CHAPTER 10

SYNTHESIS AND IMPLICATIONS

10.1 Introduction

The way in which disturbance, and the successional processes that follow it, shape the natural world has long been the subject of ecological theory.

Clements outlined what is now called ‘classical succession’ in 1916. 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 for many years. For example C.E. Lane-Poole told the Royal Commission following the 1939 fires in Victoria that “total exclusion of fire would enable natural succession to proceed, resulting in less undergrowth and a less flammable forest” (Griffiths, 2002:385).

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).

The ‘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 role for people in ecosystem management, and a focus on the conservation of processes rather than objects (Pickett *et al.* 1992). Fire fits more comfortably into the new paradigm, where it can be seen as a vital ecosystem process which mediates biodiversity.

Outgrowths of the new paradigm include:

- The vital attributes model of Noble and Slatyer (1980). This model provided the theoretical framework for the analysis of shrub vital attributes presented in Chapter 3, and can also be used to predict successional pathways.
- The state-and-transition model proposed by Westoby *et al.* (1989), which uses a catalogue of alternate states, and transitions between them, to identify land management options.
- The intermediate disturbance hypothesis, which suggests that biodiversity will be maximised where levels of disturbance are moderate (Connell 1978, Hobbs and Huenneke 1992).
- The dynamic equilibrium model (Huston 1979, 2003), which considers the interaction of productivity and disturbance in mediating species diversity.

The overall project goal was to develop a greater understanding of the relationship between fire regimes and plant diversity in the woodlands of Western Sydney's Cumberland Plain, and to draw out implications for conservation management. This chapter brings together findings from the six project studies and explores how they can be used in management. Non-equilibrium paradigm concepts both inform this exploration, and gain validity through it.

The chapter begins with a **synopsis of the effects of fire on Cumberland Plain Woodland**, organised around the study questions introduced in the context of the literature review in Chapter 1.

A **'state and transition' model of the effects of fire in CPW** is then proposed (Section 10.3). Benefits of this framework include the ability to separate ideas about what *can* (or may) happen in an ecosystem, from values as to what *should* happen (Westoby *et al.* 1989). **Values issues** are discussed in the subsequent section (Section 10.4).

Weed invasion is a major issue in CPW (Tozer 2003). Implications of project findings for management of **exotic species** are discussed in Section 10.5.

Although not the primary focus of the project, guidance as to appropriate fire interval domains for conserving plant diversity in **Castlereagh woodlands** can be gleaned from the vital attribute analysis in Chapter 3. This material is summarised in Section 10.6.

Section 10.7 broadens the management focus to include **bushfire safety** issues: how can CPW managers integrate fire management for biodiversity with protection of life and property?

Finally, the implications of project findings to processes and ecosystems beyond the Cumberland Plain are considered. Section 10.8 provides suggestions on goals and methods of determining **fire frequency thresholds**, particularly for grassy ecosystems. Section 10.9 draws on Huston's dynamic equilibrium model to explore the relevance of the CPW findings for **grassy woodlands elsewhere**.

10.2 Key findings in Cumberland Plain Woodland

Fire exerts a powerful influence on Cumberland Plain Woodland. Remnants varied in species composition: site was a significant factor in all multivariate analyses. Nevertheless, the effects of fire frequency could be clearly discerned. These effects were most apparent in the shrub layer.

10.2.1 CPW shrubs and fire

While the shrub flora of Cumberland Plain Woodland is not as diverse as that found in the Castlereagh and sandstone vegetation types, CPW still supports many shrub species. Legumes feature large: nine of the ten most abundant species across sites surveyed for the landscape study (Chapter 4) were legumes. However the most abundant shrub species, by far, was *Bursaria spinosa*: it was the only one found in all study sites, and its average frequency at subplot (2 x 2 m) scale was over 50 percent.

> **What fire-related attributes do shrub species in Cumberland Plain and Castlereagh woodlands possess, and what does this imply for fire interval domains?**

While most CPW shrub species resprout, about 40 percent are obligate seeders. In terms of Noble and Slatyer's vital attributes scheme, a high proportion of CPW shrubs fall into plant functional types 4 and 12. Species in these groups are highly sensitive to infrequent fire, as recruitment is fire-cued. They are also moderately sensitive to high fire frequency, as although their seedbanks persist through more than one disturbance, repeated short intervals will exhaust them. A small group of non-leguminous species highly sensitive to frequent fire can also be distinguished. Juvenile periods of Cumberland Plain obligate seeder shrubs are relatively short. *Grevillea juniperina* ssp. *juniperina*, with a juvenile period of four years, is the key fire response species with respect to frequent fire. Longevity data are rarely available, however analysis of estimates suggests that intervals above 15 years could cause populations of some species to decline (Chapter 3).

Does shrub species richness or composition differ with fire frequency?

Does *Bursaria spinosa* frequency, density and/or dominance increase with decreasing fire frequency?

Analysis of survey data from Cumberland Plain woodland sites with different fire histories produced findings consistent with predictions from the vital attributes model. The only relatively common shrub in this vegetation type able to recruit in the absence of fire, *Bursaria spinosa*, was found in increasing abundance as fire frequency decreased: this species dominated the landscape in sites from which fire had been excluded for 20+ years. Other shrubs, however, were most abundant in sites burnt approximately every 4 to 10 years, a finding consistent with Huston's dynamic equilibrium model prediction for environments of "intermediate" productivity (Huston 2004). Obligate seeders were more sensitive to both high and low fire frequencies, than resprouters. Bursaria, which formed clumps in sites with 1-10 year interfire intervals, tended towards evenness as fire frequency decreased. Shrub floristics in the three low fire frequency sites were similar due to ample Bursaria, a relative dearth of other native shrubs, and the presence of woody exotics. The species composition of these sites differed significantly from that in more frequently burnt areas. High and moderate fire frequency sites also differed with respect to shrub floristics. A higher abundance of obligate seeder legumes distinguished sites with mostly 4 to 10 year intervals between fires from those which had experienced shorter or longer intervals. While competition from Bursaria probably played a role in the low abundance of obligate seeders in low fire frequency sites, the direct impact of a lack of fire is likely to have been at least as important (Chapter 3).

How does *Bursaria spinosa* regenerate after a fire?

In the single site where post-fire recovery of Bursaria was studied, a large majority of pre-fire plants resprouted, although smaller plants, particularly those below 25 cm, were less likely to recover than larger ones. Winter rain brought a flush of seedling establishment in the vicinity of plants over 3 m high. Although many seedlings died, some survived, and others established over the second post-fire year. There were more Bursaria plants 25 months post-fire than there were prior to the burn. Growth in Bursaria appears to be linked to rainfall. Even small plants have swollen tap roots, although no evidence of suckering was found. These findings suggest mechanisms to explain the distribution of Bursaria in sites with different fire frequencies (Chapter 6).

10.2.2 CPW trees and fire

The current mean density of adult trees in survey remnants, 279 per hectare, is almost certainly greater than pre-settlement values. There is evidence that density in today's remnants is resource limited, and may be decreasing as post-logging regrowth self-thins. There is a high degree of variability between remnants in tree density, but a much smaller range in average basal area, indicating that remnants tend to have either a large number of small trees, or a smaller number of larger trees (Chapter 4). Large adult trees appear to be suppressing recruitment, particularly recruitment into the canopy (Chapter 5).

