Fuel load dynamics in NSW vegetation

Part 1: forests and grassy woodlands

Penny Watson
Centre for Environmental Risk Management of Bushfires
University of Wollongong (UoW)

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Executive summary

Fuel load, ie mass per unit area, is a key fuel parameter for NSW fire managers. It is the sole fuel input to the McArthur models of rate of spread (McArthur 1962; 1967), and appears in commonly-used equations for flame height and fire intensity (Byram 1959; Noble *et al.* 1980). The McArthur Mark 5 model underpins the fire behaviour simulator Phoenix (Tolhurst *et al.* 2007), developed in Victoria but potentially useful for a range of applications in NSW; proximal inputs to Phoenix are fuel loads. Accurate models describing the development of fuel load with time-since-fire in NSW vegetation classes could be of use in a range of applications, including scenario modelling and bushfire risk management planning.

Studies relevant to determining the trajectory with time-since-fire of litter, near-surface and/or elevated fuel load in NSW forests and grassy woodlands were sourced from the literature. While some studies covered a single vegetation type, others addressed more than one. Vegetation descriptions and location details were used to allocate each dataset to a vegetation class, using the classification system of Keith (2004). Where necessary, fuel load figures were adjusted to provide estimates for fine fuel (particles < 6 mm diameter), using conversion factors derived from the literature. For some datasets which involved fuel load measurements at various post-fire ages, curves were fitted or refitted. Details for each dataset were entered into an Access database, and a subjective quality rating allocated.

This report presents and synthesizes this information, using the formations and sub-formations in Keith (2004) as a basis for chapter headings. Some sub-formations are further subdivided into classes that occur primarily on the coastal and sub-coastal strip, those that occur primarily on the tablelands, and those on the western slopes and plains. Thus each chapter, from Chapter 2 (Rainforests) to Chapter 14 (Shrubby dry sclerophyll forests on the western slopes) addresses a small group of vegetation classes. Each chapter includes:

- an introduction, in which each of the Keith classes covered in that chapter is briefly described, and the scope of the literature addressing fuel parameters in those classes outlined.

- a section in which each relevant study / dataset is described and its fuel parameter figures given, along with an explanation of the purpose and results of any further data analysis undertaken.

- a section where findings from all the relevant studies are discussed and synthesised. In most chapters this section includes a table summarising litter parameters from each study together with weighted means for each relevant vegetation class grouping. Recommended values for the negative exponential model parameters *Initial* (the fuel load remaining after passage of a fire), *Limit* (steady state fuel load) and *k* (the value determining how rapidly the curve rises) are made – for litter alone, for litter plus near-surface fuel, and for elevated fuel.

- a discussion of knowledge gaps.

Key points and findings

In the final chapter, recommended values for negative exponential model parameters are summarised in a series of tables and graphs.

Key points pertaining to this investigation of fuel load include:

- Data were more readily available for some vegetation formations and subformations than others. For example, many more studies were located for wet sclerophyll forests than for shrub/grass dry sclerophyll forests. Suggested model parameters are therefore more soundly-based for some formations than others.

- Even within formations which have been widely studied, some vegetation classes are represented by limited data, if any. For example, no studies addressing fuel load measures were identified for any of the four shrubby dry sclerophyll forest classes in the north of the state.

- Relative to studies of litter dynamics, studies which provide a clear picture of post-fire development in near-surface and elevated fuel load are limited.

- Although the negative exponential model was used to characterise fuel development in both fuel layers (this is a requirement for Phoenix), available data suggest that this model does not provide a particularly good description of the development of load in the elevated fuel layer.

- For litter, values for *Limit* varied widely across and within formations, ranging from 5.5 t/ha in Pilliga Outwash Dry Sclerophyll Forests (a shrub/grass DSF class on the western plains) to 24.0 t/ha in Montane Wet Sclerophyll Forest.

- *k* values also varied extensively between vegetation types, from 0.75 in rainforests to 0.15-0.18 in dry sclerophyll forests on rocky, infertile substrates. Within subformations, cold, high altitude classes tended to have lower *k* values, and thus higher steady state litter loads, than classes with similar rates of litter fall growing in more benign climatic conditions. Where *k* is low, litter builds up more slowly than when it is high. Thus in shrubby wet sclerophyll forests where *k* is around 0.45, 95% of quasi steady state litter loads will be achieved in under 7 years. By contrast, in a dry sclerophyll forest with a *k* value of 0.15, 20 years will need to elapse before litter load reaches 95% of its eventual *Limit*.

- Even where the estimates fuel loads are based on good data, recommended values may be an approximation at best for any particular site within a forest or woodland class.

- Note also that in some vegetation types, particularly those with high *k* values which signal rapid rates of decomposition (eg wet sclerophyll forests), litter loads in sites where this fuel element has reached quasi-equilibrium will vary between years and seasons. In high decomposition environments the impact of differences in both litter fall and decomposition will be enhanced, as a relatively large proportion of standing litter load will be lost to decomposition. Where k values are low (eg in dry sclerophyll forests on shallow rocky substrates), surface litter load at steady state will be more constant, as it is more highly buffered due to the relatively small proportion of the total litter pool lost to decomposition each year.

While this report provides science-based fuel load estimates for NSW forests and grassy woodlands, these estimates will need to be refined as further information comes to hand. Priorities for filling knowledge gaps are summarised at the end of Chapter 15.

1. Aims and methods

1.1 Introduction

This document, which aims to provide a scientific basis for fuel models used by fire and land management authorities in NSW, has been produced by the University of Wollongong's (UoW) Fuels Modelling Project, with funding from the NSW Rural Fire Service (RFS). It summarises and synthesizes scientific studies which address parameters relevant to determining the trajectory with time since fire of litter, near-surface and elevated fuel load in NSW forests and woodlands.

This document is the first part of a two-part series. It covers four of the twelve formations identified by Keith (2004) in his book Ocean Shores to Desert Dunes: rainforests, wet sclerophyll forests, grassy woodlands and dry sclerophyll forests. The great majority of native vegetation occurring on the coast and ranges of NSW falls into these four formations, all of which have an overstorey of litter-producing trees. Remaining formations, including grasslands, heathlands, wetlands, semi-arid woodlands and arid shrublands will be addressed in Part 2.

I have endeavoured to include all relevant studies from NSW, as well as studies from neighbouring states which may throw light on vegetation classes across the border. Interstate studies have been sought more assiduously where local studies are lacking or sparse. While some studies were designed with bushfire fuels explicitly in mind, others address matters such as nutrient cycling and estimation of forest biomass (Bevege 1977).

Keith's system of vegetation classification (Keith 2004) provides the framework around which this document is organised. Descriptions of vegetation in each scientific study have been used to allocate findings to a Keith formation and class. While some studies address a single vegetation type only, others cover more than one, and thus appear in more than one chapter.

1.2 Fuel strata

Over the past two decades, a number of Australian authors have emphasised the importance of vegetation structure when describing bushfire fuel (Wilson 1992; McCarthy *et al.* 1999; Gould *et al.* 2007b; Hines *et al.* 2010; Gould *et al.* 2011). These authors divide the fuel array in forests and woodlands into components or strata, including:

- Litter or surface fuel – leaves, twigs, bark and other dead plant material lying on the ground, with a predominantly horizontal orientation. This layer may contain partly-decomposed matter, and usually contributes the bulk of the fuel available for burning.

- Near-surface fuel – "grasses, low shrubs, creepers and collapsed understorey" whose orientation "includes a mixture ranging from horizontal to vertical" (Gould *et al.* 2007b:10)
- Elevated fuel – "tall shrubs and other understorey plants" with a primarily upright orientation (Gould *et al.* 2007b:12)
- Bark fuel – flammable bark on tree boles and branches.

This report addresses the first three of these four commonly-identified components.

1.3 The negative exponential model

The post-fire trajectory of litter load has traditionally been modelled using a negative exponential equation, often referred to as an 'Olson curve', as Olson (1963) was one of its early proponents. The negative exponential model takes the form:

$$W_t = Limit\ (1 - e^{-kt}) \qquad (1)$$

where W_t is the fuel load (in tonnes per hectare, or t/ha) t years post-fire, *Limit* is the steady-state fuel load (also in t/ha), and k reflects the relationship between mean annual litter input (L) and *Limit*:

$$k = L/Limit \qquad (2)$$

Studies applying the Olson curve to data on litter biomass collected at varying times after fire generally find the model fits well (Fox *et al.* 1979; Raison *et al.* 1983; Fogarty 1993).

In recent decades several authors (eg Fensham 1992; Morrison *et al.* 1996) have used a modified version of Olson's equation, to take into account the finding that fire may fail to consume all available fuel. Adding the parameter *Initial*, the fuel load immediately after fire, equation (1) becomes:

$$W_t = Initial + [(Limit - Initial) \times (1 - e^{-k\,t})] \qquad (3)$$

Clearly, the extent to which fuel remains after the passage of a fire will depend on the fire's intensity. For example, Birk and Bridges (1989) report 92% consumption of fuel load after the passage of a wildfire in blackbutt forest near Taree, leaving 1.5 t/ha, while lower intensity prescribed burns removed only 53- 83% of pre-fire fuel load (fuel particles < 25 mm in diameter). The extent to which fuel remains may also vary with vegetation type and fuel stratum: the very fine material in a grassy understory may burn more completely than a shrub layer, at the same drought index and weather conditions. Values for *Initial* presented in this report may therefore be higher or lower than those following specific fires.

For litter, the parameters L, *Limit* and k can be derived in several ways. One is to survey sites at a range of different times-since-fire, and fit the model. This gives values for *Limit* and k; L can then be derived using equation (2). It is also possible to measure two of the three parameters *k*, *L* and *Limit* directly, and derive the third, again using equation (2). Quite a few studies have measured litter fall, *L*. Inter-annual variations in litter fall (Ashton 1975; Attiwill *et al.* 1978; Raison *et al.* 1986; Birk and Bridges 1989; Pook *et al.* 1997) mean that collection and measurement over several years is desirable, if average values are to be accurate. Decomposition can be measured by placing mesh bags of litter on the forest floor for a known period of time, and noting how much litter disappears:

$$k = -\ln(X_t/X_o)/t \qquad (4)$$

where X_t = remaining litter mass (in t/ha) after time *t* (in years) and X_o = initial litter mass (Olson 1963; Hart 1995).

I have used the equations in this section extensively in this document. In some cases, I have fitted or re-fitted equations (1) and/or (3) to data on fuel load collected at sites of differing post-fire age.

1.4 Fire behaviour models and Phoenix

Existing Australian fire behaviour models and their fuel inputs were discussed at length in the first report produced for the RFS by the UoW Fuels Modelling Project (Watson 2009). In focusing solely on fuel load, the current report has relevance to two of three empirical rate of spread models currently available for eucalypt forests, both developed by McArthur in the 1960s (McArthur 1962; 1967). The third and most recent rate of spread model, developed from the Project Vesta experiments in Western Australia, uses fuel inputs other than fuel load for predicting rate of spread, flame dimensions and spotting distance (Gould *et al.* 2007a). Unlike load, values for parameters in the Vesta models (hazard scores for various fuel strata, along with typical strata height) have not been widely documented for the forests and woodlands of NSW and surrounding states. The UoW Fuels Modelling Project is addressing this gap through direct assessment of fuel hazard, strata height and related parameters at various post-fire ages, in a range of forest and woodland types. Data from that aspect of the project has been reported to the RFS separately (Watson *et al.* 2012b; a).

Fuel load is also included, along with rate of spread, in Byram's model of fire intensity (Byram 1959).

The Victorian fire behaviour simulator Phoenix (Tolhurst *et al.* 2007; Tolhurst *et al.* 2008) is currently under assessment by the NSW RFS. Phoenix uses fuel, weather and vegetation inputs, together with the McArthur (1967) rate of spread model to simulate fire spread. Equation (3) is used to characterise fuel development with time since fire, although some parameters are expressed differently. In Phoenix, *Initial* is called '*c*', and rather than talking about *Limit*, Phoenix uses the parameter '*r*', which equals (*Limit* - *Initial*).

Phoenix operates on three fuel layers:

- surface fuels; this includes near-surface fuel elements such as grasses and herbs, as well as surface litter
- elevated fuels
- bark fuels

These fuel elements parallel those described in the Victorian fuel hazard guide (McCarthy *et al.* 1999). Values for *r* and *c*, for Victorian fuel types which were developed in parallel to Project Phoenix, are given as hazard scores, which are converted into fuel loads for input to the fire behaviour models underlying the simulator. Conversion equations (hazard scores to fuel loads) are given in Tolhurst (2005).

In this document I focus on fuel load directly, however equations to back-convert to fuel hazard can be derived mathematically from the equations in Tolhurst (2005). I have derived these equations and used them to present some suggested curve parameters in hazard score form (Table 47). Note, however, that the reliability and accuracy of converting between fuel load and fuel hazard has been questioned (Watson *et al.* in press). Fuel hazard takes into account a range of factors including cover, composition, proportion of dead material, fineness and height (McCarthy *et al.* 1999; Hines *et al.* 2010; Gould *et al.* 2011); while variability in some of these fuel characteristics might be expected to correlate with fuel load, for others this is unlikely to be the case. In addition, data from jarrah forest in Western Australia suggests that the post-fire trajectory of hazard scores may not parallel that of fuel load (Gould *et al.* 2011). Limitations on conversion between hazard scores and fuel loads is discussed further in Section 15.2.

Of the three fuel layers used in Phoenix, this document addresses two: surface and elevated fuels. The large majority of studies summarised here are concerned with litter, while a minority provide some insight into near-surface and/or elevated fuel load. Because very little empirical work on bark fuel load exists, it is not included in this review.

1.5 Assumptions

1.5.1 Conversion factors for standing litter load

My aim in this paper is to document values for *Initial*, *Limit* and *k*, for fine fuel. In Australia, fine fuel is generally defined as those fuel particles less than 6 mm in diameter (Luke and McArthur 1978). While some studies which have measured litter fall, or litter load, explicitly use a 6 mm cut-off, many do not. In order to put the results from all studies on to an equal footing, I have used conversion factors to estimate fine fuel load.

Studies which have measured fuel load in both the < 6 mm and the 6-25 mm diameter classes can be used to derive a factor for converting figures for fuel load < 25 mm to fuel load < 6 mm. These studies are collated in Table 1.

Table 1. Proportion of fuel load < 25 mm in diameter (< 26 mm in Lamb 1985) falling into the < 6 mm size class (= conversion factor) in a range of Australian studies. *Figure obtained through further analysis of data in paper cited.

Study	Location	Components included	Conversion factor
Van Loon (1977)	Blue Mountains in NSW	Litter, grasses, ferns and low herbs	0.85
Buckley (1990)	Near Orbost in Victoria (site 1)	Litter, including suspended litter	0.83*
Buckley (1990)	Near Orbost in Victoria (site 2)	Litter, including suspended litter	0.87*
Van Loon (1977)	Blue Mountains in NSW	Litter only	0.81*
Tolhurst and Kelly (2003)	Wombat State Forest in Victoria	Litter	0.87
Lamb (1985)	Narrabeen in Sydney NSW (community 2)	Litter	0.87*
Lamb (1985)	Narrabeen in Sydney NSW (community 1)	Litter	0.91*

When converting standing litter load from the < 25 mm to the < 6 mm size class in this paper, I've used a conversion factor of 0.87. This accords with figures arising from several studies/vegetation types (Lamb 1985, Community 2; Buckley 1990, Site 2; Tolhurst and Kelly 2003). While figures from some studies are slightly lower than this (Van Loon 1977; Buckley 1990, Site 1), higher figures have also been reported (Lamb 1985, Community 1).

Some studies use a 10 mm cut-off for litter, or total, fuel load (Sandercoe 1989; 1992; possibly Crockford and Richardson 1998). Here, I've used a conversion factor of 0.97.

Lamb (1985) also includes figures for litter load of components *over* 25 mm in diameter, including dead branches and logs. This component did not make up a large proportion of litter dry weight. Conversion factors from total litter including this large fuel component, to litter load < 6 mm were 0.86 for Community 1, and 0.82 for Community 2. The proportion of large fuel elements in this study seems low, relative to figures for coarse woody debris in Sullivan *et al.* (2002). These authors note, however, that few data are available on the amount of coarse fuel in Australian forests.

A study by Lewis (1978) in coastal dune forest at Myall Lakes in NSW, which estimated total biomass, divided forest floor mass into two components, fallen branches and trunks, and “leaves, twigs and bark” (Lewis 1978:67). The first component made up 64% of total forest floor biomass, a much higher figure than that reported by Lamb (1985). Criteria for allocating litter to one component or the other were not specified.

Applegate (1982) divided forest floor litter into components, including ‘large’ material (> 10 cm centre diameter). In this total biomass study, the weight of this component far outstripped that of finer material, despite the high cut-off point.

Hurditch (1981) also separated forest floor litter into components, including twigs < 5 mm in diameter and 'branches' over this size. Branches made up between 14 and 22% of the litter load in the five wet sclerophyll sites surveyed, with a mean of 19% falling into this category.

For this analysis, I have used a factor of 0.82 to convert litter load figures with no cut-off, or with a 10 cm (100 mm) cut-off (Applegate 1982; McElhinny 2005), to litter load < 6 mm. This is a very rough figure. The considerable variability in the extent of woody fuel reported in the studies above has recently been confirmed in a survey of 11 sites in Victoria, Western Australia and a single site in NSW (Hollis *et al.* 2011) which recorded estimates for woody particles > 6 mm, across sites, of between 13 and 175 t/ha, with a mean of 66 t/ha. This study included large logs; the mean load for material between 6 mm and 7.5 cm in diameter was a much-smaller 6 t/ha. The amount of woody debris on the forest floor will be a function of forest management, and probably of forest type and age. In addition to variability between sites, it is likely that in some studies reported here, researchers will have used a *de facto* cut-off, collecting small-diameter woody material but not branches or trunks (to some extent the word ‘litter’ implies small particle size). Others may have included more bulky woody material; where this was the case, the above findings (Hurditch 1981; Applegate 1982; Hollis *et al.* 2011) suggest that fuel load < 6 mm may have been overestimated. The uncertainty inherent in the 0.82 no-size-cut-off conversion factor has been taken into account through data weighting (Section 1.5.4).

1.5.2 Conversion factors for annual litter fall

Table 2 gives figures for the proportion of litter fall < 25 mm in diameter falling into the < 6 mm size class in two Australian studies.

Table 2. Proportion of litter fall < 25 mm in diameter (<26 mm in Lamb 1985) falling into the < 6 mm size class (= conversion factor) in two Australian studies. *Figure obtained through further analysis of data in paper cited.

Study	Location	Conversion factor
Lamb (1985)	Narrabeen in Sydney NSW (community 2)	0.92*
Van Loon (1969)	Bulls Ground in NSW	0.93*
Lamb (1985)	Narrabeen in Sydney NSW (community 1)	0.96*

In this analysis, I've used a conversion factor of 0.94 for litter fall: this is the average of values in Table 2.

Some Victorian studies use a 20 mm cut-off (Attiwill *et al.* 1978 at one of two sites; Baker 1983; Campbell *et al.* 1992). Where these studies appear in this paper, I've used a conversion factor of 0.95. On the rare occasion where a 10 or 8 mm cut-off is used (Hynes and White 1983; Thomas *et al.* 1992; Crockford and Richardson 1998), I've taken 0.99 as the conversion factor.

Attiwill *et al.* (1978), who collected fallen branches over 2 cm in diameter in 75-year-old *Eucalyptus obliqua* forest over three years, found this component of litter fall was very variable, and averaged only 2.5% of litter fall under 2 cm.

Hurditch (1981) divided litter fall into components at five of his *Eucalyptus pilularis* study sites: two at Fraser Island and two on the NSW north coast. Woody material was divided into twigs < 5 mm and 'branches' between 5 and 50 mm. In the Fraser Island sites the largest (summer) and the smallest (winter) collections were chosen for sorting. 'Branches' made up 6% and 13% of the summer and winter collections respectively in an old growth site, but only 1% and 0% in a regrowth stand. On the North Coast a single winter collection was sorted into the same categories; here, 'branches' made up an average of 8%.

I have used a factor of 0.91 to convert litter fall figures with no cut-off, to litter fall < 6 mm.

1.5.3 Fuel stratification

While many studies used in this analysis address the litter component of the fuel array only, others include living and dead vegetation in what are now called the near-surface and elevated fuel strata (Section 1.2). Usually, these exact terms are not used; authors of most studies do, however, explain the make-up and partitioning of fuel components other than surface litter included in their sampling. These descriptions often mention low vegetation such as grasses and herbs; for example Van Loon (1977:4) collected "grasses, ferns and low herbaceous vegetation less than 0.9 m in height"; I have generally allocated this portion of the fuel load to the near-surface stratum. Fuel elements from shrubs are also frequently noted; in general I have considered these to be elevated fuel. Detailed information on partitioning of fuel elements surveyed in studies into the modern categories of surface, near-surface and elevated fuel, including any assumptions made in that process, is given in study descriptions (Chapters 2 – 14).

1.5.4 Ratings and weighted means

To assist in synthesizing data from diverse studies, the values from each dataset were given a rating which aimed to reflect, from the point of view of developing fuel curves for NSW vegetation types, both the quality of the study and the applicability of its results. Ratings ranged from 1 (excellent quality, highly applicable) to 4 (doubtful quality, marginally applicable). Some of the many factors considered in allocating ratings are outlined in Table 3. Due to the diverse nature of the studies, different factors were relevant for different studies, and sometimes for different datasets reported within a single paper. Given the wide range of study types and the need to weigh up diverse criteria (many of which, despite the format used in Table 3, involved a continuum rather than a binary good/bad assessment), ratings necessarily included a subjective element. Ratings are given at the end of each dataset description, along with a summary of key points leading to the allocation of that rating. Further information on each rating category follows:

Rating 1. Only one study achieved this rating. This study (Lamb 1985) was conducted in NSW in two clearly defined vegetation classes, was of excellent quality, provided figures for fine fuel < 6 mm, and used multiple methods to derive *L*, *Limit* and *k*.

