide opportunities for slow-growing obligate seeders to reach maturity. North Coast taxa in this category are likely to include *Banksia ericifolia* var. *macrantha* and *Persoonia* species. Observation suggests the abundance of these taxa may have been considerably reduced in a North Coast heath subjected to fire return intervals of between 3 and 7 years over two decades (P. Redpath, pers. comm. 2005).

The focus on intervals in the 8-12 year range in the SEQ guidelines was proposed on the basis of findings from Cooloola north of Noosa. Here, plant reproductive effort, structural characteristics and breeding habitat for birds all peak between three and eight years post-fire (McFarland 1988a, 1990, 1992, 2000). Intervals in the 8-12 year range 'recycle' heathlands through that productive period, while still providing quite a few years of structurally dense habitat. Intervals at the lower end of this range will also help regulate the density of the dominant obligate seeder shrubs that have the potential to outcompete and exclude smaller plant species (Keith and Bradstock 1994, Bond and Ladd 2001, Tozer and Bradstock 2002). That competition issues are alive and well in North Coast heaths is attested by Benwell's findings (Benwell 1998).

The slightly lower upper threshold in the SEQ guideline for shrubby dry forests (relative to that for NSW) was predicated on the belief that growth rates were likely to be higher, and juvenile periods lower, in the warm summer rainfall climate of south-east Queensland, than 1000km further south in Sydney. Competition effects are thus likely to come into play sooner. In Sydney's sandstone woodlands, large T-species such as *Pittosporum undulatum*, *Allocasuarina littoralis* and *Eleocarpus reticulatus* progressively dominate the shrub flora where fire has been excluded for a long time (pers. obs. 2005). North Coast ecologist Tein McDonald (pers. comm. 2005) has observed this phenomenon in local dry sclerophyll forest areas on sandstone: mesic shrubs tend to take over in the absence of fire, the sclerophyll element is outcompeted, and vegetation changes. If we want to maintain the colourful sclerophyll shrub understorey of our shrubby dry forests, intervals should not be allowed to get too long. A 25 year maximum should be more than sufficient to provide dense habitat in the landscape. On the coastal ranges an even lower top threshold may be desirable.

Bond's modelling of South African vegetation types with and without fire showed that some heath communities could succeed to forest in the absence of fire (Bond 2003a). In the high rainfall environment of the Northern Rivers, this may also be a possibility in some areas. In other words, North Coast heaths may fall into Bond's 'fire limited' category; they are certainly at least 'fire modified'. Where T-species with mesic forest affinities join or increase in the absence of fire, in a community composed predominantly of I-species, the potential for displacement of short-lived, fire-cued species must be considered.

The fire ecology of headland heaths is an interesting and understudied subject. Keith (2004) records the expansion of *Leptospemum laevigatum* in these habitats. He notes the probable role of disturbance by clearing and grazing in the success of this shrub, however recent research suggests lack of fire may also play a role (Emeny 2005). The importance of kangaroo grass on some headlands suggests fire may need to be relatively frequent (see Section 2.4).

5.7 Summary recommendations

North Coast Dry Sclerophyll Forests: Variable intervals between 7 and 20 years.

Northern Escarpment Dry Sclerophyll Forests: Variable intervals between 7 and 25 years.

North Coast heathlands: Variable intervals between 7 and 20 years with an emphasis on the 8-12 year range.

5.8 Further research

Research questions whose answers would help refine fire regime guidelines for Northern Rivers heaths and shrubby dry sclerophyll forests include:

- How rapidly does the balance tip from I-species to T-species shrubs in the absence of fire in coastal dry sclerophyll forests? Does a fire 'reset' the vegetation by regenerating I-species and reducing T-species abundance, or does the drift towards dominance by T-species continue through fire cycles, if those cycles involve intervals above a certain length?
- Can short interfire intervals play a role in reducing the abundance of bitou bush? Experimentation with a range of intervals (7, 5, 3, 2) and with different numbers of fires (1-4) is suggested. If control is only achieved with very short intervals and/or multiple fires, what is the cost to native plant species? Do native species reduced in abundance through short intervals implemented to control weeds, recover after one to two intervals within threshold guidelines? Could techniques which combine one short interfire interval with other methods of weed control, be effective?
- In headland heaths, are there links between the abundance of *Leptospermum laevigatum*, *Themeda australis* or woody exotics and past fire frequency? Is plant or animal richness different where fires have been more or less frequent? Is there a tendency towards dominance by one or a small number of shrub species in these environments? If so, is the abundance or richness of other native plant species and/or native animals reduced – or enhanced – under these circumstances?

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