Does tree density or recruitment into the canopy vary with fire frequency?

Fire frequency did not significantly affect either adult tree density, adult tree basal area, or the density of juveniles or saplings, a finding which accords with the vital attributes status of the three dominant CPW eucalypts. Trends suggest frequent fire may be associated with an increased density of juveniles, but also with a decrease in the number of saplings 'getting away' into the canopy. Summer wildfire may also limit sapling numbers (Chapter 4). Both these points are moot, however, if adult tree numbers are decreasing as remnants recover from logging, and dominant trees become larger.

10.2.3 CPW herbs and fire

Does grass cover or dominance differ with burning frequency?

The primary impact of fire frequency on the ground layer appears to be on the tussock grass *Themeda australis*. This species dominated over 50%, and up to 83%, of subplots in sites with a high or moderate fire frequency, but less than 50% in all low fire frequency sites. At Scheyville, where fire had reputedly been excluded for 50 years, *Themeda* dominated only one subplot in 200 (Chapter 4). *Themeda* abundance is significantly associated with a reduction in herbaceous exotics (Chapter 8). This finding, along with findings from recent experiments which indicate that *Themeda* may play a role in regulating weeds through keeping nitrate levels low (Prober *et al.* 2002b, 2004) suggests that loss of *Themeda* may be associated with the loss of important ecosystem functions.

Is flowering and fruiting in CPW herbs greater in the post-fire period than some years after a fire?

Fire appears to play a role in the reproduction of many CPW ground layer species. Flowering and fruiting, particularly of forbs, was much greater in two sites burnt three to five months prior to survey, than in nearby unburnt areas. Bare ground was considerably more common, as were seedlings (Chapter 7). These findings are consistent with those from studies of seedbanks in grassy vegetation: although some ground layer species respond to fire-related cues, many do not, and persistent soil seedbanks are the exception rather than the rule (Section 1.7). Rather than enhancing seed germination, fire may enhance seed *production*: seeds resulting from a pulse of post-fire flowering and fruiting might be expected to germinate in the second growing season after fire, making long-term seed storage and fire cues unnecessary.

Does ground layer species richness, abundance or composition differ with fire frequency?

Despite enhanced post-fire flowering, when sites which had experienced different fire frequencies were compared, little evidence of differential effects on ground layer species was found (Chapter 8). Neither species richness of native herbs, nor species composition, differed significantly between fire frequency categories. In fact, forbs *increased* in importance relative to grasses as fire frequency decreased, though remaining a central component of the ground flora under all fire regimes. Enhanced growth of grasses, especially *Themeda*, in more frequently burnt areas may explain these findings.

Do different microhabitats support different herbaceous species?

Though evidence for a direct effect of fire frequency on ground layer composition was slight, findings in relation to the influence of microhabitat on ground layer species composition point to a strong indirect impact. Open patches, patches around trees and patches under Bursaria hosted significantly different arrays of ground layer species. Ten of 14 species with a statistically significant connection with a particular microhabitat favoured open patches, including several lilies with underground storage organs. Thus the effect of fire frequency on ground layer species composition will be mediated by the changes in the shrub layer described above. If Bursaria expansion under infrequent burning leads to a loss of open patches, a decline in herbaceous ‘open patch’ species can be expected (Chapter 8). As patches under Bursaria are more similar floristically to patches around trees than to open areas, open patches provide a unique habitat in CPW.

10.2.4 CPW exotics and fire

Does fire frequency influence exotic weeds in CPW?

Woody exotics were more abundant in low fire frequency sites than in areas which had burnt at least once a decade. Very frequently burnt sites had virtually no woody exotics (Chapter 4). Similarly, significantly less herbaceous weed species were found in very frequently burnt microhabitat plots than in plots where fire frequency had been low (Chapter 8). There was a significant negative association, at a small scale, between the abundance of *Themeda australis* and the species richness and abundance of exotic herbs (Chapter 8).

10.2.5 CPW vegetation as fuel

How does fuel accumulate over time in CPW?

Fuel accumulation in CPW starts from a low base as even low intensity fires consume most available fuel. Modelling indicates that equilibrium fuel loads will be attained within ten years, however peak loads of around nine tonnes per hectare are low relative to those in nearby sandstone woodlands. Eucalypt litter – leaves, sticks and bark – was the major contributor to fuel loads in areas sampled. Grasses were an important component in the first post-fire year, but a minor contributor thereafter, while decomposing material contributed more in both absolute and relative terms as time-since-fire progressed. The contribution of shrub fuel, mostly Bursaria twigs, was many times higher in infrequently burnt sites than where fire had occurred at least once a decade.

10.2.6 Ecology informing management

The themes of the non-equilibrium paradigm resonate through the findings of this project. Vegetation on the Cumberland Plain *is* ‘in flux’ – it changes with time-since-fire, and it changes with fire frequency. Disturbance mediates coexistence of shrubs with different life histories, and that of grasses and herbs. Patchiness in shrub distributions, itself a product of disturbance, provides diverse habitat for ground layer species. Fire truncates the succession from grassy to shrubby woodland (and perhaps beyond), a role it seems to play across the world (Bond *et al.* 2005).

The management implications of the non-equilibrium paradigm also apply. If we want to conserve the diversity of Western Sydney’s grassy woodlands, we must consciously manage the processes which sustain it, including fire. The findings of this project, and the insights into ecosystem processes they engender, contain much that may be of assistance to managers. The remainder of this chapter addresses the question:

What guidance for managers can be drawn from this research?

10.3 A state and transition model for CPW

Project findings were used to develop a model of the effects of fire on Cumberland Plain Woodland (Figure 10.1). The model uses the state and transition framework outlined by Westoby *et al.* (1989). Four 'states' in which CPW can be found are identified. Three – States 1, 2 and 3 – are stable under certain conditions; S4 is transitory.

The model allows exploration of conditions which might maintain States 1 to 3, and of transitions between states, without imposing value judgements as to the desirability of either particular states, or particular transitions. It therefore has the potential to inform a variety of management aims, for a variety of situations. Values will be discussed subsequently.