Rating 2. This rating was allocated to figures arising from studies with many good points but minor flaws (from the point of view of the current project). Over 20 datasets were allocated this rating. For example a rating of 2 would have been allocated to a well-designed study with good spatial and temporal replication which nevertheless did not provide direct data for the fine fuel component, necessitating the use of a conversion factor.

Rating 3. Around half the studies/datasets were given this rating, which pertained to studies with some good points, but sufficient flaws to throw doubt on final figures. For example a well-designed study with good replication, but conducted outside NSW using methods that necessitated use of a conversion factor, would have been rated 3. A litterfall study in a clearly-delineated vegetation class, in NSW, but with limited temporal replication would also have garnered this rating.

Rating 4. This rating was allocated to a small number of studies, most of which either lacked replication (spatial and/or temporal), were conducted in vegetation that was not clearly related to a NSW vegetation class, did not provide figures for fine fuel and/or provided very limited information on study methods.

Table 3. Factors considered in allocating ratings to values derived from datasets in this report.

Factors	Points which enhanced ratings	Points which reduced ratings
Relevance to NSW vegetation class to which dataset has been allocated	Survey sites clearly belong to this vegetation type	Survey sites may belong to this vegetation type, but this cannot be determined with certainty
	Study conducted in NSW	Study conducted outside NSW
	Study involved vegetation in a reasonably natural state	Study involved vegetation that had been subject to considerable management intervention, eg thinning, planting
Extent of replication	Study used two or more sites	Study limited to a single site
	Spatial replication within sites was adequate (eg > 10 measurements for litter load) or better than adequate	Spatial replication within sites was limited
	Temporal replication was adequate or better (eg litter fall collected over ≥ 24 months)	Temporal replication poor (eg litter fall collected for one year only)
	Figures derived from, and consistent across, more than one method eg fuel parameters cross-checked through measurement of *L*, *Limit* and *k*.	
Relevance to determining parameters for fine fuel < 6 mm	Data for < 6 mm component directly provided; no need to use conversion factor	No size cut-off; conversion factor used but confidence in accuracy of outcome limited.
		Study design meant other, relatively untested assumptions were needed in order to arrive at a figure for fine fuel < 6 mm.
Model fitting (for study involving survey of sites of different post-fire ages)	Number of data points to which model fitted is high	Number of data points to which model fitted is low
	Data points include good representation across post-fire age sequence, including early post-fire years and some long-unburnt sites	Data points cover only a limited portion of the relevant post-fire age range
	Good model fit, high R^2	Poor model fit, low R^2
	Model parameters are significant	Model parameters are not significant
	Raw data is available for model refitting	Model refitted to summary rather than raw data
Has steady state been reached (for direct measurements of *Limit*)	Time since fire is sufficiently long, and sufficiently clear, to make assumption of steady state likely to be valid	Time since fire is not stated, or is too short to ensure steady state has been reached
Additional factors occasionally encountered		Uncertainty in partitioning fuel strata
		Inconsistency in reported figures
		Figures lack face validity in context of wider dataset

For some classes, formations, subformations or parts thereof, these ratings were used to calculate weighted means for litter fall (*L*) and steady state litter load (*Limit*). Studies with a rating of 1 were given the greatest weighting, while those with a rating of 4 were given the least. Weightings were calculated as (5 - rating). Weighted means were calculated as:

$$\bar{X}_w = \frac{\sum(X\ (5 - rating))}{\sum(5 - rating)}$$

where X = value taken by fuel parameter L or *Limit*.

The value for k in each weighted mean row was derived from the weighted means for L and *Limit* ($k = L/Limit$)

1.6 Document structure

As noted above, this document addresses four vegetation formations identified by Keith (2004): rainforests, wet sclerophyll forests, grassy woodlands and dry sclerophyll forests. Wet and dry sclerophyll forests each contain two subformations: shrubby and grassy, in the case of wet sclerophyll forests; shrubby and shrub/grass, in the case of dry sclerophyll forests. The vegetation in each formation and subformation is further divided into a number of vegetation classes (Keith 2004).

In this document, formations are addressed in the order in which they appear in Keith (2004). Thus rainforests are discussed first, in Chapter 2, then wet sclerophyll forests (Chapters 3 - 5), grassy woodlands (Chapters 6 - 8), and dry sclerophyll forests (Chapters 9 - 14).

For wet and dry sclerophyll forests and grassy woodlands, where geographic spread allows, I have grouped the classes within each formation or subformation into:

- those that occur primarily along the coastal and sub-coastal strip, including the eastern fall of the Great Divide,
- those that occur primarily on the tablelands, and
- those that occur on the western slopes and plains.

Each of these areas has a different broad climate. Thus this categorisation may assist in identifying similarities and differences in fuels between vegetation classes within the same sub-formation. It also provides a framework for identifying knowledge gaps.

I have included in the description of most studies notes on average annual rainfall (in mm) and elevation (in m above sea-level). The nearest, or sometimes the most relevant, Bureau of Meteorology weather station providing climate statistics is mentioned. This information provides a climate context which may be useful when comparing fuel load parameters in different studies. The data gathered for this document will eventually be used to explore relationships between fuel parameters and climate variables more formally.

Vegetation classes in each sub-group are listed in tabular form at the start of the relevant chapter, along with a short description of their location, drawn from Keith (2004). The 'relative extent' column contains my subjective assessment of the geographic area occupied by each vegetation class relative to others. These assessments may be helpful in setting priorities for future data collection.

Relevant studies are then summarised. In most chapters, the penultimate section brings together findings from these studies and makes suggestions/recommendations as to figures for fuel curves for litter alone, litter + near-surface fuel ('surface fuel' in Phoenix), and elevated fuel. These figures are summarised at the end of each chapter, and also in Chapter 15. The final section in each chapter considers knowledge gaps.

2. Rainforests

2.1 Introduction

Broad, soft, horizontally held leaves, a closed canopy and an absence of eucalypts generally characterise the rainforest formation. While fire is rare in these forests, they have been included in this review because for some fire management applications, fuel load figures are needed.

Keith (2004) lists nine rainforest classes (Table 4); multiple studies addressing litter parameters have been identified for three of these, including the relatively extensive Subtropical and Northern Warm Temperate Rainforests. While most of the work outlined below took place in NSW, some south-east Queensland studies have been included. In rainforests, litter fall has been more extensively measured than litter load.

Table 4. Vegetation classes in the rainforest formation.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Subtropical Rainforests	38-9	On fertile soils of coastal lowlands and valleys, and in gullies and foothills of coastal ranges, north from the Illawarra, where rainfall exceeds 1300 mm.	moderate
Northern Warm Temperate Rainforests	40-1	On hilly to steep terrain on coastal ranges and plateaux, where soils are moderately fertile and rainfall is high, north from the Illawarra.	moderate
Southern Warm Temperate Rainforests	42-3	In deep, moist gullies along the coastal foothills and ranges, where soils are moderately fertile, south from the Shoalhaven.	small
Cool Temperate Rainforests	44-5	In patches on the escarpment of the Great Divide above 900 m, in moist conditions where soils are of moderate to high fertility	small
Dry Rainforests	46-7	In small, sheltered, rocky patches where rainfall is between 600-1100 mm and soils are of moderate to high fertility.	small
Western Vine Thickets	48-9	In small patches on the western slopes north from Gunnedah, on fertile soils	small
Littoral Rainforests	50-1	On coastal sand dunes and headlands from south to north	small
Oceanic Rainforests	52-3	Lord Howe Island	small
Oceanic Cloud Forests	54-5	Lord Howe Island	small

2.2 Turner *et al.* (1989)

Turner *et al.* (1989) measured both litter fall and litter load as part of a total biomass study near Wiangaree north of Kyogle in northern NSW. Their single site carried stable, mature Subtropical Rainforest with a diverse overstorey: species listed, including *Caldcluvia paniculosa*, *Heritiera trifolioata* and *Sloanea woollsii*, match those in Keith's description of this rainforest type.

Litter fall, which was measured over a single year, totaled 7.05 t/ha. As no size cut-off was specified, I have applied the 0.91 conversion factor (Section 1.5.2) to give an estimate for *L*, for particles < 6 mm, of 6.6 t/ha.

Litter load, which was measured on a single occasion, totaled 11.95 t/ha. Of this, 5.62 t/ha was 'woody'. As "the woody material tended to be large components" (Turner *et al.* 1989:639), I have assumed that the load of the non-woody component, 6.3 t/ha, approximates *Limit* for litter particles < 6 mm. This figure may include near-surface fuels: Turner *et al.* (1989) list 'understorey' as one of their forest floor components (1.37 t/ha).

An estimated value for *k* for the fine fuel fraction can now be calculated, using equation (2; $k = L/Limit$). Here, $k = 6.6/6.3 = 1.05$.

Turner *et al.* (1989) also report the biomass of understorey < 2 m tall, which was 1.93 t/ha. Tree ferns made up almost half this total. As tree fern trunks are too large to constitute fine fuel, this figure suggests that fine fuel load in the elevated layer, in this forest type, is low.

Rating: 3
For current purposes, limitations of this study include lack of spatial and temporal replication, and lack of clarity as to the size of litter load and litter fall components.

Rainfall and elevation: Turner *et al.* (1989:635) give a figure for annual rainfall of "around 3000 mm". Nearest weather station is probably Tyalgum (Wanungara View), where mean annual rainfall is 1530 mm (46 years of data) and elevation is 120 m above sea level (asl). No other weather station in the area has a higher rainfall than this.

2.3 Conroy (1993)

Conroy (1993) surveyed many sites around Sydney, at different times after fire, with the explicit aim of developing curves for fuel accumulation. While most of the sampling effort was directed towards fire-prone vegetation, data from four long unburnt rainforest sites was amalgamated to provide fine fuel load figures for this forest type; a 6 mm cut-off was used. Species included *Ceratopetalum apetalum*, *Acmena smithii* and *Doryphora sassafras* (Conroy 1996), all typical of the Northern Warm Temperate Rainforests class. Total fine fuel load averaged 8.0 t/ha. Of this, 6.5 t/ha was litter, 0.7 t/ha herbs, and 0.8 t/ha shrubs.

Rating: 2
Explicit focus on fine fuel < 6 mm adds confidence, although information on study sites is lacking.

Rainfall and elevation: Conroy (1993) does not provide figures for rainfall or elevation, however many of the sites in his study were in and around Sydney's northern suburbs. Nearest weather stations are Pennant Hills (1068 mm rainfall, 70 years of data, 173 m asl), Gosford (1315 mm rainfall, 94 years of data, 20 m asl) and Peats Ridge (1255 mm rainfall, 28 years of data, 280 m asl). For rainfall, Peats Ridge has been chosen because it is of roughly similar distance from the coast to several large national parks. Elevation has been roughly estimated at 150 m.

2.4 Watson (1977)

This was a Masters project, carried out under the supervision of staff at the University of New England with an interest in nutrient dynamics. Several sites east of Armidale, NSW, covering a range of vegetation types, were included in the study; amongst them was a rainforest patch in New England National Park, at 1335 m asl. *Nothofagus moorei*, the signature tree for Keith's Cool Temperate Rainforest class, dominated this site.

Litter fall was measured over four consecutive years, using 15 litter traps. The average amount collected each year was 4.99 t/ha. No size cut-off is mentioned. Applying the 0.91 conversion factor gives an estimate of 4.54 t/ha for annual accession of litter particles < 6 mm.

Watson (1977) also sampled litter on the forest floor, on three occasions over a 12 month period. Mean litter load was 11.86 t/ha. Using the 0.82 conversion factor gives a value, for litter < 6 mm in diameter, of 9.73 t/ha.

Using equation (2) gives an estimate for k, for the fine litter fraction, of 4.54/9.73 = 0.47.

Rating: 2
The figures for both litter fall and litter load are likely to be fairly accurate, as they are based on good temporal replication and reasonable within-site replication. Lack of replication across forest patches is a limitation of this study, for current purposes, as is the need to use conversion factors to derive estimates for fine fuel.

Rainfall and elevation: Watson (1977) gives a figure of 2403 mm for annual rainfall at this site, based on four years of measurement on the site itself. An altitude of 1335 m asl is noted in the thesis. The nearest weather station is Jeogla, where annual rainfall averages 1515 mm (43 years of data) and elevation is 1030 m asl.

2.5 Lowman (1988)

Lowman (1988) measured litter fall over a five year period in four rainforest sites around NSW, using 12 traps in each site. These sites represented three of Keith's rainforest classes:

- Subtropical Rainforests. One site, at Dorrigo National Park. Canopy trees included *Dendrocnide excelsa*, *Doryphora sassafras*, *Sloanea* sp., *Ficus* sp., *Orites excelsa* and many others.

- Northern Warm Temperate Rainforests. Two sites, one in Royal National Park (RNP) near Sydney and the other at Dorrigo. Dominant trees included *Ceratopetalum apetalum*, *Doryphora sassafras* and *Acmena smithii*.

- Cool Temperate Rainforests. One site, in New England National Park. The dominant species in this site was *Nothofagus moorei*.

As branches of all sizes were specifically included in this study, I have used the 0.91 conversion factor to estimate litter fall of particles < 6 mm.

- At the Subtropical Rainforest site total litter fall averaged 10.0 t/ha per year, giving an estimate for *L*, for fine material, of 9.1 t/ha.

- At the two Northern Warm Temperate Rainforest sites total mean annual litter fall was 7.3 t/ha in the site near Sydney, and 5.4 t/ha at Dorrigo. Averaging across the two sites and applying the 0.91 conversion factor gives an estimated *L* of 5.8 t/ha.

- At the Cool Temperate Rainforest site total litter fall averaged 6.2 t/ha per year, giving an estimate for *L*, for fine material, of 5.6 t/ha.

Lowman (1988) also measured decomposition using leaves of specific species. Decomposition was most rapid in Subtropical Rainforest and slowest in Cool Temperate Rainforest.

Rating: 2
Litter fall figures are likely to be fairly accurate, as they are based on good temporal replication and reasonable spatial replication, particularly for Northern Warm Temperate Rainforest. The need to use conversion factors to derive estimates for fine fuel adds uncertainty.

Rainfall and elevation:

- New England National Park. Lowman (1988) gives a figures of 2000 mm for annual rainfall, and 1200 m for elevation at this site. The nearest weather station is Jeogla, where annual rainfall averages 1515 mm (43 years of data) and elevation is 1030 m asl.

- Dorrigo National Park. Lowman's figures are 2004 mm for annual rainfall, and 800 m for elevation. Nearest weather station would be Dorrigo (Old Coramba

Road), where rainfall averages 2014 mm (14 years of data) and elevation is 746 m asl.

- Royal National Park. Lowman's figures are 1302 mm for rainfall, and 20 m for elevation. Nearest weather station would be Lucas Heights, where rainfall averages 1011 mm (53 years of data) and altitude is 140 m asl. This station, however, is further inland than the rainforest in RNP.

2.6 Webb *et al.* (1969)

Webb *et al.* (1969) also measured litter fall, this time over two years, in two rainforest types in Whian Whian State Forest north of Lismore in northern NSW. In this early study only a single litter tray, positioned "subjectively as 'average' for the site" (Webb *et al.* 1969:102) was used in each forest type. Keith classes surveyed were:

- Subtropical Rainforests. This site was dominated by *Heritiera trifoliata* (booyong, then *Argyrodendron trifoliolatum*), had emergents including *Ficus* spp., "tropical life forms" and was growing on basalt-derived soils.

- Northern Warm Temperate Rainforests. This site was dominated by *Ceratopetalum apetalum*.

In contrast to Lowman (1988), who specifically incorporated branches into his litter fall figures, Webb *et al.* (1969) included leaves only. I have used a conversion factor of 1.4 to estimate litter fall of particles < 6 mm. (Across all rainforest types leaves consistently made up 53-54% of the litter fall in Lowman's study. The parallel figure in Turner *et al.* (1989) was 58%).

- At the Subtropical Rainforest site leaf fall averaged 6562 lb/ac, which equates to 7.36 t/ha per year, giving an estimate for *L*, for particles up to 6 mm, of 10.3 t/ha.

- At the Northern Warm Temperate Rainforest site leaf fall averaged 4.49 t/ha (3995 lb/ac), giving an estimate for *L*, for particles up to 6 mm, of 6.3 t/ha.

Rating: 4
Litter fall figures are based on a single litter tray, so spatial replication is lacking. At two years, temporal replication is unlikely to be sufficient to cover interannual variability, a point the authors make themselves. The validity of the 1.4 conversion factor to estimate fall of fine litter including twigs is not known.

Rainfall and elevation: Webb *et al.* (1969) do not provide figures for rainfall or altitude. Nearest weather station is Whian Whian (Rummery Park), where annual rainfall averages 2314 mm (58 years of data, closed 2004), and elevation is 370 m.

2.7 Hurditch (1981)

This PhD research from UNE, which focused on the biochemistry of sulphur, included measurement of litter fall and litter load, with *k* values calculated from these two parameters. Study sites included a rainforest on Fraser Island in south-east Queensland. This site, which was dominated by *Syncarpia hillii* (satinay) and *Lophostemon confertus* (brush box) does not have a direct counterpart in NSW. I have included it because it adds to the rather sparse dataset for litter load.

Litter fall data covered three years, five litter trays were used, and annual litter fall averaged 7.26 t/ha. Litter load, which was assessed on a single occasion in May, amounted to 7.74 t/ha. As no size cut-off was specified I have used the standard conversion factors of 0.91 for litter fall and 0.82 for litter load to estimate *L* and *Limit* for particles under 6 mm, then calculated *k* as the ratio of *L* and *Limit*. Results are: *L* = 6.6 t/ha, *Limit* = 6.3 t/ha, *k* = 1.04.

Rating: 3
This study was carefully carried out, with adequate temporal replication for litter fall, if not for litter load. A major limitation, for current purposes, is that the relevance of these Fraser Island findings to rainforests in NSW is not known.

Rainfall and elevation: Hurditch (1981) gives a figure of 1688 mm per annum for Central Station, which is in the vicinity of the study sites. Elevation is given as 80 m asl. Nearest relevant weather station is probably Rainbow Beach (1397 mm, 18 yrs of data, 14 m asl).

2.8 Plowman (1979)

Plowman (1979) measured litter fall and litter load as part of a study of litter fauna at Mt Glorious northwest of Brisbane in south-east Queensland. One of two sites was in Subtropical Rainforest; this forest was closed, with many tree species, woody lianes, buttresses and epiphytes. The author reports figures for a single year of litter fall, and derived values for *k*. I have used these figures to extrapolate back to *Limit*. Unfortunately, I was unable to reconcile the figures in the text with figures for litter load given later in the paper, which castes some doubt on the conclusions drawn here from this study.

Litter fall across the single study site was 9.128 t/ha. As no size cut-off was specified, this gives an estimate for *L*, for particles < 6 mm, of 9.128 x 0.91 = 8.3 t/ha. *k* was estimated at 0.782, implying that Plowman (1979) used a value of 11.67 t/ha for *Limit*: this fits with her description of the litter layer in this forest as patchy and thin. Converting this to an estimate for particles < 6 mm gives 11.67 x 0.82 = 9.6 t/ha. *k* for this particle size can now be derived as 8.31/9.57 = 0.87.

Rating: 4
Litter fall figures are based on a single year. The genesis of the litter load figure used by Plowman (1979) is unclear. The need to use conversion factors adds uncertainty.

Rainfall and elevation: There is a weather station at Mt Glorious (Fahey Rd). Mean annual rainfall is 1633 mm (76 years of data), and elevation is 618 m asl.

2.9 Synthesis and suggested values for Phoenix

Parameters for litter from the studies above are summarised in Table 5. For each of the three rainforest classes for which data is available, these figures have been used to calculate weighted averages for *Limit* and *L* (Section 1.5.4); an overall value for *k* has then been derived from these two numbers. Both litter fall and *k* values are greatest in Subtropical Rainforests and lowest in Cool Temperate Rainforests (Table 5). This concurs with Lowman's findings on decomposition across the three classes (Lowman 1988).

Table 5. Values for *L, Limit and k*, for litter particles < 6 mm, derived from studies addressing rainforest vegetation. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit*, *k* derived from these two values (see Section 1.5.4). NA, not applicable.

Source	Rainforest class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Turner *et al.* (1989)	Subtropical Rainforests	6.6	6.3	1.05	3
Lowman (1988)	Subtropical Rainforests	9.1			2
Webb *et al.* (1969)	Subtropical Rainforests	10.3			4
Plowman (1979)	Subtropical Rainforests	8.3	9.6	0.87	4
Weighted mean	**Subtropical Rainforests**	**8.4**	**7.4**	**1.14**	
Conroy (1993)	Nthern Warm Temperate Rainforests		6.5		2
Lowman (1988)	Nthern Warm Temperate Rainforests	5.8			2
Webb *et al.* (1969)	Nthern Warm Temperate Rainforests	6.3			4
Weighted mean	**Nthern Warm Temperate Rainforests**	**5.9**	**6.5**	**0.91**	
Watson (1977)	Cool Temperate Rainforests	4.5	9.7	0.47	2
Lowman (1988)	Cool Temperate Rainforests	5.6			2
Weighted mean	**Cool Temperate Rainforests**	**5.1**	**9.7**	**0.53**	
Hurditch (1981)	NA (Fraser Island satinay)	6.6	6.3	1.04	3

Despite these differences, litter load in all the rainforest studies which measured this parameter fell between 6 and 10 t/ha. Thus in terms of material on the forest floor, all three rainforest types may be roughly equivalent, with increased litter fall in the more productive forests counterbalanced by increased decomposition. I suggest using a figure of 8.0 t/ha for litter load, across all rainforest types.