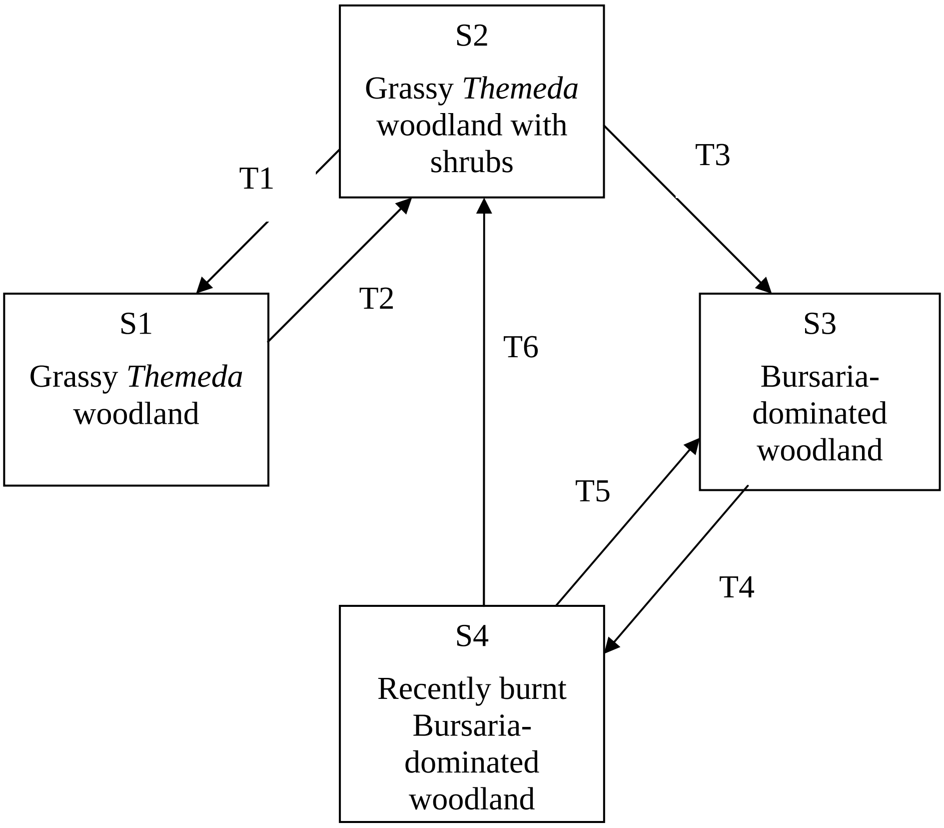

Figure 10.1. State (S) and transition (T) model describing four states in which Cumberland Plain Woodland can be found, and transitions which may occur between these states. See text for detail of each state and transition.

10.3.1 Description of states

State 1 is grassy *Themeda* woodland with occasional Bursaria patches, but few other shrubs (Figure 10.2). The ground layer is diverse, although its composition is slanted towards open patch species. State 1 has virtually no woody exotics, and relatively few herbaceous ones.

State 2 is grassy *Themeda* woodland with some Bursaria patches, as well as patches of other shrubs, including obligate seeders (Figure 10.3). It has a diverse ground layer with good representation of species that favour both open and shady patches. It has few woody weeds.

In **State 3** the woodland is dominated by *Bursaria spinosa* to the point where there are few open patches (Figure 10.4). Other native shrubs, particularly obligate seeders are in relatively low abundance. Exotic shrubs such as *Olea europaea* ssp. *africana* and *Sida rhombifolia* are in evidence. The ground layer is diverse, though representation of open patch species is relatively low, and herbaceous weeds are not uncommon.

State 4 is State 3 woodland which has recently been burnt (Figure 10.5). *Bursaria spinosa* is resprouting, as are grasses and forbs.

10.3.2 Maintaining states

What management actions might maintain states 1 to 3 (state 4 is by definition transitory)? As project studies were observational rather than manipulative, the descriptions in this section should be considered tentative. They should be used to generate hypotheses for experimental testing when resources for a long-term manipulative study are available, or to guide long-term targeted monitoring.

The results of the landscape study (Chapter 4) strongly suggest that frequent burning would be needed to maintain **State 1**. A fire every 2 - 4 years would allow regeneration of *Themeda* and other existing ground layer species, and keep the abundance of Bursaria, other native shrubs, and weeds low.

Various findings suggest a fire interval domain of approximately 4 to 12 years would be appropriate for maintaining **State 2,** open *Themeda* woodland with obligate seeder shrubs. Variable intervals between these thresholds should allow both Bursaria thickets and open grassy areas to co-exist in the landscape.

Figure 10.2. State 1: grassy *Themeda* woodland with some Bursaria patches, few other shrubs, and virtually no woody weeds.

Figure 10.3. State 2: grassy *Themeda* woodland with shrubs, including obligate seeders, some Bursaria thickets, and few woody weeds. Photo by Annie Storey.

Figure 10.4. State 3: Bursaria-dominated woodland with few other shrubs, and some woody weeds.

Figure 10.5. State 4: recently-burnt Bursaria-dominated woodland.

Interfire intervals need to be long enough to allow regeneration of the obligate seeder shrubs which characterise State 2. The key fire response species, *Grevillea juniperina* ssp. *juniperina* has a primary juvenile period of four years: the argument for pegging lower thresholds at this level is detailed in Chapter 3. The legumes amongst the CPW shrub contingent are buffered from negative effects of occasional very short interfire intervals through retention of ungerminated seed in the soil. This was demonstrated for several species, including *Daviesia ulicifolia* and *Acacia decurrens,* at Holsworthy, where sampling followed a two-year interfire interval. Both species were relatively abundant, although it is unlikely that seedlings germinating after the previous fire would have had time to produce fruits. Twenty years of short interfire intervals at Prospect had also failed to eliminate obligate seeder shrubs, which were more prevalent along landscape study transects at Prospect than in any other site; this was 15 years after annual fuel reduction burning gave way to a more moderate regime (Chapter 4). These factors strongly suggest that intervals as low as four years, within a varied regime which also includes longer periods between fires, will not disadvantage shrub species.

On the other hand, fire needs to occur before short-lived fire-dependent species and their seedbanks senesce. *Themeda* is potentially vulnerable: if decline rather than complete local extinction, and ecological importance, are considered, *Themeda* may be the key fire response species for infrequent fire. In a Victorian grassland this species declined due to self-shading between six and 11 years post-fire, and failed to recover its former abundance when a burn occurred after 11 years (Morgan and Lunt 1999). *Themeda* in CPW may be slower growing, as CPW shale soils would be less nutrient-rich than the basalt-derived clays which support Victoria's grasslands, and may therefore take somewhat longer than 11 years to collapse locally. Still, *Themeda* abundance was much reduced in all low fire frequency sites in the landscape study, suggesting intervals in CPW should not be set too high. Recent research suggests *Themeda* may play a key role in maintaining ecosystem integrity (Prober *et al.* 2004), so a precautionary approach to its preservation is warranted. When all these factors are considered, a top threshold of 12 years seems reasonable.

Short-lived shrubs also need a chance to regenerate before soil seedbanks decline. Analysis from a vital characteristics perspective in Chapter 3 led to the recommendation that maximum intervals not exceed 15 years. Factors include observations of the death of significant proportions of local populations of some obligate seeders six to 10 years post-fire, possible decline in productivity of remaining individuals (Auld and Myerscough 1986, MacFarland 1990), and concerns that seedbanks in CPW clay soils may not survive for long periods. The low abundance of obligate seeder shrubs in low fire frequency sites, despite recent fire, suggests the upper threshold should not be set too high, as does the very high vulnerability to low fire frequency evident from the vital attributes analysis. There is ample evidence that CPW shrubs thrive under intervals below 12 years (Chapter 4).

Finally, fire needs to recur with sufficient frequency to maintain a balance between open areas and Bursaria thickets if State 2 structure is to be maintained. Bursaria was a prominent species in all CPW sites, forming some thickets even in high fire frequency areas: it is therefore unlikely to be at risk at this end of the fire frequency spectrum. Keeping this very successful species within bounds is the greater challenge: this is important to ensure populations of ‘open patch’ herbs are maintained (Chapter 8), and that possible competitive effects of Bursaria on obligate seeder shrubs (Chapter 5) do not become too great. The intervals represented in landscape study sites were not sufficiently fine-grained to pin-point the threshold at which Bursaria density begins to rise sharply, although we know it has increased considerably at Mt Annan during a probable 20 year interval (Benson and Howell 2002). Observation at other CPW sites, particularly Prospect and Nurragingy, suggests Bursaria density may build up quite rapidly in some areas, despite a fire recurrence of approximately once a decade. The propensity of Bursaria to dominate may be greatest where nutrients and moisture are most readily available (Crowley and Garnett 1998, Roques *et al.* 2001, Noble and Grice 2002). Again, intervals between 4 and 12 years would likely achieve a mix of Bursaria and open patches.