Two studies, Turner *et al.* (1989) and Conroy (1993), give an indication of fuel loads in near-surface and elevated layers: both imply that in this formation, fuel load in these two layers will be low. I suggest using 1 t/ha for each.

Since fire in rainforests is rare, it could be argued that *k* values are not needed or relevant for this forest type. They are, however, required input to Phoenix, and so are discussed here. For litter, *k* values are relatively high, ranging from just below 0.5 to over 1.0 (Table 5). These levels imply rapid litter turnover in rainforests, and considerable seasonal variation in litter load. In the event of a fire, near-surface fuels such as ferns would also develop rapidly in the aftermath. If it is considered necessary to use a negative exponential model for this forest type, I suggest using $k = 0.75$ for litter and near-surface fuels, and 0.30 for elevated fuel, as shrubs will tend to grow more slowly than herbs.

Similarly, the rarity of fire in rainforest means data on fine fuel levels immediately post-fire are unavailable, and are arguably of little relevance. Until further information becomes available, I suggest setting *Initial* at a default value of zero.

Suggested parameters for the rainforest formation are summarized in Table 6, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 1.

Table 6. Summary of suggested values for negative exponential model parameters, for the rainforest formation. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit*, *Initial* and *r* in t/ha.

Classes	**Fuel layer**	***Initial***	***k***	***Limit***	***r***
All	Litter	0.0	0.75	8.0	8.0
	Litter + NS	0.0	0.75	9.0	9.0
	Elevated	0.0	0.30	1.0	1.0

2.10 Knowledge gaps

Existing studies do not appear to cover Southern Warm Temperate Rainforests, Dry Rainforests, Western Vine Thickets, Littoral Rainforests or rainforests on Lord Howe Island. It is possible that *k* values may be lower, and litter loads higher, in the drier variants, particularly if emergent eucalypts are present. These knowledge gaps could be filled through targeted litter fall and litter load surveys, across years and seasons. However the limited extent of these vegetation classes, and the usual absence of fire, suggest this would not be a high priority.

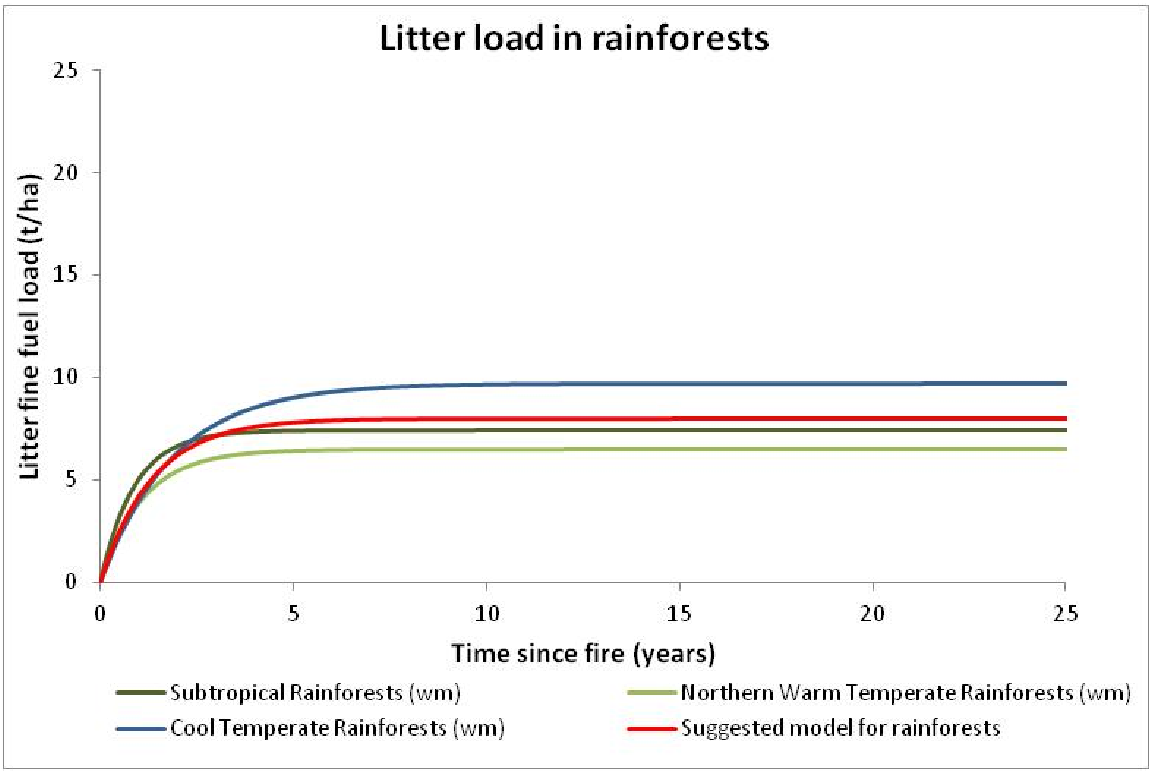

Figure 1. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in the rainforest formation. wm, model based on weighed means derived from the literature (Table 5), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 6; see text for explanation of crosswalk from literature to suggested model.

3. Shrubby wet sclerophyll forests

3.1 Introduction

Wet sclerophyll forests (WSF) are found where soils of moderate fertility occur in areas of high rainfall. Many understory plants have soft leaves and rainforest affinities (Keith 2004). In these productive forests trees are tall and conditions for decomposition are favourable. Fire, at a range of intervals and intensities, is integral to wet sclerophyll forests (Keith 2004). As we will see, litter dominates wet sclerophyll forest fuel load.

Quite a few studies address aspects of litter dynamics and/or vegetation structure in wet sclerophyll forests. These studies are discussed over the next three chapters. This chapter addresses wet sclerophyll forests in Keith's shrubby subformation. All four of the classes in this subformation occur primarily east of the Great Divide: two classes are found in coastal areas, while the other two occur on the eastern fall of the mountains, and extend onto the tablelands (Table 7). Chapters 4 and 5 address WSF classes in Keith's grassy subformation.

The boundaries between shrubby and grassy wet sclerophyll forest are not always distinct, and in some areas are almost certainly mediated by fire frequency (Keith 2004). In some cases I have had to make a judgment call when deciding whether to allocate a WSF study to the shrubby or grassy subformation.

Table 7. Vegetation classes in the shrubby wet sclerophyll forest subformation. All occur predominantly east of the Great Divide.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
North Coast WSF	62-3	On relatively fertile soils of coastal ranges and foothills, and on sheltered creek flats, north from the Illawarra and lower Blue Mountains, where rainfall exceeds 1000 mm.	large
Northern Escarpment WSF	66-7	High rainfall areas on relatively fertile fine-grained soils at altitudes of 600-1400 m asl, north from Barrington Tops.	moderate
South Coast WSF	64-5	As pockets within a matrix of DSF on the coast south from Nowra.	small
Southern Escarpment WSF	68-9	High rainfall areas on relatively fertile soils to 1300 m asl, south from Braidwood. Also on ranges further north as far as Barrington Tops.	moderate

This chapter begins with studies pertaining to North Coast WSF, from both NSW and south-east Queensland. A single study (Watson 1977), from NSW, provides insight into the Northern Escarpment WSF class. While no NSW studies located in the shrubby WSF classes in the south-east of the state have been located, several papers on forest dynamics in Victoria which may be relevant to Southern Escarpment WSF are reviewed.

3.2 Conroy (1993)

This study of fuel accumulation in vegetation types around Sydney has already been mentioned (Section 2.3). Conroy (1993) divided sites with an overstorey of sclerophyll trees into two categories, one of which was 'open forests', a group which included 9 sites with a canopy cover of 30-70%. In the absence of further information, I have allocated this group to the North Coast WSF class. However sites which more nearly approximated Northern Hinterland WSF, or even Sydney Coastal DSF, may have been included.

Conroy (1993) included shrubs up to 4 m, and used a 6 mm cut-off for fine fuel. Equation (1) parameters given in Conroy's paper for litter, herbs and shrubs all in together were: *Limit* = 18.37 t/ha, k = 0.28.

Although Conroy (1993) provides separate information for litter, herbs and shrubs, curves for individual components were not fitted. I have therefore experimented with fitting the two forms of the negative exponential model (Section 1.3). Fuel load figures for components given in Conroy (1993) are means for six time-since-fire categories. Where categories are defined by a range, I have used mid-points (eg 15 years for the 10-20 year category). For the > 20 year category I have used a time-since-fire of 25 years.[1] Parameters from this model-fitting exercise are given in Table 8.

Attempts to fit equation (3) to these data were not very successful, particularly for fuel components containing litter; standard errors are very large relative to estimated values. Thus equation (1) appears to provide the best insight into fuel accumulation in this vegetation type. Even using equation (1), R^2 values for components which contain litter are low. This is probably mostly due to uncertainties around k: SEs for this parameter are high. SEs for *Limit* are more acceptable. Model fit for shrubs and herbs is better than for components that contain litter, and is relatively consistent between equations (1) and (3).

Taking the values in Table 8 for litter only, ie *Limit* = 12.4 t/ha and k = 0.47, average annual litter fall (L) would be 5.8 t/ha.

[1] Note that the figure for total fine fuel at >20 years post-fire in the appendix to Conroy (1993) is 22.4 t/ha, however the components add to 24.0 t/ha, and this level is shown in the chart on p. 78. I have used 24.0 t/ha when fitting models.

Table 8. Parameters for negative exponential model fitted to data for 'forest' in Appendix to Conroy (1993:82). Top half of table: model assumes no fuel remains immediately after the passage of a fire. Bottom half of table: model includes a term for fuel remaining immediately after fire. SE in brackets. Significance codes: *** = <0.001; ** = < 0.01; * = < 0.05; . = < 0.1.

	Initial	***Limit***	***k***	**R^2**
Total fine fuel	Not included	19.4 (3.0)**	0.27 (0.14)	0.67
Litter only	Not included	12.4 (2.0)**	0.47 (0.31)	0.45
Litter + herbs	Not included	16.0 (2.6)**	0.34 (0.20)	0.58
Shrubs only	Not included	3.3 (0.7)**	0.14 (0.08)	0.79
Herbs only	Not included	3.7 (0.7)**	0.14 (0.07)	0.84
Total fine fuel	7.4 (2.7)	37.7 (52.2)	0.03 (0.07)	0.85
Litter only	Couldn't fit it			
Litter + herbs	Couldn't fit it			
Shrubs only	0.2 (0.7)	3.4 (1.0)*	0.12 (0.11)	0.80
Herbs only	0.3 (0.7)	3.9 (1.1)*	0.11 (0.09)	0.84

For litter + herbs, equation (1) gives the following values: *Limit* = 16.0 t/ha, *k* = 0.34. Results from fitting each of the equations to herbs only, plus the difference between the equation (1) values for *Limit* for litter only versus litter + herbs, suggest that about 3.7 t/ha of this total is made up of near-surface fuel.

For shrubs, equation (1) gives the following values: *Limit* = 3.3 t/ha, *k* = 0.14.

Rating: 3
Model fit for Conroy's nine 'forest' data points is not particularly good, particularly for components including litter. Confidence intervals around *k*, in particular, are high. This result may be due to a number of factors, including: uncertainties in vegetation type allocation; the use of data from categories, rather than raw data; and the relatively small number of points surveyed.

Rainfall and elevation: See Section 2.3.

3.3 Webb *et al.* (1969)

This litter fall study by Webb *et al.* (1969) in Whian Whian State Forest north of Lismore was also mentioned in the previous chapter (Section 2.6). In addition to rainforest sites, these researchers surveyed a *Eucalyptus pilularis* (blackbutt) dominated site with a "low dense understorey of mixed sclerophyll-vineforest spp. averaging 15-20 ft (4-6 m)" (Webb *et al.* 1969:101). Location and understorey description place this site in the North Coast WSF class. Again, only a single litter tray was deployed, over a period of a single year, and only leaves were included in litter fall figures.

Leaf fall over the study year was 5800 lb/ac, which equates to 6.50 t/ha. Using a 1.4 conversion factor to estimate litter fall of particles up to 6 mm, including bark and twigs, gives an *L* of 9.1 t/ha.

Rating: 4
Both spatial and temporal replication are lacking. The validity of the 1.4 conversion factor to estimate fall of fine litter including twigs is not known.

Rainfall and elevation: Webb *et al.* (1969) do not provide figures for rainfall or altitude. Nearest weather station is Whian Whian (Rummery Park), where annual rainfall averages 2314 mm (58 years of data, closed 2004), and elevation is 370 m.

3.4 Turner and Lambert (1983)

Turner and Lambert (1983) measured litter fall and litter load in a single site near Coffs Harbour dominated by *E. grandis*. This species had been planted into the site 27 years prior to sampling, after a wildfire. Prior to the fire the site had supported sub-tropical rainforest, and by the time of sampling a substantial rainforest understorey had developed. Location, understorey composition and dominance of *E. grandis* place this site in the North Coast WSF class, although the degree to which fuel dynamics in this plantation mimic those in 'natural' North Coast WSF is an open question.

Duration of litter fall sampling is not clear, however as figures are given for three-monthly intervals covering all 12 months, presumably sampling continued for a year. Genesis of the forest floor biomass figures is also unclear. As this was a total biomass study, no cut-offs for fine fuel were used.

Litter fall totaled 9.60 t/ha, 22% of which came from understorey plants. Using a conversion factor of 0.91 (Section 1.5.2) gives an estimate of 8.74 t/ha for fine fuels under 6 mm.

Litter load on the forest floor totaled 17.37 t/ha, the majority of this being sticks and bark. Using a conversion factor of 0.82 (Section 1.5.1) gives an estimate of 14.2 t/ha for fine fuels under 6 mm.

These values can be combined to estimate k, which in this case is 0.62.

Turner and Lambert (1983) also provide total biomass figures for the understorey, where foliage averaged 3.09 t/ha, stems a massive 38.05 t/ha, and 'minor understorey' 0.93 t/ha.

'Minor understorey' could perhaps be equated with near-surface fuel. Assuming this component is all under 6 mm in diameter, and adding it to the estimate for surface fuels above, gives a total of 15.1 t/ha for litter and near-surface fuel under 6 mm in diameter.

The figure for understorey foliage, 3.09 t/ha, can be assumed to all sit under the 6 mm cut-off. Some of the stem component will also be fine fuel, but we have no way of knowing how much. However these figures suggest that the fuel load < 6 mm in the elevated fuel layer was at least the 3.3 t/ha derived from Conroy's figures, and could perhaps be quite a bit higher in places with a substantial rainforest understorey.

Rating: 4
There are a number of uncertainties in relation to the figures derived from this study, beginning with the fact that this site was a plantation, rather than natural regrowth. Lack of detail of sampling methods, the use of a single site, and the lack of a detailed breakdown into size-classes in this total biomass study, add to the uncertainty.

Rainfall and elevation: Mean annual rainfall given by Turner and Lambert (1983) is 1760 mm. Nearest weather station is probably Lower Bucca, where long-term average is 1479 mm (88 years of data, 112 m asl). Further south at Coffs Harbour MO mean rainfall is 1686 mm (62 years of data, 5 m asl).

3.5 Turner (1986)

Turner (1986) adds additional data on litter fall and litter load in *Eucalyptus grandis* plantations near Coffs Harbour in NSW. I have classified this study as North Coast WSF on the basis of its location, and because *E. grandis* is indicative for this WSF class. However as these sites were plantations rather than native forests, the allocation is rough.

Turner (1986) surveyed litter load in four sites of different establishment ages on two occasions four years apart. As litter load stabilized when plantations were approximately 12 years old, I have used data for the three sites above this age (samples were taken from stands between 12 and 31 years old). Litter fall was measured over 15 months in the same three stands.

Across sites and sampling locations, litter load averaged 18.5 t/ha (range 16.5 to 20.7 t/ha), while litter fall averaged 7.5 t/ha (range across sites 7.3 to 7.6 t/ha). Using the standard conversion factors gives estimates for particles < 6 mm of 15.2 t/ha for *Limit*, 6.8 t/ha for *L*, and 0.45 for *k*.

Rating: 3
Again, the major limitation of this study for current purposes is its focus on plantations rather than native forests. However its spatial and temporal replication, particularly for litter load, are good. The need to use conversion factors to estimate parameters for particles < 6 mm adds uncertainty.

Rainfall and elevation: Mean annual rainfall at Coffs Harbour MO is 1686 mm (62 years of data, 5 m asl).

3.6 Hynes and White (1983)

Hynes and White (1983) measured litter fall in two sites at Tewantin in south-east Queensland. Measurements were taken over a single 12-month period. Material up to 10 mm in diameter was collected. Both sites can probably be considered North Coast WSF: the dominant species in Site 1 was *Lophostemon confertus*, while *E. grandis* dominated Site 2.

Litter fall averaged 4.9 t/ha in Site 1, and 6.9 t/ha in Site 2. Thus the mean value for the two sites together was 5.9 t/ha. Using the 0.99 conversion factor (Section 1.5.2) gives a figure of 5.8 t/ha for particles under 6 mm.

Litter load was also assessed as part of this study, however as time-since-fire was both unclear, and low, it is unlikely that steady state had been reached.

Rating: 3
As litter fall can vary considerably from year to year, a single year of measurement is unlikely to capture average values.

Rainfall and elevation: Hynes and White (1983) do not give figures for rainfall. Mean annual rainfall at the weather station at Tewantin P.O. is 1697 (101 years of data, 8 m asl).

3.7 Guinto *et al.* (2001)

This study examined nutrient levels in three different fire frequency treatments in two long-running experimental sites in south-east Queensland. The second site, at Peachester 100 km north of Brisbane, was dominated by *Eucalyptus pilularis*, *E. microcorys*, *E. resinifera*, *Lophostemon confertus* and *Syncarpia glomulifera*, with a variable understorey. Thus this wet sclerophyll forest site has common ground with both North Coast and Northern Hinterland WSF; I have included it here under the shrubby subformation.

Litter load in the long unburnt treatment, which had been without fire for at least 25 years at the time of sampling, was 20.68 t/ha. As no cut-off size was mentioned, I have used the 0.82 adjustment factor to give an estimated fuel load for particles < 6 mm of 17.0 t/ha.

Rating: 3
A time-since-fire of 25 plus years should be sufficiently long for litter load to have reached quasi steady-state. The spatial replication behind this figure appears reasonable. However the lack of temporal replication, and the use of a conversion factor to arrive at an estimated figure for particles < 6 mm, reduces confidence.

Rainfall and elevation:
Guinto *et al.* (2001) give a figure of 1711 mm for annual rainfall at this site, and an altitude of 137 m asl. Nearest weather station would be Crohamhurst (1835 mm rainfall, 200 m asl, 109 years of data).

3.8 Plowman (1979)

The study by Plowman (1979), which measured litter fall and litter load at Mt Glorious northwest of Brisbane in south-east Queensland, has already been outlined (Section

2.8). Plowman's second vegetation type fits Keith's description of North Coast WSF. Tree dominants were *Eucalyptus saligna* and *Lophostemon confertus* (then *Tristania conferta*); there was a well-developed rainforest understorey, and ferns were prominent. The author reports figures for a single year of litter fall, and derived values for *k* which I have used to extrapolate back to *Limit*.

Litter fall across the single study site was 8.866 t/ha. As no size cut-off was specified, I have used the 0.91 conversion factor to estimate *L*, for particles < 6 mm, at 8.31 t/ha. *k* was estimated in the paper at 0.407, implying a value of 21.78 t/ha for *Limit* (litter load figures given later in the paper did not exactly match up, although they were reasonably close, averaging 20.82 t/ha across four sampling periods). Using the 0.82 conversion factor gives an estimate for particles < 6 mm of 17.86 t/ha. *k* for this particle size can now be derived as 8.31/17.86 = 0.45.

Rating: 4
Litter fall figures are based on a single year. The genesis of the litter load figure used by Plowman (1979) is not completely clear. The need to use conversion factors adds uncertainty.

Rainfall and elevation: There is a weather station at Mt Glorious (Fahey Rd). Mean annual rainfall is 1633 mm (76 years of data), and elevation is 618 m asl.

3.9 Applegate (1982)

This UNE Masters thesis documents total biomass in three sites on Fraser Island in south-east Queensland. There are many reasons why the results of this study are difficult to apply in the current context; it does, however, provide some insights and suggest avenues for further exploration.

All three study sites contained blackbutt (*Eucalyptus pilularis*), with *E. microcorys* (tallowwood), *Syncarpia hillii* (satinay), *Tristania conferta* (brush box, now *Lophostemon confertus*) and a range of mesic and sclerophyll shrubs also present. In terms of NSW classes, the vegetation approximates North Coast WSF, though the fit is rough. Applegate (1982) notes the relatively slow growth rates of blackbutt on Fraser Island, where the deep sandy soils contain few nutrients: this factor too may limit applicability to mainland forests. The three sites differed in management history: one contained 18-year-old regeneration, one 46-year-old regeneration, while the third was a mixed species ‘old growth’ forest; these age classes were not replicated. All had been logged, and the two younger sites had been subject to extensive silvicultural treatment. Fire is mentioned only as a post-logging treatment, with the implication that no fire had occurred during the regeneration cycle on the younger two sites, or for many years on the older site.

Unfortunately, the categories used in this study are not convenient from a fine fuel point of view. Material on the forest floor was divided into large litter, ie branches and logs > 10 cm (100 mm), unincorporated litter < 10 cm, and incorporated litter, ie fragments mixed with sand, mycelia etc. Understorey was distinguished from small trees: anything over 2 m in height was called a small tree if it was < 10 cm diameter at breast height, and a tree if it exceeded that diameter. ‘Understorey’ consisted of shrubs and other plants (mainly sedges, cycads, grass-trees and bracken) under < 2 m. Within the small tree and understorey strata, material was divided into stems, branches and leaves. Cut-off points, however, were not specified, making it unclear whether twigs were classified as leaves or branches.

Despite these difficulties, some trends in the data are worth noting. Standing litter load decreased with stand age. Applying a 0.82 conversion factor to the sum of the two < 10 cm litter components, litter load on the youngest site averaged 18.4 t/ha, while in the oldest this figure was a very low 5.50 t/ha. Across the three sites, application of the conversion factor gives an average of 12.37 t/ha. Applegate (1982) attributes the low litter load in the old growth forest partly to the time of year when sampling took place, but also to the inclusion in the canopy of the semi-mesic species satinay and brush box, which he contends drop litter at a lower rate than eucalypts (there is some additional evidence for this for brush box, from a study by Rogers and Westman (1977) on North Stradbroke Island, and from the Hynes and White (1983) study described above). Relatively rapid decomposition may also have played a part.

In the understorey and small tree layer there was evidence of succession across the age-classes, with the sclerophyll species prominent on the youngest site much reduced in abundance in the 46-year-old stand. On the old-growth site, mesic species dominated the understorey and small tree strata. To arrive at a biomass estimate for elevated fuel I have made a number of assumptions. I have included the total figure for understorey (this may include some components > 6 mm in diameter, but if so this component would be small, as most of the prominent species did not have stems), and one third of the mass of the foliage component of the small tree layer. Adding these components gives an average for understorey (including near-surface) fine fuel load, across the three sites, of 2.62 t/ha, with a range from 2.32 to 2.85 t/ha. In other words, the understorey component in these Fraser Island forests does not carry a high fine fuel load, and it appears relatively consistent across age classes.

A general point which arises from this study is the influence of silvicultural management on fuel load and fuel structure. Applegate (1982) often calls on the management history of his sites to explain his findings, noting factors such as the existence of coppice in the small tree layer, and the manipulation of tree composition (and thus litter fall, and litter load). He suggests that the high fuel load in the youngest site may partly reflect post-logging debris which was not consumed in the regeneration burn.

Rating: 4
There are many uncertainties in relation to the figures derived from this study. Chief amongst them are the number of assumptions I needed to make to convert the findings into mass per unit area of fine fuel. Replication across space, and time, was limited: the author himself remarks that better replication would have been desirable. Note also that these sites had been subject to various management interventions to do with their status as production forests.

Rainfall and elevation: Applegate (1982) gives a figure of 1500-1600 mm per annum for Central Station, which is in the vicinity of the study sites. Nearest relevant weather station is probably Rainbow Beach (1397 mm, 14 m asl, 18 yrs data).

3.10 Watson (1977)

Again, this Masters project from UNE has already been outlined in the rainforest chapter (Section 2.4). Amongst Watson’s sites was a wet sclerophyll forest patch on the eastern fall of the Great Divide, at an altitude of 790 m in New England National Park. The vegetation in this site most closely approximates Keith's Northern Escarpment WSF class. Tree species mentioned in both Watson's site description and the class description in Keith (2004) include *E. saligna*, *E. microcorys* and New England Blackbutt (then *E. andrewsii*, now *E.campanulata*). The tree fern *Cynathea australis* also appears in both descriptions. *E. pilularis* was also present on this highly productive site, where rainfall exceeded 1500 mm per annum and the tallest trees were over 50 m high.

Litter fall was measured over four consecutive years, using 15 litter traps. The average amount collected per year was 9.16 t/ha. No size cut-off is mentioned. Applying the 0.91 conversion factor gives an estimate of 8.34 t/ha for annual accession of litter particles < 6 mm.

Watson (1977) attempted to determine decomposition rates in this forest site using litter bags stocked with freshly-fallen leaves from the overstorey species. Over the 56 week period litter bags were left out, a mean of 27.8% of the weight of these leaves was lost. Using Olson's model (Section 1.3), this equates to a *k* value of 0.30. Taking this figure and the estimate for litter fall in the paragraph above gives a value of 27.8 t/ha for steady state fuel load.

Watson (1977) also sampled litter on the forest floor, on three occasions over a 12 month period. Mean litter load was 13.45 t/ha. Using the 0.82 conversion factor gives a value, for litter < 6 mm in diameter, of 11.03 t/ha − considerably lower than the figure derived from *L* and *k*. Again, however, time-since-fire is not mentioned: it is interesting in this context to note that litter load rose over the three sampling periods.

Watson's figure for *k* seems somewhat low given the high rainfall and site productivity, particularly since bags contained leaves only, with no bark or twig material. The large difference between the two estimates for *Limit* implies either that steady state had not been reached when Watson's forest floor sampling took place, or that the decomposition experiment somehow failed to properly assess *k*. A recent fire in the site would explain the low decomposition rate, and would also imply that steady state litter load might be somewhat higher than the measured 11.03 t/ha. A larger *k* value would mean the derived figure for *Limit* (presently 27.8 t/ha) would be reduced, better aligning the two estimates.

Rating: 3
The litter fall figure for this study is probably reasonably accurate, as it was based on four years of data collection, and good within-site replication. Lack of a specified size cut-off reduces confidence in my derived estimate for fine material, to a small extent. The problems with the estimated values for *Limit* are discussed above; I have not

included values for *Limit* or *k* from Watson's study when calculating weighted means (Table 9).

Rainfall and elevation: Watson (1977) gives a figure of 1536 mm for annual rainfall at this site, based on four years of measurement on the site itself. An altitude of 790 m asl is noted in the thesis. The nearest weather station is Jeogla (1515 mm rainfall, 1030 m asl, 43 yrs of data).

3.11 Campbell *et al.* (1992)

This Victorian study measured litter fall over a two year period at two sites near streams. Vegetation at both these sites is reminiscent of Keith's Southern Escarpment WSF class. Dominant eucalypts were *Eucalyptus cypellocarpa*, *E. obliqua* and *E. viminalis*, all indicative for Southern Escarpment WSF. Understorey species noted in the descriptions of both Keith (2004) and Campbell *et al.* (1992) include *Blechnum nudum*, *Pomaderris aspera* and *Bedfordia arborescens*.

At both sites, litter collection included a transect in the riparian vegetation immediately adjacent to the stream. In one of the sites, a further transect in the surrounding forest, 300 m from the stream, was also included. Five traps were used on each transect. Sticks up to 20 mm in diameter were collected.

At the first site, Keppel Creek near Marysville, litter fall averaged 8.00 t/ha. Using the 0.95 conversion factor gives an estimated value for *L* of 7.60 t/ha, for particles < 6 mm.

At the second site, Loch River north of Noojee, litter fall in the riparian zone averaged 8.37 t/ha, while on the forest transect it was 7.44 t/ha, giving a mean of 7.91 t/ha. Multiplying by 0.95 gives 7.51 t/ha as the estimate for particles < 6 mm.

Rating: 3
Across the entire study, spatial replication was good, and temporal replication reasonable. Use of a conversion factor adds uncertainty. The main difficulty with this study for current purposes is its location in Victoria.

Rainfall and elevation:
Campbell *et al.* (1992) don't provide rainfall figures for their sites, and location details are scant. Nearest weather station to Keppel Creek is probably Toolangi, where the mean annual rainfall is 1358 mm (55 years of data), and elevation is 595 m asl. Nearest weather station to Loch River is probably Noojee (Slivar), with a mean annual rainfall of 1106 mm (29 years of data) and elevation of 275 m asl.

3.12 Attiwill *et al.* (1978)

A second Victorian study in vegetation with some similarities to Southern Escarpment WSF was conducted by Attiwill *et al.* (1978) in Mt Disappointment State Forest. Here, *Eucalyptus obliqua* dominated, "with scattered individuals of *E. cypellocarpa* and *E.*

radiata". *E. obliqua* and *E. cypellocarpa* are indicative for Southern Escarpment WSF. The Victorian vegetation had a "well-developed understorey" with common species including *Acacia dealbata* and *Bedfordia aborescens* (then *B. salicina*), both of which feature in Keith's description of this vegetation class (Keith 2004).

Attiwill *et al.* (1978) measured litter fall, in three sites over two years. Five traps were used at each site.

Litter fall averaged 3.56 t/ha. No size cut-off was specified. Using a conversion factor of 0.91 gives a value for *L*, for particles < 6 mm, of 3.24 t/ha.

A previous paper by Attiwill (1968) reported the weight of litter on the floor of this forest as 18.25 t/ha. Using the 0.82 conversion factor and assuming steady state gives an estimate, for *Limit*, of 15.0 t/ha for particles < 6 mm.

Solving equation (2) with *L* = 3.24 and *Limit* = 15.0 gives an estimate for *k* of 0.22 for particles < 6 mm.

Rating: 3
While spatial and temporal replication in this study was reasonable, the lack of a size cut-off introduces uncertainty for current purposes. The location of the study site outside NSW is also an issue. The value for litter on the forest floor given by Attiwill (1968) had some uncertainty associated with it because of the difficulty of separating litter from soil.

Rainfall and elevation: Attiwill (1968) provides a figure for rainfall at this site, 45 inches (1143 mm), and a figure for elevation, 2000 ft (610 m). The nearest weather station in a similar environment may be Toolangi (Mt St Leonard DPI), which averages 1356 mm of rainfall per year (56 years of data), at 595 m asl.

3.13 Howard (1973)

Yet another record of litter dynamics in Victoria comes from a study of *Nothofagus cunninghamii* on the slopes of Mt Donna Buang, approximately 80 km NW of Melbourne. While this appears to be a rainforest study, the litter fall in the study site came predominantly from *Eucalyptus nitens*. Thus the vegetation could be considered late successional shrubby wet sclerophyll forest, with affinities, once again, to Keith’s Southern Escarpment WSF class. Keith’s description of this vegetation class lists *E. nitens* as a typical overstorey species. *N. cunninghamii* does not occur in NSW.

Howard (1973) gives virtually no information on methods used to collect litter fall, but sampling appeared to cover two years. Litter load on the forest floor was also measured, and a value for *k* calculated. No size cut-off is mentioned.

For litter fall, Howard gives a value of 6.5 t/ha. Applying the 0.91 conversion factor gives an estimated *L* of 5.9 t/ha for particles under 6 mm.

No value for steady-state litter load is given (steady state can be presumed to exist given the well-developed mesic understorey), but a *k* of 0.42 is calculated from this value.

Solving equation (2) for *Limit* gives 15.5 t/ha. Applying the 0.82 conversion factor gives an estimated value for *Limit* of 12.7 t/ha for particles < 6 mm.

With *L* = 5.9 t/ha, and *Limit* = 12.7, *k* would be 0.46.

Rating: 4
Lack of information on methods used adds considerable uncertainty. The location of the study site outside NSW is an issue, as is the dominance of the understorey by a species not found in NSW.

Rainfall and elevation: Howard (1973) provides a figure for elevation of 3300 feet, which is 1006 m, but does not provide figures for rainfall. The nearest weather station may be Toolangi (Mt St Leonard DPI), which averages 1356 mm of rainfall per year (56 years of data), at 595 m asl – though the actual site was considerably higher than this.

3.14 Ashton (1975)

This is again a Victorian study, in wet sclerophyll forest at Wallaby Creek dominated by the obligate seeder eucalypt *E. regnans*, which is not found in NSW. However dominant trees in the Southern Escarpment WSF class include *E. fastigata*, an obligate seeder closely related to *E. regnans* (Brooker and Kleinig 1999, Keith 2004). The understorey of Southern Escarpment WSF has much in common with the understorey of Alpine Ash at Wallaby Creek: *Pomaderris aspera* and *Olearia argophylla* are notable in the descriptions of each (Ashton 1975, Keith 2004).

Ashton (1975) measured litter fall over six consecutive years, as well as litter load. Various age classes of forest were sampled: I have focused on the figures for mature forest (220-330 years post-fire). No cut-off size for woody branches and twigs is mentioned.[2]

Litter fall in mature forest averaged 7.76 t/ha (Ashton 1975:416, Table 2). Figures for spar-stage forest (52-57 years old) were very slightly lower at 7.73 t/ha, while pole-stage forest averaged 6.61 t/ha. Using the figures for mature forest, and a conversion factor of 0.91 (Section 1.5.2), the estimated litter fall of particles < 6 mm in diameter is 7.06 t/ha.

Load of litter on the floor of the mature forest averaged 22.25 t/ha (20.25 t/ha in pole-stage forest). Using the figure for mature forest and a conversion factor of 0.82 (1.5.1) gives an estimated 18.25 t/ha for *Limit*.

Using figures of 7.06 t/ha for *L* and 18.25 t/ha for *Limit* gives an estimated *k* value for particles < 6 mm of 0.39.

Rating: 3
Figures for total litter fall are likely to be highly accurate, as sampling covered such a long period (six years). Litter load data will be less reliable as it was assessed on only

[2] Note that figures for total litter fall in Table 3 (Ashton 1975:416) differ slightly to those in Table 2 – I have used the 'corrected averages' in Table 2.

one occasion, using limited replication (10 quadrats: not clear whether this sampling intensity was employed in each age class or overall). A major difficulty for current purposes is the lack of information on the extent to which 'wood' fell into the < 6 mm size class. Further limitations, for present purposes, include the fact that this study did not take place in NSW, and that the vegetation studied, while sharing some characteristics with a NSW vegetation class, was dominated tree species not found in this state.

Rainfall and elevation: Ashton (1975) gives figures of 1300-1350 mm for mean annual rainfall, and 670-700 m for elevation. Nearest relevant weather station is probably Toolangi (595 m asl, mean annual rainfall 1356 mm, 56 yrs of data); other nearby weather stations are either much lower in elevation, or much lower in rainfall.

3.15 Synthesis and suggested values for Phoenix

The studies reviewed above provide considerable insight into the dynamics of shrubby wet sclerophyll forests.

Table 9. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the shrubby subformation of wet sclerophyll forests. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit*, *k* derived from these two values (see Section 1.5.4).

Source	WSF class	***L* (t/ha)**	***Limit* (t/ha)**	***k***	R'g
Conroy (1993)	North Coast WSF	5.8	12.4	0.47	3
Webb *et al.* (1969)	North Coast WSF	9.1			4
Turner and Lambert (1983)	North Coast WSF	8.7	14.2	0.62	4
Turner (1986)	North Coast WSF	6.8	15.2	0.45	3
Hynes and White (1983)	North Coast WSF	5.8			3
Guinto *et al.* (2001)	North Coast WSF		17.0		3
Plowman (1979)	North Coast WSF	8.3	17.9	0.45	4
Applegate (1982)	North Coast WSF		12.4		4
Weighted mean	**North Coast WSF**	**7.0**	**14.9**	**0.47**	
Watson (1977)	Northern Escarpment WSF	8.3			3
Campbell *et al.* (1992)	Southern Escarpment WSF	7.6			3
Attiwill *et al.* (1978)	Southern Escarpment WSF	3.2	15.0	0.22	3
Howard (1973)	Southern Escarpment WSF	5.9	12.7	0.46	4
Ashton (1975)	Southern Escarpment WSF	7.1	18.3	0.39	3
Weighted mean	**Southern Escarpment WSF**	**6.0**	**15.9**	**0.38**	
Weighted mean	**All shrubby WSF studies**	**6.7**	**15.2**	**0.44**	

Litter parameters are summarised in Table 9, which also includes weighted means for the North Coast and Southern Escarpment WSF classes, and for the formation as a whole (Section 1.5.4). While values are roughly equivalent across all classes for which information is available, there is some indication of slightly higher rates of litter fall and decomposition, and slightly lower values for *Limit*, in the northern forests within this subformation, relative to those in the south. Litter fall is of a similar order to that observed in rainforests (Section 2.9). Decomposition rates, while lower than in rainforest, are still relatively high. These factors produce moderately high levels of standing litter load at steady state, and imply rapid development of surface fuels after a fire: the summary decomposition constants derived from the weighted means for *L* and *Limit* equate to 6.4 and 7.9 years to reach 95% of steady state in North Coast and Southern Escarpment WSF, respectively. High *k* values also mean a fair degree of variability in fuel loads between seasons and years even when (quasi) steady state has been attained (see Section 4.3). Thus some of the inconsistency in values for *Limit* returned by the studies in this chapter may be due to time of sampling, while some no doubt reflects site factors (Turner 1986), silvicultural treatments (Applegate 1982) and previous fire history. As very long-unburnt wet sclerophyll forests succeed towards rainforest, and/or where eucalypts are replaced by semi-mesic Myrtaceous species such as *Lophostemon confertus* and *Syncarpia* spp, standing litter loads may decline (Applegate 1982). That eucalypts continue to contribute litter to the forest floor, to the point where fire could still be expected to carry in drought conditions, is attested by the 'rainforest' study of Howard (1973) outlined above.

Despite the hint of differences between southern and northern forests in this subformation, these do not appear sufficiently great to warrant separate parameters in management applications. As severe fires are likely to occur in summer when litter fall is greatest and litter loads may therefore be tending towards their maximum, I suggest using a figure of 17.0 t/ha for *Limit*, for litter alone, with k = 0.45 (weighted mean value rounded up).

We do not have information on litter load immediately post-fire, however given the failure of attempts to fit the form of the negative exponential model with a term for *Initial* to Conroy's data (Conroy 1993, Section 3.2), I suggest using a relatively low figure, say 1.0 t/ha.

Three studies provide indications as to fuel load in the near-surface and elevated layers in this forest type. Models fitted to data from Conroy (1993) suggest a maximum of 3.7 t/ha of herbaceous, and 3.4 t/ha of elevated fuel, with *k* values of around 0.13. Extrapolation from figures provided by Turner and Lambert (1983) imply a herbaceous load of under 1 t/ha, and an elevated load of above 3 t/ha. Figures in Applegate (1982) suggest a total for near-surface and elevated fuel of 2-3 t/ha. These figures, particularly those of Applegate (1982), which were consistent across his study sites, are in line with the general observation that high canopy cover limits understorey development (Specht and Specht 1999). I suggest, for *Limit*, using a figure of 2.0 t/ha for near-surface fuel, and 3.0 t/ha for elevated fuel.

Thus, for litter + herbs ('surface fuel' in Phoenix), suggested values are: *Initial* = 1.0 t/ha; *Limit* = 17.0 + 2.0 = 19.0 t/ha; *k* = 0.35. I have reduced *k* slightly with the addition of near-surface fuel because the *k* value for litter+herbs derived from Conroy's data was lower than that for litter alone (Table 8).

Conroy's work suggests that elevated fuel levels immediately post-fire in this vegetation formation are very low. Suggested values for this component are: *Initial* = 0.0 t/ha; *Limit* 3.0 t/ha; *k* = 0.15.

Suggested parameters for the shrubby sub-formation of wet sclerophyll forests are summarized in Table 10, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 2.

Table 10. Summary of suggested values for negative exponential model parameters for the shrubby subformation of wet sclerophyll forests. NS, near-surface. *r = Limit - Initial. Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	Fuel layer	*Initial*	*k*	*Limit*	*r*
All	Litter	1.0	0.45	17.0	16.0
	Litter + NS	1.0	0.35	19.0	18.0
	Elevated	0.0	0.15	3.0	3.0

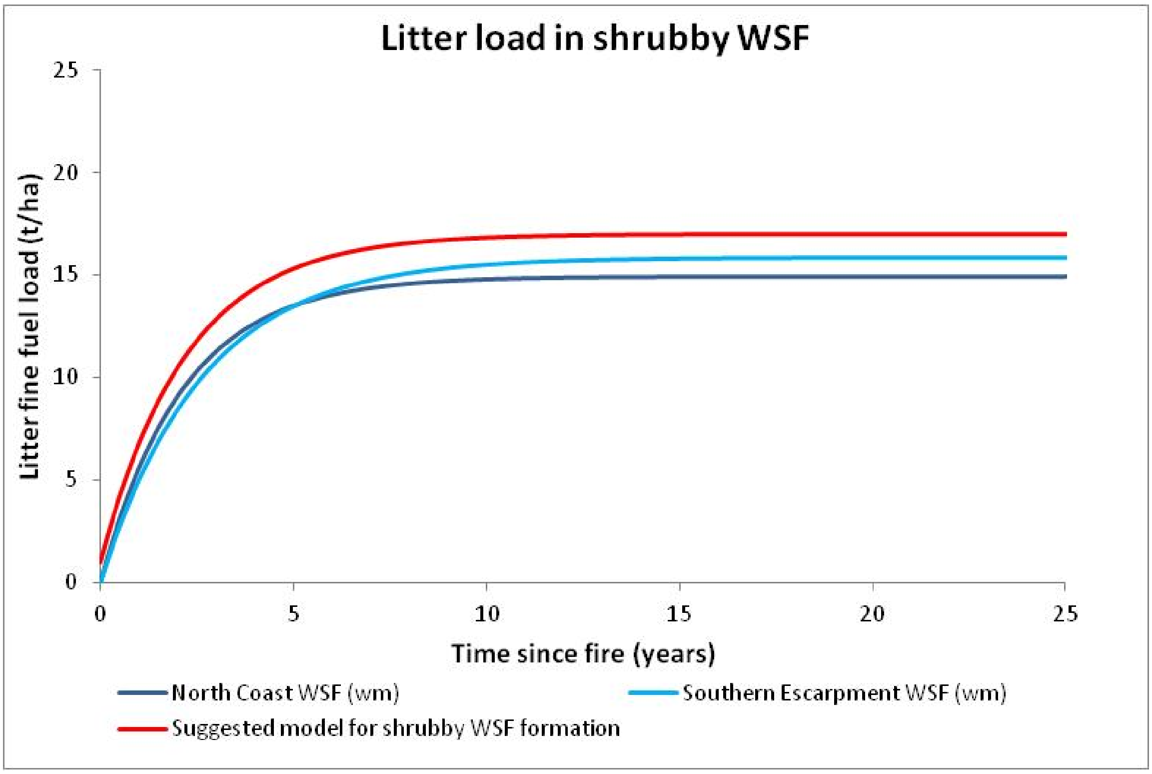

Figure 2. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in the shrubby subformation of wet sclerophyll forests. wm, model based on weighed means derived from the literature (Table 9), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 10; see text for explanation of crosswalk from literature to suggested model.