Given the variability in juvenile periods in obligate seeder shrubs, and uncertainties about maximum intervals for limiting Bursaria expansion and maintaining *Themeda*, it is recommended that CPW managers seeking to maintain State 2 characteristics monitor:

- Flowering of obligate seeder shrubs. Fire should normally be excluded until these species have had a couple of good flowering years. In some years, flowering and seed set may be limited by drought (pers. obs. 2002; Auld and Myerscough 1986, Bell *et al.* 1993).
- Bursaria expansion. Fire may need to be applied more frequently if Bursaria is encroaching into previously open areas.
- *Themeda*. Fire may need to be applied more frequently if *Themeda* clumps are dying.

Monitoring these parameters would be relatively simple, and could help tailor fire management to the needs of particular sites, and to variations in plant growth resulting from variations in rainfall.

Experience in low fire frequency sites suggests that **State 3** would be adequately maintained by fire exclusion, or a low fire frequency. How often could fire recur without reducing Bursaria density? Research from other localities where shrub encroachment is occurring suggests that once a thicket is established, it has considerable inertia (Scholes and Archer 1997). New successional processes begin to drive the system, shrubs modify soils and microclimate, and seedbanks change (Archer 1989). Monitoring at Mt Annan (Chapter 6) showed an increase, rather than a decline, in Bursaria density after a single fire following a probable 20-year interfire interval. In a well-established Bursaria-dominated woodland, 12 - 15 year intervals might cause little change.

10.3.3 Transitions

Some possible transitions between states are shown in Figure 10.1. Again, these descriptions should be viewed as tentative until experimentally tested.

Transition 1 takes open grassy woodland with shrubs to open grassy woodland with few shrubs. Frequent burning, say every one to three years, should accomplish this transition.

Transition 2 takes open grassy woodland with few shrubs to open grassy woodland with shrubs. A reduction in burning frequency should encourage this transition, although fire should not be completely suppressed. Experimentation with intervals in the 6 - 10 year range is suggested. Six to ten years would allow obligate seeder shrubs time to build up seedbanks, and fuel loads would be sufficiently developed to support a moderately intense fire and thus good germination.

Transition 3 takes grassy woodland with shrubs to Bursaria-dominated woodland. Fire exclusion should support this transition. How quickly Bursaria would spread would almost certainly depend on its initial abundance and distribution (Clarke and Davison 2001), as well as on the local availability of soil nutrients and moisture. Stocking with domestic animals might hasten this process, by removing grass competition and making fire less likely.

What about the transition from State 3 to State 2? This is where State 4 becomes relevant.

Transition 4, which takes State 3 to State 4, is simply a fire in a State 3 woodland. Though simple conceptually, accomplishing this transition may be difficult for managers, as State 3 woodlands are hard to burn (J. Sanders, NPWS, pers. comm 2004). Bursaria does not appear to be as flammable as more sclerophyllous shrubs, and the closed nature of Bursaria thicket may create a more mesic environment than that found in open grassy areas. Similar dynamics have been observed in Australia's semi-arid rangelands (Noble 1997). Transition 4 planned burns may therefore need to be carried out in conditions outside those appropriate for other vegetation types. In some situations, wildfire may supply this transition. However fragmentation means many remnants are now cut off from wildfire paths (Bond 1997), so this option is unlikely to be viable for many CPW sites.

Transition 4 represents an opportunity to move from State 3 to State 2 via State 4. However management action is required to take advantage of this opportunity. Without action, a burnt Bursaria-dominated woodland will rapidly return to its previous state. This is **Transition 5**. During the course of the project this process occurred at all three low fire frequency sites: Bursaria resprouts at Orchard Hills and Scheyville reached 2 m in height by 2.5 years post-fire, and Bursaria frequency and density was high in post-fire surveys (Chapter 4). Plant numbers reached 110% of pre-fire totals by two years post-fire in monitoring plots at Mt Annan (Chapter 6).

What might encourage **Transition 6**, that is a return to grassy woodland with open patches and obligate seeder shrubs? Research from other ecosystems has demonstrated that an increase in fire frequency can be used as a management tool to help regain open grasslands and woodlands in the face of shrub increase (Hodgkinson and Harrington 1985, Roques *et al.* 2001). Experimentation with 4 or 5 year intervals, but also with intervals between 1 and 3 years in parts of the landscape without obligate seeder shrubs, is suggested. The more open landscape of State 4 would probably carry a fire more easily than State 3; grass growth would provide flammable fuel (Chapter 9) as would dead Bursaria stems remaining from the Transition 4 fire. In semi-arid woodlands, resprouting *Eremophila* spp. which appear to have similar life-history strategies to Bursaria are vulnerable to two autumn fires a year apart, even though a single fire has little effect (Hodgkinson 1986, cited in Hogkinson 1998).

The primary aim of short intervals would be to reduce Bursaria density and encourage *Themeda* growth. *Themeda* clumps and some dead Bursaria plants have been noted in a small patch at Scheyville subject to a two-year interfire interval after a long period of fire exclusion; *Themeda* is absent from adjacent woodland burnt only in the first fire. This observation suggests long unburnt CPW may be able to demonstrate remarkable resilience when burning is reinstated. However there is no guarantee one or two short intervals will reintroduce *Themeda* to sites where it is not currently found. Nor is it likely to assist shrubs other than Bursaria to establish and expand; in fact very short intervals might eliminate any remaining obligate seeders. One way to address this problem could be to collect seed of *Themeda* and local shrubs, particularly obligate seeders, and spread it in patches some time before the second fire (McDougall and Morgan 2005).

10.4 Conservation values and fire management in CPW

Section 10.3 above outlines actions managers *could* take in CPW remnants, however it does not address the question of which actions *should* be taken. This section argues for actions I believe would benefit conservation of biological diversity in Cumberland Plain Woodland. As such it reflects my values, which may not be shared universally; values are, by their nature, subjective.

10.4.1 Conservation value of states

All four states described above have high conservation value; no remnant should be devalued because it fits into a particular category. In terms of plant diversity, all three states support many native grass and herb species. The CPW ground layer is resilient in the face of even quite extreme fire regimes (Chapter 8). Ground layer species richness at the 10 m^2 scale is similar in States 1, 2 and 4. As State 4 remnants were recently in State 3, presumably this state too hosts similar ground layer diversity, even if some species are not visible above ground.

10.4.2 Value of *Bursaria spinosa*

Although *Bursaria spinosa* tends to dominate the CPW landscape under particular circumstances, this does *not* imply that it is a 'problem plant' *per se*. Bursaria is a natural and important component of all CPW remnants. Its thorny nature and tendency to form thickets make it important habitat for birds such as the Striated Thornbill, Eastern Yellow Robin, and White-browed Scrubwren. Many bird species use a mix of shrubby and open patches (H. Recher, unpub data). Bursaria leaves and bark provide food for insects and other grazing animals, including macropods (pers. obs., 2001-4). Intricate Bursaria-insect interactions have been noted (Bellingham 2003, Watson 2004). Unlike exotics such as African Olive and Lantana, the canopy of Bursaria is not completely closed, and it does not shed much litter (pers. obs. while collecting fuel load samples, 2004). Thus it does not exclude ground layer herbaceous species, although as noted in Chapter 8 some species are more likely to be found in open patches.