3.16 Knowledge gaps

In the north of the state, although existing studies provide good coverage of the coastal variant of this forest type (North Coast WSF), the escarpment variant (Northern Escarpment WSF) is represented only by a single litter fall study. In the south, all the studies reviewed in this chapter for Southern Escarpment WSF were conducted outside NSW, with no studies in South Coast WSF identified at all. The gap in the north could be filled by sampling litter load in long-unburnt Northern Escarpment WSF, across years and seasons. Adding near-surface and elevated fuels to this exercise would increase understanding of these components, in this forest type. In the south, both litter fall and litter load studies would be needed. However given the small extent of South Coast WSF, and the relative consistency of existing results across the formation, this work would probably not be a high priority.

4. Grassy wet sclerophyll forests east of the Divide

4.1 Introduction

Two of Keith's five grassy wet sclerophyll forest classes are found predominantly east of the Great Divide (Table 11); the remaining three, which occur primarily on the tablelands, will be addressed in Chapter 5. Of the two coastal grassy wet sclerophyll forest classes, the Northern Hinterland WSF, which occurs north from Sydney in a mosaic with shrubby North Coast WSF, are the more abundant.

Table 11. Vegetation classes in the grassy wet sclerophyll forest subformation, which occur predominantly east of the Great Divide.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Northern Hinterland WSF	70-1	Throughout coastal hinterland north from Sydney	large
Southern Lowland WSF	72-3	Coastal hills and lowlands, mostly between Nowra and Bega	moderate

Fuel load studies have been conducted in each of these vegetation classes. Northern Hinterland WSF has been the subject of detailed research by Hurditch (1981), Birk and Bridges (1989), and Penman and York (2010). Insight into litter dynamics in Southern Lowland WSF comes from studies by McColl (1966), Pook *et al.* (1997) and Roxburgh *et al.* (2006).

4.2 Hurditch (1981)

This PhD research from UNE, which measured both litter fall and litter load, was introduced in the rainforest chapter (Section 2.7). Sites were located either on the NSW North Coast or on Fraser Island in Queensland. Study sites in NSW were:

- A "virgin stand of moist blackbutt" (Hurditch 1981:2-14) in the Lorne Flora Reserve north-west of Kendall (Site LOGS.87). *E. pilularis* dominated this site, along with *E. microcorys*, *E. grandis* and *E. acmenoides*. *Allocasuarina torulosa* was common, as was *Acacia binervata* and *Imperata cylindrica*.

- An approximately 45-year-old regrowth stand of *E. pilularis*, with co-occuring tree species *E. microcorys*, *E. carnea* and *E. resinifera* (Site BRG.29). Again, *A. torulosa* formed a small tree layer. Common understorey species included *Persoonia linearis* and *Eupomatia laurina*. This site was located in Burrawan State Forest, just off the Pacific Highway south of Wauchope.

- An old-growth stand of *E. pyrocarpa* (big-fruited blackbutt) in Conglomerate State Forest west of Woolgoolga (Site COG.26). Other tree species included *E. microcorys*, *E. carnea* and *Angophora costata*, while the understorey featured a mixture of sclerophyll and mesic shrubs.

I have allocated all three sites to Keith's Northern Hinterland WSF class. While elements of both LOGS.87 and COG.26 are not completely typical for this forest type, after considering other feasible options (North Coast WSF for LOGS.87, North Coast DSF for COG.26), this class appeared the most appropriate.

Litter fall data used in analysis covered a single 12-month period, with ten litter trays per site. No size cut-off was specified. In Sites LOGS.87 and COG.26 litter load was assessed twice, in November 1978 and the following July, while in BRG.29 only the July measurement was carried out. Some assessment of litter load components was undertaken, with the 'branches' category, which included material with a diameter of 5-50 mm, averaging 19%. To estimate material under 6 mm I have used the standard conversion factors of 0.91 for litter fall, and 0.82 for litter load. Results for the three sites are given in Table 12.

Table 12. Measured and derived parameters for litter for three North Coast sites studied by Hurditch (1981).

Site	Measured *L* (t/ha)	Estimated *L* < 6 mm (t/ha)	Measured litter load (t/ha)	Estimated *Limit* < 6 mm (t/ha)	Estimated *k* < 6 mm
LOGS.87	8.86	8.06	25.16	20.63	0.39
BRG.29	7.19	6.54	21.67	17.77	0.37
COG.26	8.67	7.89	20.81	17.06	0.46

Estimated values for *Limit* and *k* assume litter load has obtained steady state. While no information on fire history was given in the thesis, discussion with the author suggests that while the first two sites had not burnt for some time, COG.26 may have had a fire a few years prior to sampling (pers. comm. Bill Hurditch 2010).

Hurditch (1981) also reports unpublished data collected independently of his study for a site adjacent to BRG.29. Results were very similar.

Rating: 3
This study was carefully carried out, with adequate spatial replication. The short-term nature of the litter fall data is, however, a major limitation, as is the question of whether litter load had reached quasi-equilibrium.

Rainfall and elevation: The three sites are sufficiently dispersed to warrant separate treatment for elevation and rainfall. Hurditch (1981) gives specific information for elevation, but not for long-term rainfall.

- LOGS.87. Elevation was 290 m. Nearest weather station would be Wauchope (1283 mm, 9 m asl, 18 yrs data), however the higher-elevation station at Yarras may be more similar (1724 mm, 155 m asl, 61 yrs data). For rainfall I've taken the average for these two stations, ie 1503 mm.

- BRG.29. Elevation was 100 m. This site is approximately equidistant between Laurieton (1542 mm, 12 m asl, 124 yrs data) and Wauchope (1283 mm, 9 m asl, 18 yrs data). For rainfall I've used the mean of these two stations, ie 1413 mm.

- COG.26. Elevation is 405 mm. Nearest weather station is probably Lower Bucca (1481 mm rainfall, 112 m asl, 89 years of data).

4.3 Birk and Bridges (1989)

Birk and Bridges (1989) report on a 20-year experiment, set up in 1967 in 27-year-old *Eucalyptus pilularis* regrowth 27 km north of Taree. Understorey vegetation varied from grassy to shrubby, however much of the shrub layer was apparently lantana, and I have classified this site as Northern Hinterland WSF.

This was a fire frequency study with three replicated treatments: burning every 2 years, burning every 4 years, or no burning. The aim was to assess the effects of fire frequency rather than to develop a fuel curve *per se*.

Fuel measurements included all material, dead or alive, < 25 mm in diameter and up to 0.9 m in height. This total is broken down into leaves, twigs, bark, miscellaneous (these are the forest floor components), and green and cured understorey.

To establish a figure for *Limit*, I have drawn on the findings from the unburnt/control treatment, which stabilized at around 25-30 years post-fire. Total fine fuel in the control plots averaged 19.92 (± 2.36) t/ha in 1979. Of this, 0.7 t/ha was understorey vegetation up to 0.9 m in height, while 19.21 t/ha was litter on the forest floor. As this figure is for material < 25 mm in diameter, the 0.87 conversion factor applies (Section 1.5.1), giving an estimate of 16.7 t/ha for fine litter fuel < 6 mm in diameter.

Litter fall inputs varied from year to year, however the mean value in the control plots was 7.8 t/ha, for material < 25 mm. Using the 0.94 conversion factor (Section 1.5.2) gives an estimated 7.3 t/ha for material < 6 mm.

Using equation (2), k can therefore be estimated as 7.3/16.7 = 0.44. This figure accords with the general finding in this paper that fuel accumulated rapidly in the early post-fire years. Data from this study show that, as expected, this high k value was associated with relatively large inter- and intra-annual fluctuations in standing litter load. This was because much of the litter input, which itself varied with season and from year to year, was quickly broken down, causing peaks and troughs even in plots where litter load had reached a quasi-steady state.

From the data in Birk and Bridge's paper, *Limit* can be estimated for litter + herbs. As noted above understorey vegetation up to 0.9 m in height weighed only 0.7 t/ha. We do not know how this figure breaks down between herbaceous and woody vegetation.

Assuming the majority – say 0.5 t/ha − was herbaceous, the total for litter < 6 mm plus herbs becomes 16.7 + 0.5 = 17.2 t/ha.

Birk and Bridges (1989:70) also report on fuel load remaining immediately after a fire: "The wildfire of December 1979 resulted in almost total removal of the accumulated fine fuels, leaving an average of less than 1.5 t/ha." All fractions were reduced by at least 92%. Prescribed burning removed less fuel, however it is not clear to what extent the figures given in the paper are the result of patchiness in these fires.

Rating: 2
This is a long-term, well-designed study. The figures for *Limit* and *L* are soundly-based, though use of conversion factors adds some uncertainty.

Rainfall and elevation: Birk and Bridges (1989) give a figure of 1455 mm for mean annual rainfall, and 31 m for elevation. The nearest weather station is probably Taree, where the long-term average is 1179 mm (123 years of data, 21 m asl).

4.4 Penman and York (2010)

Penman and York (2010) report findings for litter fall and litter load from a second long-term fire experiment on the NSW north coast, at Lorne State Forest north-east of Port Macquarie. The authors specifically identify their site as Northern Hinterland WSF. Overstorey dominants were *Eucalyptus pilularis* and *Corymbia gummifera*, with *Syncarpia glomulifera*, *E. resinifera* and *E. punctata* occurring infrequently.

Data for both litter load and litter fall were collected over a 22-year period, albeit with some gaps. Both were assessed in plots representing each of two experimental treatments, frequent burning (usually every 3 years), and fire exclusion. Each treatment was replicated seven times; litter load was measured in all 14 plots, while litter fall was measured in a subset of six plots. All flammable material (twigs, fallen leaves, bark, low green herbs and dried vegetation) up to 25 mm diameter at or near ground level was collected.

Litter load in the unburnt plots averaged 19.59 t/ha, with a slight increase over time (measurements began 12 years after plots had been selectively logged and burnt), and a degree of inter-annual fluctuation. Litter load in the burnt plots, one month post-fire, averaged 6.51 t/ha; the authors report burn coverage of 70-100%. Fitting equation (1) to litter load data from all plots, measurement years and treatments gave a value of 18.32 for *Limit*, and 0.665 for *k* (Penman and York 2010:1793). As considerable fuel remained immediately post-fire, equation (3) may have been more appropriate; a value above 0 for *Initial* would reduce *k* somewhat. The values for equation (1) given in the article imply a litter fall of 12.18 t/ha.

In fact, mean quarterly litter fall across the study period was 1.4 t/ha, or 5.6 t/ha per year.

Converting the litter fall average into an estimate for *L*, for litter particles < 6 mm, gives 5.6 x 0.94 = 5.26 t/ha. Taking the average value for litter load in the unburnt sites and converting it to an estimate for *Limit*, for litter particles < 6 mm, gives 19.59 x 0.87 = 17.04 t/ha. Using these two figures gives an estimate for *k* of 5.26/17.04 = 0.31.

Rating: 2
This is again a long-term, well-designed study. The figures for *Limit* and *L* are soundly-based, though use of conversion factors adds some uncertainty.

Rainfall and elevation: Penman and York (2010) give a figure of 240 m asl for elevation. They use weather statistics from the Port Macquarie weather station. Mean annual rainfall at Port Macquarie (Bellevue Gardens) is 1534 mm (150 years of data), though elevation is only 20 m.

4.5 McColl (1966)

This early study of litter fall and litter decomposition was carried out in spotted gum (*Corymbia maculata*) forest on the NSW south coast near Batemans Bay. Understorey varied, with wattles or the cycad *Macrozamia communis* dominant in some sites. This understorey composition fits well with Keith's description of Southern Lowland WSF (Keith 2004).

McColl (1966) measured litter fall in sites with trees of different ages, over approximately 18 months, using six traps per stand. In general, litter fall increased with stand age. I have averaged figures for the three oldest stands, one "virgin, overmature", one about 60 years old, the third "pole-sized" like the second. Average annual litter fall for these three sites was 4964 lb/acre, which equates to 5.56 t/ha, with greater accession in the overmature than in the pole-sized stands, partly due to sticks brought down by a storm. As no size cut-off is mentioned in this paper, I have used the 0.91 conversion factor to arrive at an estimate of 5.06 t/ha for litter fall of particles < 6 mm.

Decomposition was measured through litterbag studies, in three pole-sized stands. Leaves, capsules and twigs to 6 mm (1/4"), were used. After 72 weeks, 30-39% of the contents of the bags had been lost. Exact figures for the different treatments are given graphically: the average over the three stands appears to be around 34% lost, ie 66% remaining. Thus $k = -\ln(0.66)/t$, where $t = 72/52 = 1.385$ years. Thus $k = 0.41/1.385 = 0.30$.

A value for *Limit*, for litter particles under 6 mm, can be estimated by dividing *L* by *k*, ie 5.06/0.30 = 16.9 t/ha.

Rating: 2
This study covered replicate stands, with a reasonable degree of within-stand replication (more so in the litter fall study than for decomposition). Temporal replication was better than in some studies, but insufficient to ensure inter-annual and year-to-year variability had been fully captured. Use of the conversion factor to estimate litter fall for particles < 6 mm has also reduced precision.

Rainfall and elevation: McColl (1966) does not provide figures for rainfall or elevation. There is a weather station at Batemans Bay, where mean annual rainfall =

868 mm and elevation = 11 m asl. This rainfall figure is based, however, on a limited data set (20 years), and seems low for WSF. I've therefore allocated the rainfall figure measured on site over 15 years by Pook *et al.* (1997), ie 1142 mm.

4.6 Pook *et al.* (1997)

Pook *et al.* (1997) studied litter fall in *Corymbia maculata* forest over a 15 year period, in a single site in Kioloa State Forest 15 km north-east of Batemans Bay. Tree species associated with the dominant spotted gum were *E. globoidea*, *E. paniculata* and *Acacia mabellae*, placing this site firmly in the Southern Lowland WSF vegetation class (Keith 2004).

The survey site was regenerating from an unspecified disturbance, probably logging, in 1962, with measurements from 1977 to 1992. Nine randomly-located traps were used. All litter particles < 6 mm in diameter were collected, with some fruits which exceeded this size included.

The amount of litter collected varied considerably from year to year and month to month. The overall average was 5.765 t/ha.

Rating: 2
Temporal replication in this study was exemplary, however measurements were only made in a single, regenerating stand. The extent to which litter fall figures can be considered representative of the Southern Lowland WSF class is therefore limited. Use of a 6 mm cut-off is beneficial, for current purposes.

Rainfall and elevation: Pook *et al.* (1997) logged rainfall in their site, over most of the study period, and found that it averaged 1142 mm per annum. This is much greater than the mean value at the Batemans Bay weather station, which is 878 mm, albeit from a limited data set (21 years). I have used the authors' figure. Elevation at the Batemans Bay station is 11 m.

4.7 Roxburgh *et al.* (2006)

Roxburgh *et al.* (2006) surveyed 17 sites around Kioloa with varying management histories. All, however, had apparently remained unburned for at least 18 years. Dominant tree species were *Corymbia maculata*, *Corymbia gummifera*, *Eucalyptus pilularis*, *E. botryoides* and *E. sieberi*. The first four place these study sites in the Southern Lowland WSF vegetation class, as does their geographic location.

Roxburgh *et al.* (2006) report figures for carbon in litter < 25 mm; average across sites was 10.4 t/ha. As the authors assumed carbon made up 45% of litter biomass, this figure can be back-converted to a litter load of 23.1 t/ha. Applying the 0.87 conversion factor, and assuming steady state, gives an estimate for *Limit*, for litter particles < 6 mm, of 20.1 t/ha.

Rating: 3
This study involved excellent spatial replication, covering a range of management histories which could be expected across forest sites. However the need to employ a conversion factor decreases precision. Additionally, the assumption of steady state may not be legitimate for all sites, and some may lie outside the Southern Lowlands WSF class.

Rainfall and elevation: Roxburgh *et al.* (2006) do not provide figures for rainfall or elevation. There is a weather station at Batemans Bay; see Section 4.5.

4.8 Synthesis and suggested values for Phoenix

Litter parameters derived from the six studies in this chapter are presented in Table 13, along with weighted means for the two grassy WSF classes east of the Divide separately, and together.

In Northern Hinterland grassy WSF, *L*, with a weighted mean of 6.9 t/ha, is on a par with the co-occuring forests in the shrubby subformation (weighted mean in North Coast WSF is 7.0 t/ha, Section 3.15). *k*, however, may be a little lower than in North Coast WSF (0.39 versus 0.47), making *Limit* somewhat higher (weighted means of 17.7 and 14.9 t/ha in Northern Hinterland and North Coast WSFs respectively). This fits with the observation that Northern Hinterland forests tend to occupy drier, less sheltered sites than North Coast WSFs (Keith 2004:62).

Table 13. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the grassy subformation of wet sclerophyll forests east of the Great Divide. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Source	WSF class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Hurditch (1981)	Northern Hinterland WSF	8.1	20.6	0.39	3
Hurditch (1981)	Northern Hinterland WSF	6.5	17.8	0.37	3
Hurditch (1981)	Northern Hinterland WSF	7.9	17.1	0.46	3
Birk and Bridges (1989)	Northern Hinterland WSF	7.3	16.7	0.44	2
Penman and York (2010)	Northern Hinterland WSF	5.3	17.0	0.31	2
Weighted mean	**Northern Hinterland WSF**	**6.9**	**17.7**	**0.39**	
McColl (1966)	Southern Lowland WSF	5.1	16.9	0.30	2
Pook *et al.* (1997)	Southern Lowland WSF	5.8			2
Roxburgh *et al.* (2006)	Southern Lowland WSF		20.1		3
Weighted mean	**Southern Lowland WSF**	**5.5**	**18.2**	**0.30**	
Weighted mean	**All studies in this group**	**6.4**	**17.8**	**0.36**	

In the south, available data suggests both litter fall and decomposition rate may be lower than in equivalent grassy wet forests in the north of the state, and also that both parameters may be lower in Southern Lowland WSF than in the shrubby wet forests of the south (Table 9, Section 3.15). However as for rainforests, it appears that within the group addressed in this chapter, lower decomposition may balance lower litter fall, resulting in similar values for *Limit* (Table 13).

So again, despite the hint of differences between northern and southern forests in this group, I suggest using a single value for *Limit*, for litter alone, of 18.0 t/ha, with *k* = 0.35 (weighted mean value rounded to nearest 0.05).

Data on litter load remaining immediately post-fire is scant. However Birk and Bridges (1989) report less than 1.5 t/ha remaining after a wildfire in their site. As this includes particles up to 25 mm in diameter, I suggest using a figure of 1.0 t/ha for *Initial*.

Data on near-surface and elevated fuels is also in short supply, although again Birk and Bridges (1989) provide some information. These authors reported only 0.7 t/ha of understorey vegetation up to 0.9 m in height, in their long unburnt treatment. It is quite possible that near-surface fuel is more prominent in the early post-fire years than later in the post-fire sequence. In the absence of further information, I suggest using the same figures for *Initial*, *Limit* and *k*, for surface + NS fuel, as for litter alone. Again in the absence of further information, I suggest setting *Limit* for elevated fuel at 2.0 t/ha, and using the same *k* value as for shrubby forest, ie 0.15.

Suggested parameters for the grassy sub-formation of wet sclerophyll forests east of the Divide are summarized in Table 14, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 3.

Table 14. Summary of suggested values for negative exponential model parameters for classes in the grassy subformation of wet sclerophyll forests east of the Great Divide. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	**Fuel layer**	***Initial***	***k***	***Limit***	***r***
All	Litter	1.0	0.35	18.0	17.0
	Litter + NS	1.0	0.35	18.0	17.0
	Elevated	0.0	0.15	2.0	2.0

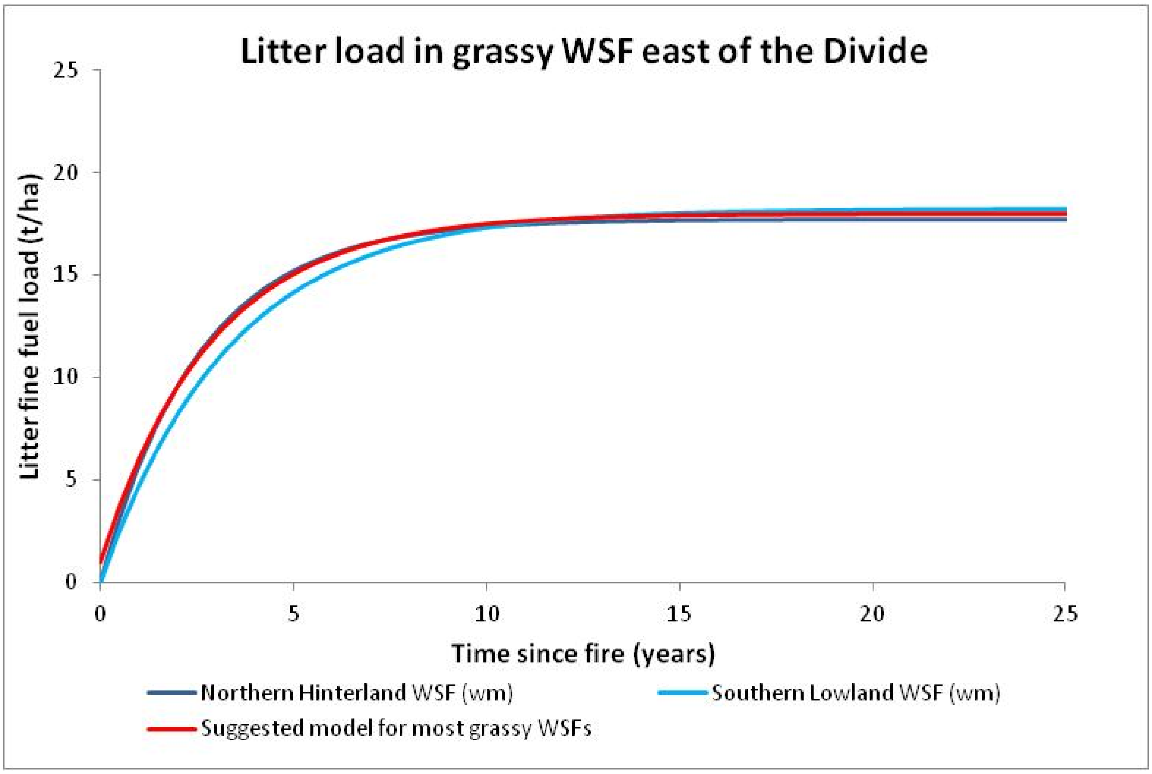

Figure 3. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in the grassy subformation of wet sclerophyll forests east of the Divide. wm, model based on weighed means derived from the literature (Table 13), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 14; see text for explanation of crosswalk from literature to suggested model.