10.4.3 Value of open grassy woodland

Although maintenance of existing species richness is obviously vital (Benson and Howell 2002), the structural integrity of Western Sydney's grassy woodlands is also worthy of conservation focus. There is a real risk that the open grassy character of Cumberland Plain Woodland could be completely lost over the next 50 years under the combined influence of fire exclusion and increased atmospheric carbon dioxide, which may also encourage woody plant growth (Berry and Roderick 2002, Bond *et al.* 2003b).

10.4.4 Management of grassy woodland with shrubs

Resources available for management are often limited, and priorities for conservation must be set. There are strong arguments for giving precedence to State 2 remnants.

Conservation values in State 2 remnants are likely to be relatively high. These remnants have a good shrub complement, and a balance between open and shrubby patches. This may give them particular value as fauna habitat, as habitat requirements vary widely between animal species, and some species use resources from a variety of habitats (Friend 1993, Catling and Burt 1995, York 1999, Tasker and Dickman 2004, Woinarski *et al.* 2004). Woody weeds are not a major problem in State 2 remnants. Although a number of areas on the Cumberland Plain are in this state, including parts of the large remnants at Prospect and Holsworthy, without conscious management they are at risk.

10.4.5 Management of Bursaria-dominated woodland

State 3 remnants have continuing conservation value, however they do not provide a hospitable environment for either obligate seeder shrubs or open patch ground layer species. Weediness is also an issue. Quite a number of CPW remnants are either currently in State 3, or appear to be heading that way. Fire exclusion, which has been the de facto management strategy for most CPW remnants over the last 15-20 years, is likely to have been the major factor behind this trend, although increased atmospheric carbon dioxide may also have played a role through stimulation of woody plant growth (Berry and Roderick 2002, Bond *et al.* 2003).

Managers of remnants currently dominated by Bursaria, or in which Bursaria is thickening, need to consider their options carefully. Fire exclusion may be justified in rare instances, for example as protection for cover-dependent fauna. However Bursaria dominance is likely to be associated with a decline in other native shrubs, in ground layer species which favour open patches, and in birds which need open foraging areas (Chapman and Harrington 1997). Weed abundance is likely to continue to increase. Experimentation with Transitions 4 and 6 is suggested. Given the difficulties of burning where Bursaria covers the landscape (see discussion of Transition 4 in Section 10.3.3), managers of remnants with moderate Bursaria density which still retain open patches may be well advised to introduce fire sooner rather than later.

10.4.6 Management of grassy *Themeda* woodland

State 1 remnants are not common, and those that do exist are not adequately conserved. Although shrub abundance is low, these areas are less weedy than others, have a diverse ground flora, and provide habitat for macropods. While a decrease in fire frequency would be desirable, I believe there is value in conserving these open grassy woodlands, even if arsonists prove intractable.

10.4.7 Importance of active management

Elsewhere in Australia, the need for urgent action to preserve fire-maintained habitats is being recognised (eg Crowley and Garnett 1998, Russell-Smith and Stanton 2002). As Lunt (1998a:644) pointed out after cataloguing the conversion of open grassy woodland at Ocean Grove in Victoria to impenetrable Casuarina thicket, "To conserve biodiversity in the future, ecologists and land managers must develop and instil an informed philosophy of active vegetation management, rather than perpetuating a pervasive attitude of passive non-intervention." These sentiments echo those of non-equilibrium paradigm theorists overseas (Pickett *et al.* 1992).

10.5 Managing weeds

In this project, frequent fire was associated with significantly lower levels of weediness than infrequent fire, for both shrubs (Chapter 4) and herbs (Chapter 8). The relationship appears to be linear, with very frequently burnt remnants having the lowest abundance of weeds. The dominant tussock grass *Themeda australis* may play an important role in keeping exotic herbaceous weeds at bay (Prober *et al.* 2002b, 2004). This species dominated sites with a high or moderate fire frequency, but not those which had been infrequently burnt. These findings have profound implications for management.

The finding of a low weed frequency in frequently burnt areas is not exclusive to this project. For example Yibarbuk *et al.* (2001) found no weed species whatsoever in traditionally burnt savanna in Arnhemland. However the current project is one of very few Australian studies in which the extent of exotic weed invasion has been compared between sites with different degrees of exposure to fire.

It is possible that a number of exotic shrub species are advantaged, under low fire frequencies, by their ability to recruit all though the interfire interval (T species of Noble and Slayer 1980, see also Kirkpatrick 1986). They may also, however, grow relatively slowly, and thus be vulnerable when young. Fire at intervals shorter than the time taken for these species to reach fire tolerance would prevent their establishment. In CPW, there may be an argument for concentrating on shorter intervals in the moderate 4 - 12 year range, or at least for adding "establishment of woody exotics" to the list of indicators for monitoring in State 2 remnants (Section 10.3.2).

Although many exotics may be deterred either directly or indirectly through regular burning, other weed species may be well equipped to take advantage of the “stable invasion window” provided by frequent fire (Morgan 1998d, Setterfield *et al.* 2005). Concerns that this might apply to two grass species with high invasive potential in temperate areas – *Eragrostis curvula* (African Love Grass) and *Nassella neesiana* (Chilean Needle Grass) – have been expressed (Stuwe 1994, Nadolny *et al.* 2003). Neither of these species is currently a major problem in the areas surveyed for this project, although *E. curvula* was often found on the edges of frequently burnt remnants, particularly where grass had been mowed, or soil disturbed. Managers are strongly advised to target these species as they regenerate in the weeks after a fire, before they flower.

In addition, although fire appears to have limited weed encroachment into State 1 and 2 remnants, it unfortunately does not follow that frequent fire will eliminate weeds from State 3 remnants. Companion strategies such as hand-weeding and the use of herbicides are almost certain to be needed (Little 2003, Willis *et al.* 2003). The post-fire environment may present opportunities to target weed species while in an active growth phase, and while they can easily be disentangled from natives. The extent to which fire, and other strategies along with fire, can play a role in reducing weediness in CPW would be an excellent subject for the adaptive management approach (Bradstock *et al.* 1995, Lunt and Morgan 1999, Whelan and Baker 1999, Gill *et al.* 2002, Keith *et al.* 2002b).

10.6 Fire interval domains for Castlereagh woodlands

While the grassy Cumberland Plain Woodland vegetation type was the primary focus of the project, information on regeneration mechanisms and juvenile periods of shrub species in the more shrubby Castlereagh woodlands were also collected. This information was used to inform application of the vital attributes model to Castlereagh woodlands (Chapter 3).

10.6.1 Lower thresholds

Petrophile pulchella was identified as the key fire response species amongst Castlereagh woodland taxa for frequent fire. Bradstock and O'Connell (1988) found that this serotinous obligate seeder first flowered at four years post-fire on sandstone, although time to maturity varied between sites. In the current study, plants were observed flowering just under three years post-fire at Castlereagh, although other populations of this post-fire age had not yet flowered. The figure of six years for the juvenile period of this species is an average of 3-9 years (the 9 year figure came from the range in the NSW Database of 4-9 years), and is probably conservative.