4.9 Knowledge gaps

For litter, existing studies provide good coverage for both the grassy WSF variants in this chapter. However information on near-surface and elevated fuels is generally lacking.

5. Grassy wet sclerophyll forests on the tablelands

5.1 Introduction

This category includes the remaining three of Keith's five grassy wet sclerophyll forest classes (Table 15). Again, the northern class in this category is the most extensive.

Table 15. Vegetation classes in the grassy wet sclerophyll forest subformation which occur predominantly on the tablelands.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Northern Tableland WSF	74-5	On fertile loams above 800 m in areas where mean annual rainfall exceeds 950 mm, on the tablelands north from Barrington Tops	large
Montane WSF	78-9	Western and southern fall of the Kosciuszko plateau, north to Canberra and south into Victoria. Outliers at lower altitude between Shoalhaven River and Bombala.	moderate
Southern Tableland WSF	76-7	On moderate to high fertility tableland soils where annual rainfall averages 750-1300 mm, south from Orange. Highly fragmented in the northern part of their range.	moderate

A number of studies address the classes in Table 15. Watson (1977) assessed litter fall, and to some extent decomposition, in two Northern Tableland WSF sites on the tablelands east of Armidale. For Montane WSF we have a suite of litter studies carried out by CSIRO researchers Raison, Woods and Khanna during the 1970s and 1980s, in the Brindabella Ranges to the west of Canberra. Thomas *et al.* (1992) report litter fall figures for a Southern Tableland WSF site in the ACT, while data from the Victorian study by Attiwill *et al.* (1978) may also assist in understanding the dynamics of this forest class.

5.2 Watson (1977)

In this section two further sites from Watson's UNE Masters project are discussed (see also Sections 2.4 and 3.10). Both fall into Keith's Northern Tableland WSF class. Watson refers to these sites as Grassy Forest (GF) and Tall Grassy Forest (TGF).

The GF site, situated in an area of very high rainfall in the vicinity of Point Lookout, New England National Park, was structurally simple, featuring 25 m specimens of the tree species *E. obliqua*, *E. fastigata* and *E. viminalis* over a grassy *Poa sieberiana* (snow grass) understorey with mossy patches and very few shrubs. Site TGF was structurally similar, though trees were taller (up to 50 m). Overstorey species included *E. obliqua*, *E. campanulata* and *E. cameronii*, all indicative for the Northern Tableland WSF class; ground cover was again dominated by *Poa sieberiana*, along with *Lomandra* species; again, shrubs were sparse. This site was located on the northern boundary of Styx River State Forest.

Litter fall was collected at each of these grassy forest sites, with measurements at the GF site spanning four years, while those at the TGF site covered a single 12 month period only. The mean value for *L* on the GF site, 3.47 t/ha, did not differ greatly from the TGF 12-month figure of 3.15 t/ha. Given the better temporal and spatial replication on the GF site, I have applied the 0.91 conversion factor to the GF mean, giving an estimate of 3.16 t/ha for annual accession of litter particles < 6 mm in this forest type.

Watson's litter bag studies have already been described (Section 3.10); the GF site was included in this aspect of his work, though the TGF site was not. Over a 56 week period, a mean of 39.9% of the weight of the bagged leaves was lost, a considerably greater proportion than in the two other sites in which decomposition was assessed. These numbers equate to a *k* value of 0.47. Taking this figure and the estimate for litter fall in the paragraph above gives a value of 6.72 t/ha for steady state fuel load. Note, however, that the use of leaves alone in litter bags may have somewhat inflated *k*, as the bark and twig components of litter are likely to decompose more slowly.

Watson (1977) also sampled litter on the forest floor, on three occasions over a 12 month period in Site GF and on a single occasion in Site TGF. Litter load in Site GF averaged a low 3.96 t/ha (with a decrease across sampling periods), while the single August sampling at site TGF returned a figure of 9.07 t/ha. Again, time-since-fire is not mentioned, so steady state cannot be assumed. The structure of these sites − almost no shrubs − suggests fire might have been a quite frequent visitor.

Although this study does not provide a clear figure for *Limit*, it does suggest that steady state fuel load in this forest type will not be high.

In discussing the rapid decomposition in the GF site, Watson (1977:43) notes that "Litter, on falling to the floor of this forest, initially becomes entangled within the mat of grass leaves and, when subsequently deposited on to the soil surface, is covered by them. Moisture regimes at the floor of this community could therefore be expected to be maintained at higher levels than those in the [other] communities [included in the decomposition study], and would therefore account for the more rapid decay of eucalypt leaves."

Rating: 2
The litter fall figure for this study is probably quite accurate, as it was based on four years of data collection, good within-site replication, and has some confirmation from a second site. Lack of a specified size cut-off reduces confidence in my derived estimate for fine fuel, to a small extent. Issues with the estimated values for *Limit* are discussed above.

Rainfall and elevation: Watson (1977) gives a figure of 2234 mm for annual rainfall at Site GF, based on four years of measurement on the site itself, and a figure of 1680 mm for Site TGF, based on a single year of on-site recording. Although altitude is not noted for either site, both are definitely on the tablelands. Site TGF was located close to Watson's rainforest site, at 1335 m asl. The nearest weather station is Jeogla (1515 mm rainfall, 1030 m asl, 43 yrs of data).

5.3 Woods and Raison (1983)

The bulk of this study focused on decomposition, which was assessed through litter bags using leaves only and thus is not reported here. Values for *k* were also calculated from litter fall and litter load measurements for litter particles < 6 mm in diameter. I have focused here on values for litter fall and litter load presented in Table 1 (Woods and Raison 1983:288). This table describes two sites dominated by *E. delegatensis*, the obligate seeder eucalypt which typifies Montane WSF. The site of most interest for the current exercise is Site FD, which was dominated by mixed-age old growth trees, and had not been burnt for over 30 years.

Litter fall, which was collected over five years, averaged 5.1 t/ha annually.

Litter load, which was assessed in March 1980, averaged 22.7 t/ha.

Assuming litter load is at steady state, $k = 5.1/22.7$ ie 0.22.

In the second *E. delegatensis* site surveyed by Woods and Raison (1983), Site PD, the regrowth was younger than in Site FD, and fire had occurred within the last 10 years, raising questions as to whether this site had reached steady state. Although methods were carefully thought through, parameters arising from this study did not present a coherent picture. Fuel load in 1982 was lower than in 1980. Although *k* values were derived using an equation that did not assume steady-state fuel load, using the two fuel load measures, when *Limit* is derived from the resulting values for *k* and *L*, it is considerably lower than the average of the 1980 and 1982 litter load figures. Because of these issues, and because other information is available for this vegetation type, I have not included this site in the review.

Rating: 2
This study reports figures from five years of litter fall measurement, so mean values are likely to be close to long-term averages. Litter load however was assessed at only a single point in time, and sampling in other sites found some year-to-year variability in this parameter. However overall the figures from this study should be fairly accurate. Because particle size reported is the same as the standard being used in this document, conversion factors, with their inherent uncertainties, were not required.

Rainfall and elevation: Woods and Raison (1983) note that rainfall approximates 1150 mm. The most relevant weather station may be Honeysuckle Creek, at an altitude of 1116 m asl; Site FD is at 1110 m. Tidbinbilla, while closer, is only 700 m above sea level. Average annual rainfall at Honeysuckle Creek is 1001 mm (14 years of data, from 1967 to 1981), while at Tidbinbilla it is slightly lower at 919 (43 years of data).

5.4 Raison *et al.* (1983)

This paper reports values for steady state litter load and *k* for several vegetation types in the ACT, developed by fitting equation (1) to fuel load figures assessed at a number of different times after fire. Of interest in relation to Montane WSF are the parameters for *E. delegatensis*. Again, the cut-off size for litter particles in this study was 6 mm. Sampling involved a range of sites in the same general area; both patches recovering from wildfire and patches subject to low-intensity prescribed fire were included. The majority of data points represent early post-fire years.

Values given in the paper are: *Limit*, 26.2 t/ha; *k*, 0.16. Solving equation (2) for *L* gives 4.19 t/ha.

Rating: 2
Raison *et al.* (1983) give minimal information on methods used, however the number of data points seems reasonable: although not explicitly stated, they are shown graphically (Raison *et al.* 1983:297), and appear to number 11. Most are from the early post-fire years, with two points from much older stands (38 and 56 years). What is not clear is whether the early points represent fuel accumulation after a low intensity fire that left trees intact, or after a high intensity tree-killing fire: it is possible that fuel development, and thus *k* values, are somewhat different in these two circumstances.

Rainfall and elevation: Raison *et al.* (1983) give minimal information on site locations and characteristics. I have assumed sites come from a similar area to Site FD in Woods and Raison (1983), and have used the same parameters ie 1150 mm for rainfall. Elevation figures for Woods and Raison's two *E. delegatensis* sites average 1118 m asl. Again, the most relevant weather station may be Honeysuckle Creek (1116 m asl, average annual rainfall 1001 mm, 14 years of data).

5.5 Raison *et al.* (1986)

Raison *et al.* (1986) report further data from the Brindabella Ranges in the ACT, including a curve for post-fire development of litter fuel in *E. delegatensis*. This curve is based on approximately 12 data points, and includes a wider spread of post-fire ages than the curve reported in the previous section. Again, the size cut-off for litter particles was 6 mm.

Values given in the paper are: *Limit*, 22.9 t/ha; *k*, 0.31. Solving equation (2) for *L* gives 7.1 t/ha.

In a comparison of *k* values derived in different ways, Raison *et al.* (1986) note that those estimated from curve-fitting were generally higher than those derived in other ways. This may be less the case, however, if equation (3) is used instead of equation (1).

Rating: 3
Again, Raison *et al.* (1986) give minimal information on methods used, however again data points appear to number 11. The wider spread of age classes in this study, relative to Raison *et al.* (1983), gives confidence, though this time the low number of points in the early post-fire years raises questions about the accuracy of *k*, and thus of *L*.

Rainfall and elevation: Raison *et al.* (1986) direct readers to Woods and Raison (1983) for details of study sites. I have used the parameters for Site FD: see Section 5.3.

5.6 Park (1975)

Park (1975) measured litter fall in a *Eucalyptus delegatensis* forest at Bendoura Hill in the Brindabella Ranges over a period of 12 months. No size cut-off is mentioned; 'branches' were included. Litter fall totaled 6.25 t/ha. Applying the 0.91 conversion factor gives an estimate for *L*, for particles < 6 mm, of 5.69 t/ha.

Rating: 4
This study lacked replication across years, and was limited to a single site. Use of a conversion factor adds to uncertainty.

Rainfall and elevation: Information on this study site is minimal. The most relevant weather station may be Honeysuckle Creek: see Section 5.3.

5.7 Thomas *et al.* (1992)

Thomas *et al.* (1992) measured litter fall along two transects in Southern Tableland WSF dominated by *Eucalyptus viminalis* and *E. robertsonii*. The study, which was conducted in the Lees Creek catchment in the Brindabella Ranges west of Canberra, ran for over two years. Size cut-off was 8 mm. Litter fall averaged 4.37 t/ha. Using a conversion factor of 0.99 gives a value for *L*, for particles < 6 mm, of 4.33 t/ha.

Rating: 2
This study was replicated across years and transects, and used a size cut-off close to the standard used in this report.

Rainfall and elevation: Thomas *et al.* (1992) cite a mean annual rainfall for the catchment of 750 to 1200 mm. Nearest relevant weather station may be Tidbinbilla with an annual rainfall of 925 mm (44 years of data) and an elevation of 700 m asl.

5.8 Attiwill *et al.* (1978)

This Victorian study, which was outlined in Section 3.12, included a second forest type with some similarities to Southern Tableland WSF. The single site in this forest type, at

Stewart's Creek in Wombat State Forest, was dominated by *Eucalyptus obliqua*, "with occasional individuals of *E. radiata*". *E. radiata* is indicative for Southern Tableland WSF, although *E. obliqua* is not. The Victorian vegetation had sparse shrubs and a "well-developed ground flora" with common species including *Pteridium esculentum* and *Lomandra longifolia*, both of which feature in Keith's description of Southern Tableland WSF (Keith 2004).

Litter fall was measured at a single site, using five traps over three years. Size cut-off was 20 mm.

Litter fall averaged 5.5 t/ha. Using a conversion factor of 0.95 (slightly higher than the one for 26 mm) gives a value for *L*, for particles < 6 mm, of 5.23 t/ha.

Rating: 4
While temporal replication in this study was good, and spatial replication reasonable, the unusual size cut-off introduces some uncertainty for current purposes. The location of the study site outside NSW is a bigger issue: while there are some similarities between the vegetation in this study and Keith's description of Southern Tableland WSF, the links are tenuous.

Rainfall and elevation: Attiwill *et al.* (1978) do not provide values for rainfall or altitude. I've used figures from Tolhurst's studies in Wombat State Forest (Tolhurst *et al.* 1992) ie 900 mm for mean annual rainfall, and 640 m asl for elevation. The weather station in the vicinity which most closely approximates these conditions is Macedon, at 505 m asl, where rainfall averages 839 mm per annum (114 years of data).

5.9 Synthesis and suggested values for Phoenix

All seven studies in this chapter focused exclusively on litter; no studies of near-surface or elevated fuels were found. Litter parameters are presented in Table 16, along with weighted means for Montane WSF and Southern Tableland WSF (litter fall only). Clearly considerably more information is available for Montane WSF than for the other two classes addressed in this chapter.

Table 16. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the grassy subformation of wet sclerophyll forests on the tablelands. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Source	WSF class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Watson (1977)	Northern Tableland WSF	3.2			2
Woods and Raison (1983)	Montane WSF	5.1	22.7	0.22	2
Raison *et al.* (1983)	Montane WSF	4.2	26.2	0.16	2
Raison *et al.* (1986)	Montane WSF	7.1	22.9	0.31	3
Park (1975)	Montane WSF	5.7			4
Weighted mean	**Montane WSF**	**5.3**	**24.1**	**0.22**	
Thomas *et al.* (1992)	Southern Tableland WSF	4.3			2
Attiwill *et al.* (1978)	Southern Tableland WSF	5.2			4
Weighted mean	**Southern Tableland WSF**	**4.5**			

Montane WSF appears to be shedding litter at a rate comparable to that in Southern Lowland WSF (Table 13, Section 4.8). Decomposition, however, is slower than in any of the forest classes reviewed to this point, leading to a higher steady state litter load than previously encountered. This suggests that Montane WSF is sufficiently different to be distinguished from other grassy WSFs for management purposes. For litter alone, I suggest setting *Initial* to 1.0 t/ha (as for other forest types in this formation), *Limit* to 24.0 t/ha, and *k* to 0.20. In the absence of information on near-surface and elevated fuels, I suggest using these same values for litter+NS fuel, and duplicating the values for elevated fuels suggested previously for other grassy WSF types (Section 4.8).

Though data for the other two grassy WSF classes on the tablelands is sparse, what evidence there is suggests that their litter dynamics may differ considerably from those in Montane WSF. Litter fall is lower, and although we have no definitive measurements of *k*, the rapid decomposition observed by Watson (1977) in his Northern Tableland WSF site (Section 5.2) suggests *k* may be quite a bit higher here than in Montane WSF. Both lower litter fall and faster decomposition will result in lower values for *Limit*. Litter load figures from Watson's study are in line with that possibility. In the absence of better data for Northern and Southern Tableland WSF, I propose that they be parameterised in the same way as the grassy wet sclerophyll forest classes reviewed in Chapter 4.

Suggested parameters for classes in the grassy sub-formation of wet sclerophyll forests on the tablelands are summarized in Table 17, with a comparison between literature-derived and suggested models for litter fuel in Montane WSF presented in Figure 4.

Table 17. Summary of suggested values for negative exponential model parameters for classes in the grassy subformation of wet sclerophyll forests on the tablelands. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	Fuel layer	*Initial*	*k*	*Limit*	*r*
All but Montane WSF	Litter	1.0	0.35	18.0	17.0
	Litter + NS	1.0	0.35	18.0	17.0
Montane WSF	Litter	1.0	0.20	24.0	23.0
	Litter + NS	1.0	0.20	24.0	23.0
All	Elevated	0.0	0.15	2.0	2.0

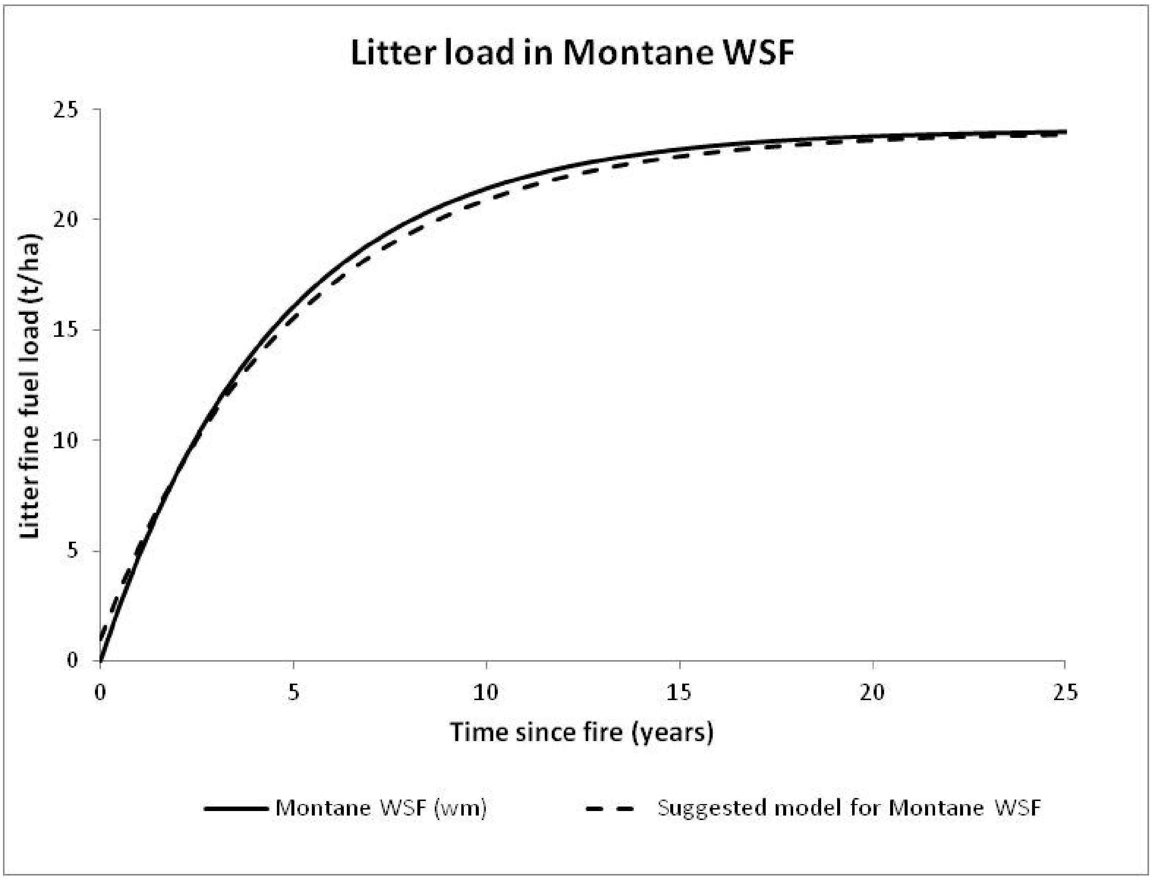

Figure 4. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in Montane WSF. wm, model based on weighed means derived from the literature (Table 16), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 17; see text for explanation of crosswalk from literature to suggested model.

5.10 Knowledge gaps

There are major gaps in our knowledge of fuel dynamics in grassy wet sclerophyll forests on the tablelands. First and foremost, systematic measurements of litter load in long-unburnt sites in Northern Tableland and Southern Tableland WSF are needed, across years and seasons. Coupled with existing litter fall figures, this information would allow us to refine figures for *k* as well as *Limit*. Even in Montane WSF, data collection beyond the Brindabellas might be advisable, to ensure figures from the ACT do indeed generalise to NSW. Further data on near-surface and elevated fuels in this subformation is also needed.

6. Grassy woodlands east of the Divide

6.1 Introduction

Grassy woodlands are dominated by well-spaced trees, most of which are eucalypts. This formation is characterized by a prominent layer of grasses and herbs; typically, shrubs are sparse (Keith 2004). Surface fires spread readily through a mixture of grasses and eucalypt litter on and near the ground. In some grassy woodlands, lack of vertical continuity limits canopy fire potential.

Only one of Keith's seven grassy woodland classes occurs east of the Great Divide: Coastal Valley Grassy Woodlands (Keith 2004:86-7). This vegetation type occupies low altitude rain shadow patches with deep, moderately fertile soils, right the way along the NSW coast. Plant assemblages vary, though *Eucalyptus tereticornis* occurs throughout. These woodlands have been heavily cleared and are highly fragmented.

Two studies, one from Western Sydney, the other from central Queensland, provide insight into the fuel dynamics of this woodland class.

6.2 Watson (2005)

Watson (2005) developed a fuel curve for Cumberland Plain Woodland (CPW), the Coastal Valley Grassy Woodland variant found in Sydney's western suburbs. 14 sites representing a range of times-since-fire, from two weeks to 50 years, were surveyed. All sites contained the CPW dominant tree species *Eucalyptus moluccana*.

All material below 6 mm in diameter was collected from 20 points in each site. Fuel was partitioned into four categories: material from trees; material from shrubs; grasses and herbs; and a 'comminuted fraction' of decomposing fragments. Watson (2005) fitted equation (3) to the data for the entire fuel array; parameters were *Initial* = 1.39 t/ha, *Limit* = 9.04 t/ha, *k* = 0.46.

I have extended this analysis, fitting both versions of the negative exponential model to the fuel array as a whole, to the litter component (defined as material from trees + the comminuted fraction), and to litter + grasses (Table 18). I also attempted to fit curves to the data for grasses alone, and for shrubs alone, however this proved either impossible, or returned nonsensical results.

Model fit was slightly better when *Initial* was included, however standard errors for this parameter were high. Taking the values for litter only from equation (1), *Limit* = 6.46 t/ha and *k* = 0.57, annual litter fall would average 3.68 t/ha.

Table 18. Parameters for negative exponential model fitted to 14 CPW data points surveyed by Watson (2005). Top half of table: model assumes no fuel remains immediately after the passage of a fire. Bottom half of table: model includes a term for fuel remaining immediately after fire. SE in brackets. Significance codes: *** = <0.001; ** = < 0.01; * = < 0.05.

	Initial	*Limit*	*k*	R^2
Total fine fuel	Not included	8.91 (0.60)***	0.62 (0.14)***	0.82
Litter only	Not included	6.46 (0.55)***	0.57 (0.15) **	0.77
Litter + grass	Not included	7.06 (0.57)***	0.73 (0.20)**	0.73
Total fine fuel	1.39 (0.92)	9.08 (0.62)***	0.46 (0.15)**	0.84
Litter only	0.48 (0.92)	6.49 (0.58)***	0.51 (0.20)*	0.78
Litter + grass	1.12 (0.99)	7.16 (0.60)***	0.56 (0.23)*	0.76

The equation (3) values for litter + grass can be used to inform estimates for the Phoenix surface fuel parameter: *Initial* = 1.12 t/ha, *Limit* = 7.16 t/ha, $k = 0.56$.

Shrub fuel load did not show a relationship with time-since-fire. In CPW, the most abundant shrub, by far, is *Bursaria spinosa*, which grows to a height of over 2 m. Other studies conducted by Watson (2005) showed this shrub at its most abundant in sites where fire frequency had been low. In some sites, *B. spinosa* completed dominated the understorey, even as early as two years post-fire; *B. spinosa*, once established, resprouts prolifically. Shrub biomass ranged from nil, to 4.49 t/ha in the site unburnt for 50 years.

Fuel load in the grassy near-surface layer also showed no relationship with time-since-fire. In sites with a time-since-fire of six months or more, biomass of this component ranged from 0.42 to 1.62 t/ha.

Rating: 2
The number of data points in this study is adequate, as was the sampling strategy. A 6 mm cut-off was used. In my re-analysis I have assumed that the components identified by Watson (2005) are equivalent to the surface, near-surface and elevated fuel layers; some slight error may have been introduced in this process.

Rainfall and elevation: Watson's sites were dispersed across the Cumberland Plain, and she provides annual rainfall data for several weather stations. I have taken Prospect Dam as typical: this site, at 61 m asl, has an average annual rainfall of 869 mm (123 years of data).

6.3 Burrows and Burrows (1992)

Burrows and Burrows (1992) collected litter fall in a range of grassy woodland sites in Central Queensland's Fitzroy River basin west of Rockhampton. Four sites were dominated by trees familiar from Keith's description of Coastal Valley Grassy Woodlands, *Eucalyptus moluccana* (1 site) and *E. crebra* (3 sites). Rainfall in these four sites ranged from 725 to 829 mm, towards the bottom of the range cited by Keith for the NSW vegetation class (700 to 1000 mm).

Litter fall was collected for three years in three sites, including the site dominated by *E. moluccana*, and for a single year in the fourth, using 15 to 20 traps per site. Averaging across sites and years gives a figure of 2.10 t/ha/yr for total litter fall. Applying the 0.91 conversion factor gives an estimated *L* of 1.91 t/ha for particles < 6 mm.

This paper also gives figures for grass fuel load prior to fires that occurred during the study in two of the sites: 0.50 and 0.72 t/ha. Burrows and Burrows (1992:401) note that this level of grass fuel would not be sufficient to carry fire under normal conditions and suggest that "Litter material could be an important fuel source for carrying grass fires through areas beneath canopies."

Rating: 3
Replication across time and space was excellent in this study. However two factors may have introduced error: my use of a conversion factor to estimate *L* for particles < 6 mm, and adjustments to the original figures made by the authors to account for stratified placement of traps. Additionally, while tree species and environmental conditions appear to have much in common with Coastal Valley Grassy Woodlands in NSW, the sites used by Burrows and Burrows (1992) are a long way north of the NSW border, and almost certainly experience warmer conditions than their southern counterpart.

Rainfall and elevation: Annual rainfall in three of the four sites included in this study is given as 725 mm, with one at 829 mm, giving an average of 751 mm. The nearest and most relevant weather station would probably be Baralaba Post Office, with a mean annual rainfall of 720 mm (85 years of data) and an elevation of 100 m asl.

6.4 Synthesis and suggested values for Phoenix

Although the number of studies available for this woodland class is limited, litter parameters from Watson (2005) and Burrows and Burrows (1992) can still be combined to provide a weighted mean for *L*, which when linked with Watson's figure for *Limit*, provides a modified *k* value of around 0.45 (Table 19).

Table 19. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the grassy woodland formation east of the Divide. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Watson (2005)	Coastal Valley Grassy Wdlds	3.7	6.5	0.57	2
Burrows and Burrows (1992)	Coastal Valley Grassy Wdlds	1.9			3
Weighted mean	**Coastal Valley Grassy Wdlds**	**3.0**	**6.5**	**0.46**	

For litter, model fitting to Watson's data suggests a starting point, immediately post-fire, of around 0.5 t/ha (Table 18). Suggested parameters for litter, for Coastal Valley Grassy Woodlands, are: *Initial* = 0.5 t/ha; *Limit* = 6.5 t/ha; *k* = 0.40. I have reduced *k* slightly below the weighted mean because it seems unlikely that decomposition in a relatively dry grassy woodland would greatly exceed that in a grassy wet sclerophyll forest.

Grass fuel load, which was measured in both the studies in this section, ranged from 0.42 to 1.62 t/ha: I suggest adding 1.5 t/ha to *Limit*, to account for near-surface fuel. Analysis of Watson's data suggests that adding the grass component to litter in this forest type may *increase k* (Table 18), probably because grass growth post-fire is very rapid. Suggested parameters for litter + NS fuel, for Coastal Valley Grassy Woodlands, are: *Initial* = 1.0 t/ha; *Limit* = 8.0 t/ha; *k* = 0.45.

Turning to elevated fuel: heavy *B. spinosa* fuel loads in Watson's long-unburnt CPW sites may be a-typical for this grassy woodland type; certainly these sites no longer appeared 'grassy'. Failure of shrub fuel load to follow the negative exponential model (Section 6.2) means any *k* value set for elevated fuel will be fairly meaningless, however since this is needed for Phoenix I suggest: *Initial* = 0.0 t/ha; *Limit* = 2.0 t/ha; *k* = 0.30.

Suggested parameters for the Coastal Valley Grassy Woodland class are summarized in Table 20, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 5.

Table 20. Summary of suggested values for negative exponential model parameters, for the Coastal Valley Grassy Woodland class in the grassy woodland formation. NS, near-surface. *r* = *Limit* - *Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	Fuel layer	*Initial*	*k*	*Limit*	*r*
Coastal Valley Grassy Woodlands	Litter	0.5	0.40	6.5	6.0
	Litter + NS	1.0	0.45	8.0	7.0
	Elevated	0.0	0.30	2.0	2.0

6.5 Knowledge gaps

While Watson (2005) provides data for Coastal Valley Grassy Woodlands on the Cumberland Plain, data for this woodland class to the north and south of Sydney is lacking.

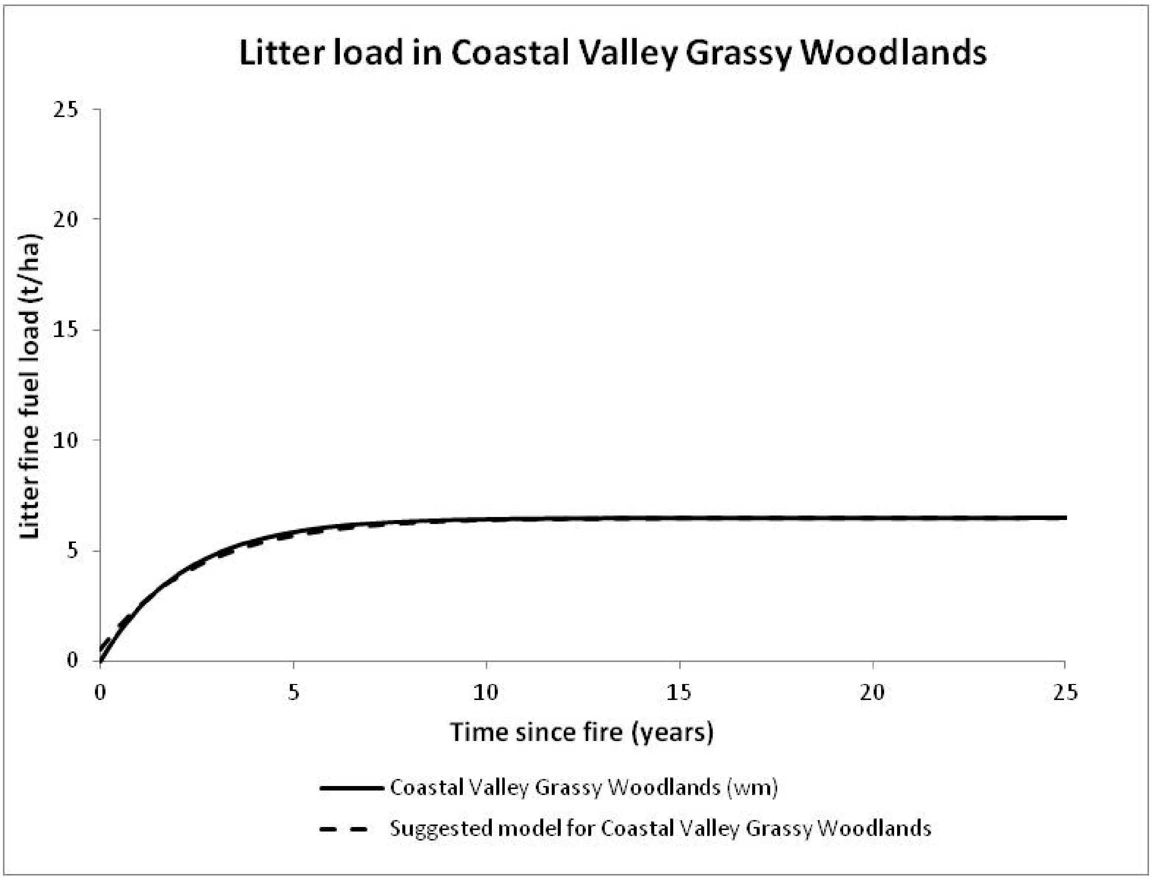

Figure 5. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in Coastal Valley Grassy Woodlands. wm, model based on weighed means derived from the literature (Table 19), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 20; see text for explanation of crosswalk from literature to suggested model.

7. Grassy woodlands on the tablelands

7.1 Introduction

Four of Keith's seven grassy woodland classes occur predominantly on the tablelands (Table 21). These vegetation classes have been heavily cleared and grazed, and have often been subject to pasture improvement. Thus although their extent was once considerable, they now exist mostly as small remnants. Shrubs are generally sparse in these grassy woodland types, although some subalpine woodlands host a relatively high density of sclerophyll shrubs (Keith 2004). The Subalpine Woodlands are probably more intact than those in the other three classes included in this chapter.

Table 21. Vegetation classes in the grassy woodland formation which occur predominantly on the tablelands.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Tableland Clay Grassy Woodlands	88-9	On rich alluvial or basalt-derived soils of both the northern and southern tablelands	Small, due to clearing
New England Grassy Woodlands	90-1	New England tablelands above 600 m asl, north from Walcha on relatively fertile loamy soils where rainfall averages 550-800 mm.	Small, due to clearing and dieback
Southern Tableland Grassy Woodlands	92-3	Southern tablelands below Bathurst and into Victoria. On moderately fertile loamy soils above 600 m als when precipitation averages 550-900 mm.	Small, due to clearing
Subalpine Woodlands	94-5	From 1000-1800 m asl, on mountain slopes and summits, and in frost hollows. Mostly in the southern part of the state, though patches also occur further north.	Moderate

A suite of studies addresses litter dynamics in Subalpine Woodlands; most were carried out during the 1970s and 1980s in the ACT by staff from the CSIRO. Several studies from this body of work have already been encountered in the chapter on tablelands wet sclerophyll forests (Park 1975; Raison *et al.* 1983; Woods and Raison 1983; Raison *et al.* 1986).

A single study of litter fall in New England Grassy Woodlands (Pressland 1982) extends understanding of the grassy woodland formation, as does recent work in a range of woodland sites across the southern and central tablelands (McElhinny 2005).

7.2 Woods and Raison (1983)

This paper reports findings from investigations into litter dynamics in four sites in the Brindabella Ranges in the ACT. I have allocated two sites, one dominated by *Eucalyptus pauciflora*, the other by *E. dives*, to the Subalpine Woodlands class. In both cases the primary driver for this allocation was elevation, however the *E. dives* site could perhaps have been placed in the Southern Tableland Grassy Woodland class, while Southern Tableland WSF is another possibility. *Daviesia mimosoides*, the dominant understorey shrub in each of these sites, is indicative for Subalpine Woodlands. Tree height, at 17-18 m, suggests woodland rather than wet sclerophyll forest structure.

Woods and Raison (1983) report litter fall figures over five years, from 1977 to 1982, for each site. Litter load figures are also given, however similar problems to those described for Woods and Raison's *E. delegatensis* PD site were encountered (Section 5.3), including fairly recent exposure to fire. Standing litter load was lower in August 1982 than in March 1980; the authors attribute this to the effects of low litter fall and favourable conditions for decomposition. These factors were taken into account in estimating *k*.

In the *E. pauciflora* site, litter fall over five years averaged 4.1 t/ha, and *k* was estimated at 0.27. Standing fuel loads in 1980 and 1982 measured 16.2 and 15.0 t/ha respectively.

In the *E. dives* site, litter fall over five years averaged 3.5 t/ha, and *k* was estimated at 0.28. Fuel loads in 1980 and 1982 were 16.6 and 14.2 t/ha.

In the summary table in Section 7.11 (Table 22) I have assumed that the values for 1980 approximate *Limit*.

Rating: 2
Methods were sound, and the size cut-off appropriate for current purposes. Issues to do with time since fire and variability in standing litter load are noted above.

Rainfall and elevation: This paper gives an elevation for both the *E. pauciflora* (1245 m asl) and the *E. dives* site (1100 m asl), and an overall mean rainfall figure of 1150 mm per annum. For a discussion of nearby weather stations, see Section 5.3.

7.3 Raison *et al.* (1983)

This paper reports values for steady state litter load and *k* for several subalpine vegetation types in the ACT, developed by fitting equation (1) to fuel load figures assessed at different times after low-intensity fire. Of interest in this section are the parameters for *E. pauciflora*, and for *E. dives – E. dalrympeana*. I have allocated both these curves to the Subalpine Woodlands class on the basis of tree species and the description of the sites as "subalpine". The cut-off size for litter particles was 6 mm.

Parameters for the two curves were virtually identical. In both cases, *k* was 0.31. *Limit* was 17.0 t/ha for the *E. pauciflora* site, and 17.2 t/ha for the site with *E. dives and E.*

dalrympleana. Taking 17.1 t/ha as the average value for *Limit*, and solving equation (2) for *L* gives 5.3 t/ha.

Rating: 3
Raison *et al.* (1983) give minimal information on methods, however replication (10 quadrats per data point) appears to have been reasonable. The number of data points is not explicitly stated, however they are shown graphically (Raison *et al.* 1983:297), and appear to number 8 for *E. pauciflora* and a fairly minimal 5 for *E. dives – E. dalrympeana*. All are from sites with a time-since-fire of less than 15 years.

Rainfall and elevation: Raison *et al.* (1983) give minimal information on site locations and characteristics. Assuming sites come from a similar area to the *E. pauciflora* and *E. dives* sites in Woods and Raison (1983), mean annual rainfall would be around 1150 mm. Averaging the elevation figures for Woods and Raison's *E. pauciflora* and *E. dives* sites gives 1173 m asl. The most relevant weather station may be Honeysuckle Creek (1116 m asl, average annual rainfall 1001 mm, 14 years of data).

7.4 Raison *et al.* (1986)

This paper, already mentioned in Section 5.5, presents two fuel curves which I have allocated to the Subalpine Woodlands vegetation class. Both were again developed through sampling a range of sites with differing fire histories in the Brindabella Ranges. The dominant tree species for Curve 1 was *E. pauciflora*, while *E. dives* was the species of interest for Curve 2. Raison *et al.* (1986) again used a 6 mm cut-off, and focused on litter only.

For *E. pauciflora*, *Limit* = 16.9 t/ha and *k* = 0.32, giving a value for *L* of 5.4 t/ha.

For *E. dives*, *Limit* = 14.9 t/ha and *k* = 0.42, giving a value for *L* of 6.3 t/ha.

This paper also provides direct measurement data for *L* in *E. dives* forest, from a seven-year study of litter fall. A mean litter fall of 3.36 t/ha/year is clearly much lower than that suggested by curve-fitting. As for the *E. delegatensis* parameters discussed in Section 5.5, it would appear that the *k* value derived from curve-fitting is higher than that derived from *Limit* and *L*.

Rating: 3
As for all the studies conducted by this research group, methods were sound, and the size cut-off matched the standard in this review. Again, data points are shown graphically (Raison *et al.* 1986:16), and appear to number 10 for the *E. pauciflora* curve and 7 for *E. dives*, with several points from sites with a time-since-fire greater than 15 years. The values for *Limit* are probably more soundly based than those for *k* and *L*, which the authors themselves note may be too high.

Rainfall and elevation: See Section 5.3. I have assumed sites come from a similar area to the *E. pauciflora* and *E. dives* sites in Woods and Raison (1983), and have used those parameters.

7.5 Woods *et al.* (1983)

This post-fire study in *Eucalyptus pauciflora* woodland, again in the Brindabella Ranges, provides a figure for *Initial*, the fuel load remaining immediately post-fire, after a low intensity burn. An autumn HR "consumed 10.5 of the 16.1 t ha-1 of fine (< 8 mm diameter) litter present" (Woods *et al.* 1983:174). Thus 5.6 t/ha of litter in this size class remained. Assuming the fire was less likely to have consumed the larger material in this size range, I have used a conversion factor of 0.90 to estimate *Initial* for particles < 6 mm at 5.0 t/ha.

Rating: 4
This study measured post-fire litter load after a single, low-intensity fire at a single site, so generalization is problematic. Unlike other studies by this group, a cut-off for fine fuel particle size other than 6 mm was used, necessitating the use of a conversion factor.

Rainfall and elevation: See Section 5.3. I have assumed this site is located in a similar area to the *E. pauciflora* site of Woods and Raison (1983), and have used those parameters, ie elevation 1245 m asl, mean annual rainfall 1150 mm.

7.6 Keith *et al.* (1997)

This paper reports on later work by Raison's group in *E. pauciflora* woodland, again in the Brindabella Ranges. As part of a study of carbon allocation, litter fall was measured over a single year, in 1993-4. The average litter fall over three earlier years (1987-1989) was also reported.

I've averaged across the four years. For 1993-4 I've used the value for the unfertilized plots, which was 4.90 t/ha. For 1987-1989, the average litter fall was 5.4 t/ha. Mean over all four years was therefore 5.28 t/ha.

Unlike earlier studies, no size cut-off is mentioned. As this carbon study was concerned with total biomass, I've applied a conversion factor of 0.91 to these figures, giving an estimated *L* of 4.8 t/ha for particles under 6 mm.

Rating: 2
Litter fall figures are likely to be accurate. However uncertainty about size cut-off decreases confidence in this figure.

Rainfall and elevation: See Section 5.3.

7.7 Park (1975)

Park (1975) measured litter fall in a *Eucalyptus pauciflora* forest at Bendoura Hill in the Brindabella Ranges over a period of 12 months. No size cut-off is mentioned;

‘branches’ were included. Litter fall totaled 3.76 t/ha. Applying the 0.91 conversion factor gives an estimate for *L*, for particles < 6 mm, of 3.42 t/ha.

Rating: 3
This study lacked replication across years, and was limited to a single site. Use of a conversion factor adds to uncertainty.

Rainfall and elevation: Information on this study site is minimal. The most relevant weather station may be Honeysuckle Creek: see Section 5.3.

7.8 Leigh *et al.* (1987)

Leigh *et al.* (1987) present figures for total fuel load at a site situated approximately 1390 m above sea level near Kiandra, NSW. Vegetation at this site, which was subject to treatments aimed at assessing the effects of rabbit grazing and low-intensity planned fire, was monitored over a 7-year period. Reported fuel load figures are averages across grazed and ungrazed treatments.

One of the main vegetation communities on the study site was *Eucalyptus niphophila* (snowgum) woodland with an understorey of *Bossiaea foliosa* and tussock grasses, particularly *Poa sieberana* and *P. phillipsiana*.