Petrophile pulchella occurs in sandy Castlereagh Scribbly Gum sites, but not on the finer-textured Castlereagh Ironbark Forest soils. No other species classified as highly sensitive to frequent fire had a juvenile period above five years.

Shale-Gravel Transition Forest hosts a subset of the shrub species found in Cumberland Plain and Castlereagh woodlands. Short-lived obligate seeder legumes are prominent. There is a rough gradient both in soil texture (clay to sand) and species complement from CPW, though Shale-Gravel Transition Forest and Castlereagh Ironbark Forest, to Castlereagh Scribbly Gum woodland. Keeping this in mind, the following minimum intervals are suggested:

- Castlereagh Scribbly Gum Woodland, 6 years;
- Castlereagh Ironbark Forest, 5 years;
- Shale-Gravel Transition Forest, 5 years; and, as already discussed,
- State 2 Cumberland Plain Woodland, 4 years.

10.6.2 Upper thresholds

Application of the vital attributes model using longevity estimates from the NSW Database led to the recommendation that the maximum interval in Castlereagh woodlands should be no higher than 23 years. In CPW, expansion of Bursaria at the expense of open grassy areas and possibly obligate seeder shrubs led to recommendation of a somewhat lower top threshold than that suggested by vital attributes analysis alone. Are there reasons to think similar issues may also arise in Castlereagh woodlands?

No hard data on Castlereagh woodland species able to recruit between fires are available. Only three relatively common ‘T’ species were identified: *Bursaria spinosa*, *Hakea sericea* and *Styphelia laeta* ssp. *laeta*. *Bursaria spinosa* did not appear to act in the same manner in Castlereagh woodland as in CPW: no landscapes dominated by this species were encountered in the former vegetation type. Perhaps the existence of other large resprouting shrubs keeps it in check. *Hakea sericea* was prominent in some long-unburnt woodlands. The inclusion of some intervals just above lower thresholds in variable regimes would ensure this species did not become overwhelming. *Styphelia laeta* was placed in the T category because observations suggested recruitment between fires. This species is a relatively low-growing obligate seeder shrub which is unlikely to cause problems for other species.

It is possible that a number of other T species occur in Castlereagh woodlands. *Persoonia nutans* has already been mentioned (Section 3.4.7). *Kunzea ambigua* is another possibility: this Myrtaceous species dominated wetter depressions in some areas; its dead branches loomed over fields of flowering obligate seeder shrubs 2 years after fire (Figure 10.6). A number of Myrtaceous resprouters, including *Melaleuca nodosa* and *Leptospermum* spp. were prominent in areas which had had long intervals between fires. *Kunzea, Leptospermum* and *Melaleuca* species have demonstrated encroachment potential elsewhere (Judd 1990 cited in McMahon *et al.* 1996, Bennett 1994, Crowley and Garnett 1998), as has *Casuarina littoralis* (Withers and Ashton 1977, Lunt 1998a,b) which is also found in Castlereagh woodlands.

The potential for encroachment by a small number of shrub species in the absence of fire may be greater on the deep clay Castlereagh Ironbark Forest soils than in drier sandy areas (Section 10.8.3). Taking a precautionary approach in relation to possible competition issues, and considering soil productivity gradients, the following maximum intervals are proposed:

- Castlereagh Scribbly Gum Woodland, 20 years;
- Castlereagh Ironbark Forest, 18 years;
- Shale-Gravel Transition Forest, 15 years; and, as already discussed
- State 2 Cumberland Plain Woodland, 12 years.

Figure 10.6. *Kunzea ambigua* skeletons above a field of flowering obligate seeder shrubs, particularly *Pimelea linifolia* ssp. *linifolia* and *Dillwynia rudis*, 23 months post-fire, at Castlereagh.

10.7 Managing fire on the urban fringe

This section addresses the question:

> **Do fire regimes compatible with bushland conservation in CPW overlap those needed to achieve protection from wildfire?**

The answer to this question is basically "yes, to a large extent they do." If CPW is managed for bushland conservation, fuel loads over much, if not all, of the landscape should remain below the levels considered hazardous from the point of view of property protection.

10.7.1 Intervals for bushland conservation

Fire frequencies for conservation of biodiversity in CPW are outlined in Section 10.3.2. Intervals between 4 and 12 years are predicted to maintain State 2: remnants in this state have high biodiversity values due to a patchy habitat structure, a good complement of obligate seeder shrubs and a *Themeda*-dominated understorey. Maintenance of the open grassy nature of State 1 remnants could be achieved with intervals between 2 and 4 years, although longer intervals should encourage greater shrub biodiversity.

Maintenance of State 3 would not require any fire, however experimentation with intervals between 1 and 5 years may increase habitat diversity, discourage weed invasion, and increase the proportion of *Themeda* in the understorey. Once this was achieved, State 2 thresholds would be predicted to maintain diversity.

Ideally, then, fire frequency in CPW remnants managed for plant and habitat diversity would involve fires at intervals between 4 and 12 years, with some shorter intervals either to maintain very open grassy habitat, or to open up areas currently occupied by thick Bursaria.

Within these thresholds, **variability in both time and space** is strongly recommended. Variability in interfire intervals is widely advocated by ecologists (Cowling and Gxaba 1990, Yeaton and Bond 1991, Bradstock *et al.* 1995, Morrison *et al.* 1995a, Keith 2002b). This is because even within a single vegetation type, fire-related vital attributes, and thus ability to persist within fire cycles, varies between species (Richardson *et al.* 1995, Hobbs 2002, Williams *et al.* 2003). For the full species complement to co-exist, some intervals which are less than ideal for dominant species may be important (Keith and Bradstock 1994, Tozer and Bradstock 2002). Field research indicates that plant species diversity is maximised through diversity in interfire intervals in sandy Sydney environments (Morrison *et al.* 1995a).

In large CPW remnants, the concept of variability could be expanded to include management practices compatible with maintenance of all three states on site. Given the greater conservation values of State 2 relative to States 1 and 3, it is suggested that while a majority of the landscape should be subject to intervals between 4 and 12 years, shorter intervals could be employed in limited areas, while other restricted parts of the landscape could be managed for denser vegetation through intervals over 12 years. Characteristics of local native fauna, particularly dispersal distances, could inform further thinking about the optimal distribution of states across a landscape.

10.7.2 Intervals for property protection

"The primary motivation for use of prescribed fire is to manipulate fuel structure and quantity to levels which ameliorate intensity of unplanned fires under severe fire weather" (Bradstock 1999:12). The acceptable hazard level in the sclerophyll vegetation of southern Australia is considered to be about 8 to 12 tonnes per hectare

(Walker 1981, Simmons and Adams 1986, Fensham 1992, Tolhurst 1996a). In Cumberland Plain Woodland, modelling indicates equilibrium fuel loads of around 9 t/ha. Thus if the aim is to maintain loads below 10, or below 12 t/ha, fuel reduction burning would appear to be unnecessary in this vegetation type – although, as Fensham (1992:315) cautions, figures based on fuel accumulation curves "can only be relied upon to provide management guidelines in a broad sense."

The point at which a load of 8t/ha is likely to be reached may vary depending on the state of the vegetation. When State 3 remnants were excluded from modelling inputs, it was predicted that this level of fuel would accumulate by 6.1 years post-fire. However this figure dropped to 4.3 years post-fire when three data points from a very infrequently burnt, Bursaria-dominated area were included (Section 9.3.1). The difference almost certainly relates to the rapid build-up of shrub fuel as Bursaria resprouts (Section 9.4.3). Dead Bursaria stems also contribute to the fuel load in State 3 remnants in the months and years following a fire.

Thus intervals of six or fewer years should maintain fuel loads below even the most conservative hazard figure, where CPW is in State 1 or 2. Intervals below four years, however, may be needed in State 3 remnants where Bursaria is thick.

10.7.3 Managing for multiple aims

In **State 1 and 2** remnants, then, there is an absolute overlap between fire frequencies compatible with biodiversity conservation and those needed to keep fuel below hazardous levels. A fire frequency of between four and six years should allow obligate seeder shrubs to persist, though perhaps at relatively low levels. *Themeda* dominance of the understorey would be maintained, Bursaria thickets would survive but be of limited extent, and ground layer forbs would have many opportunities for recruitment. Fuel loads should remain below 8 t/ha.

However better biodiversity outcomes are likely to be achieved if intervals between 6 and 12 years were also included in variable regimes. These intervals would favour shrubs, both Bursaria and obligate seeders. Habitat diversity would increase: Bursaria thickets would be larger, and areas with a time-since-fire of above six years would provide 'old' habitat for invertebrates and other fauna with a preference for later timessince-fire (Fox and McKay 1981, Fox 1982, 1983, McFarland 1988b, Friend 1993, Wilson 1996, Woinarski 1999, York 1999).

One option in State 1 and 2 remnants would be to manage areas **near built assets** on the 4-6 year intervals that would keep fuel levels below 8 t/ha, and areas **away from these assets** on intervals between 4 and 12 years. Short intervals at remnant edges might have the additional advantage of providing a partial barrier to weed invasion: in this project, very frequently burnt areas were the least weedy (Section 10.2.4). Variable intervals in time and space in areas away from assets would not only have conservation benefits, but would ensure that fuel loads were broken up. Patches of ‘old’ fuel would be interspersed with patches which had been burnt more recently, making suppression in the event of a wildfire more likely to be effective (Raison *et al.* 1983). As Friend *et al.* (2003:2) point out, “All fires (and indeed absence of fires) have an ecological dimension, while many ‘ecological burns’ may also provide some asset protection.”

In remnants where the vegetation is in **State 3**, life and property issues may be somewhat more problematic. While CPW vegetation in this state is probably less flammable than open *Themeda*-dominated woodland (Section 10.3.3), when a fire does occur fuel loads may be higher, and Bursaria may ladder fire into the canopy (Section 9.4.3). Woody weeds such as olive and privet, which are more likely to be found in long unburnt State 3 than elsewhere (Chapter 4) may enhance fuel loads still further, as these species produce a litter layer that is significantly deeper and heavier than that produced by native species (J. Cooke, unpub. data). In addition, the low fire frequency compatible with maintenance of this state means equilibrium fuel loads will tend to prevail across most of the landscape. As noted above, when a fire does occur, hazardous levels may be achieved relatively rapidly, due to the contribution of dead and resprouting Bursaria.

Here is yet another reason for experimentation with Transition 6. A move from Bursaria-dominated woodland to State 2 woodland with its balance between shrubby and open areas would not only enhance biodiversity values and hopefully slow weed invasion, it would also provide more options for keeping fuel loads across the landscape in a state which would make fire suppression easier if a wildfire were to occur.

In shrubby woodlands on sandstone around Sydney, the conflict between burning frequencies compatible with biodiversity conservation, and those which keep fuel below hazardous levels, is significant. Not only do the two regimes fail to overlap, minimum intervals for biodiversity conservation are years above maximum intervals for keeping fuel loads low, even where 10 or 12 t/ha is used as the benchmark (Morrison *et al.* 1996, Section 9.3.1). The situation in Western Sydney's grassy woodlands is very different, and may be reflected in grassy woodlands elsewhere.

10.8 Implications for setting fire frequency thresholds

The findings of this project have implications for the goals and methods of determining fire frequency thresholds for vegetation types, particularly those with a grassy character.

10.8.1 Fire management goals

In NSW, it is widely accepted that the goal of 'biodiversity conservation', which fire frequency thresholds are designed to meet (NPWS 2004c), can be translated into the more measurable objective of the avoidance of extinction of all species currently present in a particular unit of interest, such as a vegetation type, a conservation reserve or a remnant (eg Bradstock 1999, Benson and Howell 2002). This definition focuses at the level of individual species, however 'biodiversity' also encompasses biotic communities and ecosystems (Noss and Cooperrider 1994, NPWS 2004b). Grassy ecosystems are characterised by their structure as well as by their species complement. The findings of this project suggest that the open grassy structure of some grassy woodland ecosystems may be at risk before individual plant species become locally extinct, although this outcome may follow for some species. It seems somewhat perverse to seek to maintain the species complement of a grassy woodland vegetation type, but to be unconcerned at the loss of its grassy character. In addition, changes in ecosystem structure may affect fauna species; in grassy woodlands, fauna which utilise open patches may no longer find the habitat they need. It is therefore recommended that maintenance of ecosystem structure be considered, along with maintenance of species complements, when fire frequency thresholds are determined.

10.8.2 Setting lower thresholds

Vital characteristics data relevant to setting lower thresholds – regeneration modes and juvenile periods – are reasonably easy to obtain. Local observations combined with data from the NSW Flora Fire Response Database (DEC 2002) were able to provide information for the large majority of shrub species in the vegetation types surveyed for this project. In addition, where data were available from both the Database and local observations, agreement was generally good (Chapter 3). Predictions based on vital attributes analysis with respect to the effects of short interfire intervals were borne out in the field (Chapter 4). The findings of this project support the conclusion that:

- The Vital Attributes model provides a sound basis for determining minimum interfire intervals;
- Information on regeneration modes and juvenile periods in the NSW Database is accurate and useful for this purpose;
- Local observation can contribute valuable input when determining minimum intervals.

10.8.3 Setting upper thresholds

Data relevant to setting upper thresholds – longevity of adults and seeds – are much less readily available. This project’s findings also suggest that the model and assumptions currently being used to set upper thresholds may require some modification.

One issue for upper thresholds concerns assumptions about longevity. In the NSW Flora Fire Response Database (DEC 2002), seeds with hard coats, including legumes, are assumed to live 30 years, while Bradstock and Kenny (2003) use a figure of 40 years. Longevity estimates for Cumberland Plain legumes (lifespan plus seedbank) in the NSW Database clustered around 50 to 60 years (Chapter 3). Subtracting the seedbank estimate of 30 years means adult plants were assumed to live between 20 and 30 years. However local observations of mortality in populations less than 10 years after fire, together with the reduced abundance of obligate seeder legumes in sites whose most recent interfire interval exceeds 20 years, suggests these estimates may be too high.

A second issue concerns the level at which upper thresholds are set vis-a-vis the longevity (*y*) of the key fire response species. As noted in Chapter 3, in Victoria

(Friend *et al.* 2003) and NSW (NPWS 2004c), the upper threshold is set at y (y includes seedbank longevity, if seeds persist beyond the life-span of adult plants). West Australians Burrows and Abbott (2003:446), however, suggest $0.75y$ 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 at 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). The need to consider decline rather than local extinction may be particularly important for species which play keystone roles in ecosystem function. *Themeda australis* may be such a species in some grassy woodland ecosystems, including CPW (Section 10.3.2).

Finally, the potential for one or a small number of species to dominate under extended interfire intervals, and concomitant interspecific interactions, may mean that upper thresholds need to be lower than an assessment based solely on life history characteristics would suggest. Huston (2003) considers competitive exclusion to be *the* issue for biodiversity conservation under a low disturbance frequency.

The need to consider the effect of dominant shrubs on other species has previously been recognised in Sydney's heathlands (Keith 2002b, Tozer and Bradstock 2002). When life history characteristics are considered, a feasible fire frequency for the conservation of both dominant obligate seeder shrubs 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 some species in the understorey. An understanding of this dynamic has highlighted the need to include in 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), but is not explicitly discussed in the recently-developed fire interval guidelines for NSW, although the importance of variability within thresholds is noted (NPWS 2004c).

In Cumberland Plain Woodland, *Bursaria spinosa* also affects co-occurring species (Chapters 5 and 8). However unlike the heathland dominants, Bursaria resprouts after a fire, and thus will continue to exert competitive pressure by drawing on soil resources, and once its cover is re-established, on light resources. Thus the strategy recommended to provide relief for competitively inferior species in heathlands – inserting one short interval amongst longer ones – is unlikely to work in CPW. The evidence suggests that moderately frequent fires will be needed to allow open patch biota, Bursaria thickets and obligate seeder shrubs to co-exist long-term. A high maximum threshold, particularly if coupled with a recommendation that ecological burning be limited to sites where maximum thresholds have been exceeded, is likely to lead to expansion of Bursaria and increasing capture of resources by this species, to the detriment of other shrubs, open patch forbs, and fauna which forage in open areas.

The potential for Bursaria to dominate in the shrub layer could be predicted once its ability to recruit between fires was recognised. The vital attributes model explicit identifies these species (T and R species), and their propensity to dominate in the absence of disturbance (Noble and Slatyer 1980).

It is therefore recommended that:

- More emphasis be placed on determining the rate of decline with time-since-fire of adult populations and fecundity, in species which recruit only post-fire (I species);
- More emphasis be placed on identifying species able to build up population numbers in the interfire interval, particularly those able to capture large slices of ecosystem resources through this strategy (some T and R species will be more able to capture resources than others). Effects of these species on the next generation of I species also need to be identified.
- These factors be explicitly considered when upper thresholds are set.
- That as an interim rule of thumb, upper thresholds not exceed 0.75*y*, where *y* is the longevity (including seedbank) of the key fire response species for infrequent fire.

10.9 Relevance of CPW recommendations for grassy woodlands elsewhere

Grassy woodlands occur in a wide range of climatic conditions, and on various substrates. Fire frequencies appropriate for Cumberland Plain Woodland are likely to be most relevant to woodlands growing under similar conditions.

Productivity may hold the key to determining how frequently fire should occur to maintain woodland plant diversity. Huston (1979, 2003) addresses the interaction of productivity and disturbance in mediating species diversity in his dynamic equilibrium model. Where productivity is low, a high disturbance frequency is predicted to reduce diversity, as organisms will be unable to recover between disturbances. Diversity is also predicted to decline in highly productive systems where disturbance frequency is low, due to competitive exclusion. Additional reasons why a high disturbance frequency is likely to be more appropriate in more productive areas can also be advanced.

Productivity in grassy woodlands will increase with:

- Rainfall. At around 800 mm per annum, rainfall on the Cumberland Plain is at the high end of the gradient for Australian temperate grassy woodlands.
- Temperature. Mean temperatures on the Cumberland Plain are lower than those in coastal woodlands to the north of the state, but higher than those in the south and on the Tablelands where altitude contributes to severe frosts (Reseigh *et al.* 2003).
- Season of rainfall. Where rainfall and warm temperatures coincide, there is a greater potential for plant growth. Rainfall on the Cumberland Plain falls predominantly in summer, as it does over most of northern NSW. The proportion of precipitation falling in winter increases with latitude.
- Soil fertility. The shale-based clays which support Cumberland Plain Woodland would be less productive than the basalt-based soils of the Darling Downs and parts of the Tablelands. However they may be higher in nutrients than the more sandy soils which support grassy woodland elsewhere.

These factors are likely to be associated with extent of grass production, and thus with potential for competitive exclusion of interstitial forbs (Stuwe 1994). Grazing is associated with increased species richness in productive grassy systems, but not in unproductive ones (Proulx and Mazumder 1998); fire, the “large generalist herbivore”

(Bond 1997) may operate similarly. The tendency for dominant clump grasses such as *Themeda* to ‘crash’ due to litter inhibition may also be greater, or occur more rapidly, in more productive environments (Tilman and Wedin 1991). Frequent firing may thus be more appropriate in productive systems than in those whose productivity is limited by poor soils, low rainfall or a short growing season (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 in the vital attributes study reported in Chapter 3 were often shorter where resources were 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).

Encroachment and dominance by one or a small number of shrub species in the absence of fire may be more likely in more productive communities, providing a further rationale for more frequent burning in these areas. Roques *et al.* (2001) compared their findings of rapid shrub encroachment in fertile, mesic savanna in Swaziland with findings in similar studies, and concluded encroachment occurs more rapidly in more productive areas. *Melaleuca viridiflora* encroachment on Cape York Peninsula was higher in seasonally inundated grasslands than in nearby, dry eucalypt woodlands (Crowley and Garnett 1998); a similar pattern was found for *Melaleuca minutifolia* in the Northern Territory (Sharp and Bowman 2004). Woody plant encroachment is most problematic in fertile ‘run on’ areas in semi-arid woodlands (Noble and Grice 2002).

A final argument for more frequent fire in more productive areas is purely pragmatic. Fuel accumulation will be faster in more productive woodlands, and thus the ability to support frequent fire will be higher. In southern Africa, fire frequency follows a rainfall gradient. The mean interfire interval in high rainfall sourveld is three years, while semi-arid sweetveld burns at a mean frequency of eight years. Herbivory plays an increasingly important role in ecosystem dynamics as rainfall decreases. In sourveld, lack of fire is the primary factor in shrub invasion, while in more arid areas grazing is the principal trigger (Bond 1997).

Overall, it is suggested that the relevance of the findings of this project to grassy woodlands beyond the Cumberland Plain will depend on the effects of climate and soil fertility on productivity. Related factors for consideration include the resulting potential for competitive exclusion by dominant grasses and/or shrubs, growth rates of shrubs (particularly obligate seeders), and how soon, and often, the vegetation is able to support fire. The potential, need and tolerance for fire will, I predict, decrease with productivity.

10.10 Conclusion

> "Living with fire requires cultural shifts. This takes time, requires trial and error and the development of new ways of thinking, new stories and novel approaches." (Bowman 2003:115-6).

Fire frequency has a profound influence on the grassy woodlands of Western Sydney's Cumberland Plain. Structure, composition, habitat diversity and fuel loads are all affected. Now isolated in remnants, maintenance of biodiversity in Cumberland Plain Woodland will depend on active fire management. The story of fire in this vegetation type illustrates the importance of disturbance in mediating species co-existence; it is a non-equilibrium paradigm story. Ultimately, conservation of Sydney's grassy woodlands requires that human beings understand and appreciate fire's role, and act accordingly.

Similar stories no doubt await telling, and hearing, in grassy woodlands elsewhere.