Figures for total fuel load of particles < 5 mm, including shrubs, grasses, herbs and litter, are presented graphically for times-since-fire between 0.8 and 3.8 years, and between 13 and 19 years. Fitting equation (1) to these data gives a value for *Limit* of 8.6 t/ha, with $k = 0.21$ ($R^2 = 0.80$). The maximum measured value, in any study year, was around 11.5 t/ha at 19 years post-fire.

A survey soon after an experimental fire in 1982 recorded approximately 1 t/ha of remaining fuel.

While Leigh *et al.* (1987) report separate results for shrubs, grasses, and litter, variability across grazing treatments makes generalization difficult. Shrub biomass ranged from around 1 to 4 t/ha, while grass fuel (excluding dead *Poa* leaves) was always below 1 t/ha.

Rating: 2
This was a carefully designed, replicated, longitudinal study, conducted in NSW. For current purposes, the fact that figures represent averages of grazed and ungrazed treatments is somewhat limiting, as is the lack of fuel load figures for times since fire between 4 and 13 years.

Rainfall and elevation: Leigh *et al.* (1987) note that the elevation of their study site ranged from 1370 to 1410 m (mean 1390 m). Nearest weather station is probably Kiandra chalet, where rainfall averages 1559 mm per annum, and elevation is 1395 m asl

7.9 Pressland (1982)

Pressland (1982) measured litter fall and litter load in two catchments near Armidale, one partially cleared, the other still retaining its native tree cover. Results from this second catchment, on the slopes of Mt Duval, will be considered here.

I have placed this site in the New England Grassy Woodland class because of its location, substrate (granite) and understorey (grassy, with *Poa* species dominant; shrubs were sparse). The dominant tree species, *E. laevopinea* (New England Stringybark) is indicative for New England Grassy Woodlands as are *E. calignosa* and *E. bridgesiana* which were also common. Less typical for this vegetation class are *E. viminalis* and *E. obliqua*, which were also found in the catchment.

Twenty litter traps were emptied monthly for over two years. Twigs up to 25 mm were collected. Total litter fall was 3.37 t/ha in Year 1 and 3.75 t/ha in Year 2, giving an average of 3.56 t/ha for particles < 25 mm. Applying the 0.94 conversion factor gives an estimated litter fall for particles < 6 mm of 3.35 t/ha.

Litter load, which was assessed on a single occasion, totaled 11.05 t/ha. Assuming the same size cut-off as for litter fall (although this is not explicitly stated), and applying the 0.87 conversion factor gives 9.6 t/ha. Assuming steady state had been reached − previous fires are not mentioned − this value can be taken to approximate *Limit* for particles < 6 m. Thus *k* can be estimated as 3.35/9.6 = 0.35.

Rating: 3
The litter fall figure is likely to be fairly accurate, as replication in time and space were reasonable, and inter-annual variability low. The estimate for *Limit* is more doubtful, as time-since-fire was not considered. Use of conversion factors adds some uncertainty, as does the somewhat a-typical nature of the vegetation.

Rainfall and elevation: Pressland (1982) does not provide information on rainfall, however he does note that Mt Duval rises to 1393 m. Nearest weather station with adequate data is probably Armidale (average annual rainfall of 791 mm, 980 m asl, 135 years of data). Duval Nature Reserve Management plan notes that rainfall is higher on the mountain than in surrounding country, rising to 1000 mm on the summit. I've used 900 mm as a half-way point between rainfall at the summit and in the surrounding matrix.

7.10 McElhinny (2005)

As part of a study of structural complexity, McElhinny (2005) measured litter load in 16 woodland sites across the southern and central tablelands. Sites varied in their degree of modification, but all were dominated by *Eucalyptus melliodora* (yellow box), *E. blakelyi* (Blakely's red gum) and/or *E. bridgesiana*. Their geographic location and overstorey composition locates them in the Southern Tableland Grassy Woodland class, with some perhaps moving into the area where Western Slopes Grassy Woodlands predominate.

In each site, all dead organic matter below 10 cm (100 mm) in diameter was collected from 15 quadrats. The average load, across the 16 sites, was 6.8 t/ha. Low fuel loads were recorded across the woodland dataset (12.5 percentile, 3.4 t/ha. 87.5 percentile, 7.3 t/ha). Using the 0.82 conversion factor gives an estimated mean, for fine fuel, of 5.6 t/ha.

McElhinny (2005) does not provide information on time since fire in his study sites, although he does note that many of them have not been burnt for a long time. In this fragmented landscape, fire is rare. It therefore seems reasonable to assume that *Limit* in yellow box-Blakely's red gum sites is generally quite low.

A second study in yellow box-Blakely's red gum woodland in the ACT (McElhinny *et al.* 2010) found considerable variation between litter load under trees (mean 12.5 t/ha) and in gaps (mean 1.27 t/ha).

Rating: 3
This study has the great advantage of having surveyed multiple woodland sites across a wide geographic area. Its downsides, for current purposes, are the lack of explicit information on post-fire age, and the focus on litter < 10 cm rather than fine fuel.

Rainfall and elevation: Sites were selected through stratification into rainfall bands of 600-700 and 700-800 mm. Altitude ranged from 500 - 1100 m (mean 800 m). Yass (Linton Hostel) is the most centrally-located weather station given study site distribution. Here, rainfall averages 651 mm per year (112 years of data) and elevation is 520 m asl.

7.11 Synthesis and suggested values for Phoenix

The bulk of the data in this chapter comes from studies in vegetation dominated by *Eucalyptus pauciflora* and *E. dives*, at altitudes above 1100 m asl in the ACT. These studies, which focus exclusively on litter and which used a variety of methods, are summarised in Table 22.

Values for *L*, *Limit* and *k* arising from these studies fall within a fairly narrow range, with almost identical weighted means for sites dominated by *E. pauciflora* and *E. dives* (Table 22).

Table 22. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing Subalpine Woodland in the ACT. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Study	Dominant tree species	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Woods and Raison (1983)	*E. pauciflora*	4.1	16.2	0.27	2
Woods and Raison (1983)	*E. dives*	3.5	16.6	0.28	2
Raison *et al.* (1983)	*E. pauciflora*	5.3	17.0	0.31	3
Raison *et al.* (1983)	*E. dives/E. dalrympleana*	5.3	17.2	0.31	3
Raison *et al.* (1986)	*E. pauciflora*	5.4	16.9	0.32	3
Raison *et al.* (1986)	*E. dives*	6.3	14.9	0.42	3
Raison *et al.* (1986)	*E. dives*	3.4			3
Keith *et al.* (1997)	*E. pauciflora*	4.8			2
Park (1975)	*E. pauciflora*	3.4			3
Weighted mean	***E. pauciflora***	**4.5**	**16.3**	**0.28**	
Weighted mean	***E. dives***	**4.6**	**16.6**	**0.28**	
Weighted mean	**All**	**4.5**	**16.5**	**0.28**	

The Subalpine Woodland story becomes more complex, however, when the data from the study by Leigh *et al.* (1987) is added to the mix. Although these researchers included grasses and shrubs as well as litter in their fuel load figures, *Limit*, at 8.6 t/ha, was considerably lower than that derived from the ACT studies of litter alone. Thus there appears to be quite a range in fuel load across the Subalpine Woodland class. The community in the Leigh *et al.* (1987) study, which bordered a frost hollow, probably represents Subalpine Woodland at one extreme of its range, where trees are small and relatively sparse. On the other hand, much of the work in the ACT appears to have taken place at the most forest-like end of the Subalpine Woodland range. It is interesting to note that the litter fall mean in Table 22 is identical to that for Southern Tableland WSF in Table 16 (Section 5.9). Litter fall almost certainly differs across the Subalpine Woodland range, being high at the 'forest' end, and lower near the tree-line. *k*, on the other hand, is not so different in the ACT forest-like woodlands (mean 0.28) and in the woodlands adjoining the frost-hollow (0.21; Leigh *et al.* 1987). What difference there is may reflect either the higher altitude of the frost-hollow site, or constraints imposed by the addition of shrubs to the fuel load curve.

Giving some acknowledgment to likely differences across the Subalpine Woodland class, while still being conservative, I suggest using a figure of 15.0 t/ha for *Limit*, and 0.25 for *k*, for litter alone in grassy woodlands. This is for equation (1); but what about *Initial*?

The study by Woods *et al.* (1983) suggests that the curve for litter in this vegetation type should perhaps start up to 5 t/ha above zero. However these same researchers (Raison *et al.* 1986:17) note that "Partially burnt litter remaining after fire was observed to fragment rapidly and become incorporated into the mineral soil…The rapid fragmentation and incorporation of the post-burn litter residue is reflected in the fact that best fits (not forced through zero) of the exponential equation to the pattern of re-accumulating litter passed very near to the origin (i.e. suggest that a negligible mass of the post-fire residue remains after 1-2 years)." Also, the Woods *et al.* (1983) study, besides being limited by a lack of replication, followed a low intensity HR burn; wildfire would probably leave less. Taking these factors into account, I suggest using a figure of 2.0 t/ha for *Initial*.

Would near-surface fuel, which in this formation is primarily provided by grasses, add much to these figures? Again, we have very little data, although we do know that grass biomass in the woodlands studied by Leigh *et al.* (1987) peaked just below 1.0 t/ha. Adding this figure to *Limit*, and assuming a slightly higher *k* when grass fuel is added to litter (Section 6.2), gives *Initial* = 2.0, *Limit* = 16.0 t/ha, *k* = 0.30.

What about shrubs? In Subalpine Woodlands, shrub cover varies considerably in response to soil type (Keith 2004:94), while grazing (Leigh *et al.* 1987) and fire frequency may also be influential. Shrubs in the high country which have not burned for many years may, or may not, regenerate in the absence of fire; in some very long-unburnt areas, shrubs may be replaced by grasses (Wimbush and Costin 1979; Williams and Ashton 1987). All this implies that the ability of the negative exponential model to represent shrub biomass as a function of time since fire, will be very limited. However as this is required by Phoenix, I suggest using the same value for *Limit* for elevated fuel as for Coastal Valley Grassy Woodlands, ie 2.0 t/ha, with a lower *k* of 0.20 to reflect the slower growth patterns which are likely to occur in the cool subalpine climate.

Data for woodland classes on the tablelands other than Subalpine Woodlands is sparse. However the studies by Pressland (1982) and McElhinny (2005) suggest steady state litter loads closer to those in the Coastal Valley Grassy Woodlands reviewed in the last chapter, than to those in Subalpine Woodlands (Table 23). Pressland's value for *L* is similar to the estimate for the structurally-similar Cumberland Plain Woodland (Section 6.2), while *Limit* is somewhat higher and *k* somewhat lower. These differences might be expected to result from the higher mean annual rainfall on the Cumberland Plain (800-900 mm) relative to that reported by Keith (2004) for non-alpine grassy woodlands on the tablelands (500-800 mm). The study by McElhinny (2005) serves to remind us that tree removal in these woodlands may have altered fuel dynamics, although the consistently low litter loads in the remnants he surveyed, which covered a wide range in terms of both geography and condition, suggest that litter fuels in this woodland class tend to be low across the landscape.

Table 23. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing some vegetation classes in the grassy woodland formation on the tablelands . R'g, rating for confidence level and relevance. Weighted means from Tables 19 and 22 are provided for comparison.

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Weighted mean	**Coastal Valley Grassy Wdlds**	**3.0**	**6.5**	**0.46**	
Weighted mean	**ACT Subalpine Wdlds**	**4.5**	**16.5**	**0.28**	
Pressland (1982)	New England Grassy Wdlds	3.4	9.6	0.35	3
McElhinny (2005)	Southern Tableland Grassy Wdlds		5.6		3

Fuel load parameters for tablelands grassy woodland vegetation classes other than Subalpine Woodlands will be further discussed with those on the western slopes and plains, at the end of the next chapter (Section 8.6).

Suggested parameters for classes in the grassy woodland formation on the tablelands are summarized in Table 24, with a comparison between literature-derived and suggested models for litter fuel in Subalpine Woodlands presented in Figure 6.

Table 24. Summary of suggested values for negative exponential model parameters, for classes in the grassy woodland formation on the tablelands. NS, near-surface. *r* = *Limit* - *Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	**Fuel layer**	***Initial***	***k***	***Limit***	***r***
Subalpine Woodlands	Litter	2.0	0.25	15.0	13.0
	Litter + NS	2.0	0.30	16.0	14.0
	Elevated	0.0	0.20	2.0	2.0
Other grassy woodland classes on the tablelands	Litter	1.0	0.35	8.0	7.0
	Litter + NS	1.0	0.40	10.0	9.0
	Elevated	0.0	0.20	0.5	0.5

7.12 Knowledge gaps

Although the extensive suite of studies by CSIRO researchers detailed in this chapter provides a clear picture of litter dynamics in Subalpine Woodlands in the ACT, the relevance of the parameters derived from this work across the range of this vegetation class in NSW is unclear. And while Pressland (1982) and McElhinny (2005) offer useful information for Northern and Southern Tableland Grassy Woodlands across part of their range, neither explicitly considers time since fire. If more robust parameters for litter fuels are desired for these fragmented woodland systems, considerable data collection is needed.

Across all the vegetation classes in the grassy woodland formation on the tablelands, data on non-litter fuels is almost non-existent.

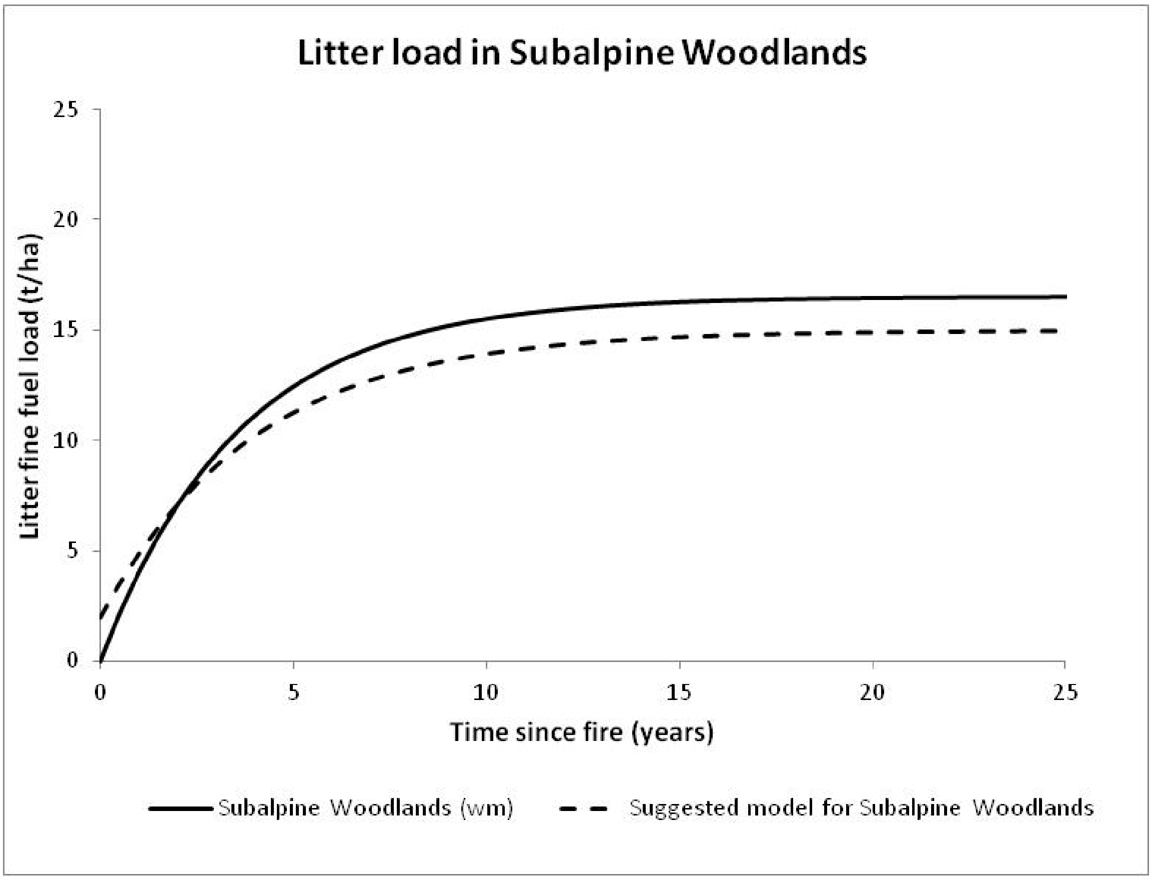

Figure 6. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in Subalpine Woodlands. wm, model based on weighed means derived from the literature (Table 22), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 24; see text for explanation of crosswalk from literature to suggested model.

8. Grassy woodlands on the western slopes and plains

8.1 Introduction

The remaining two of Keith's seven grassy woodland classes occur predominantly on the western slopes and plains (Table 25). Though once extensive, both the Western Slopes Grassy Woodlands, also known as grassy white box woodlands, and the Floodplain Transition Woodlands which lie to their west, have been heavily cleared, fragmented and modified (Keith 2004). Both classes are heavily used for production purposes, particularly grazing.

Table 25. Vegetation classes in the grassy woodland formation which occur on the western slopes and plains.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Western Slopes Grassy Woodlands	96-7	Throughout western slopes of the Great Divide below 700 m asl, where rainfall averages 550-800 mm. These woodlands stretch the length of NSW, continuing north into Queensland and south into Victoria.	Small, due to clearing
Floodplain Transition Woodlands	98-9	On fertile soils of upper flood-plains and in outwash areas at the edge of the semi-arid zone	Small, due to clearing

No NSW studies specifically addressing fuel load in either of these vegetation formations have been found, although some of the sites in the study by McElhinny (2005; Section 7.10) probably fall into the Western Slopes Grassy Woodland class. Several Victorian studies, however, provide clues to fuel dynamics in these classes.

8.2 McElhinny (2005)

This study, which measured litter load in 16 woodland sites across the southern and central tablelands, was discussed in the previous chapter. While most sites were located on the tablelands, some were at an altitude (500-700 m asl) and had an annual rainfall (600-700 mm) consistent with Keith's description of Western Slopes Grassy Woodlands. The estimated mean fine fuel load, across study sites, was 5.6 t/ha (Section 7.10).

8.3 Chatto (1996)

Chatto (1996) sampled surface fine fuel load along a series of transects in box-ironbark country in Chiltern Regional Park, south of the NSW-Victorian border about 30 km west of Albury. Dominant trees included *E. albens*, *E. blakelyi*, *E. microcarpa*, *E. sideroxylon* and *E. macrorhyncha*; the understorey was mostly grassy with some shrub patches. Rainfall averaged 685 mm per annum. While not an exact match for Keith's Western Slopes Grassy Woodlands, the vegetation in this study approximates his description of this vegetation class.

Transects were located in areas with known times-since-fire. Fire had occurred 2, 4, 9, 10, 11, 28 and 50 years previously. All times-since-fire were represented by a single transect, which the exception of the oldest age class where 8 transects were located.

Cut-off size for fine fuel in this study was 6 mm for dead material and 2 mm for live. This latter point suggests that grasses and herbs were included, although this is not explicitly stated. Humus was specifically excluded. This may not have greatly affected the fuel load figures, however, as humus is not a salient component of surface fuels in this vegetation type (C. Orcheg, pers. comm. 2009).

Equation (1), fitted to all data points with the exception of one 'outlier' (which was near a fenceline and thus considered a-typical), gave a value for *Limit* of 7.15 t/ha, while *k* was 0.87.

For current purposes, I will assume that the load contributed by grasses offset the humus fraction that was omitted from Chatto's sampling, and that therefore 7.15 t/ha approximates *Limit* for litter alone.

The exclusion of humus may help explain the very high value for *k*: Simmons and Adams (1986) found that the 'comminuted fraction' of their fuel load samples, which included humus and decomposing leaves, increased as a proportion of total surface fuels with time-since-fire. Inclusion of grasses may also have elevated *k* above the level for litter alone (Section 6.2).

Rating: 3
While within-transect replication was good (15 points per transect), the number of transects in the early post-fire years was limited. Problems with inclusion of grasses and exclusion of humus are outlined above.

Rainfall and elevation: Chatto (1996) gives figures for average rainfall (approximately 685 mm per annum), and for elevation (300 m asl). Nearest weather station with similar parameters may be Beechworth Woolshed, where rainfall averages 750 mm, elevation is 330 m asl, but length of record is only 23 years. Beechworth Composite, with 141 years of data, has an average annual rainfall of 946 mm but is at a higher elevation (580 m).

8.4 Adams and Attiwill (1986)

Adams and Attiwill (1986) measured litter fall and litter load in a number of vegetation types around Victoria; I have used two of them in this review. Site RI dominated by *Eucalyptus sideroxylon* (red ironbark) was almost certainly located close to the NSW border in the vicinity of Albury, as this species has a very limited distribution in Victoria (Brooker and Kleinig 1999). This site will be discussed later in the review (Section 11.3). Site GB, dominated by *E. microcarpa* (inland grey box) appears to be in the same general area as Site RI, as rainfall, soil type and fire history in the two sites are identical. In the southern part of NSW, *E. microcarpa* occurs in Floodplain Transition Woodlands.

Site GB had remained unburned for at least 50 years. Litter fall, which was measured over two years, averaged 2.80 t/ha. Applying the 0.91 conversion factor, since no size cut-off was specified, gives an estimated *L* for particles < 6 mm of 2.55 t/ha. Litter load, which was measured on a single occasion, averaged 12.48 t/ha. Using the 0.82 conversion factor gives an estimate for *Limit*, for fine fuel, of 10.23 t/ha. *k* can now be calculated: 2.55/10.23 = 0.25.

Rating: 3
Litter fall data from this study are probably reasonably accurate, for the single site surveyed. Litter load data may be more problematic, given the single sampling time. Thus *Limit* and *k* may be less accurate than *L*.

Rainfall and elevation: Adams and Attiwill (1986) give a figure of 570 mm for mean annual rainfall, and 260 m for elevation. The nearest weather station may be Rutherglen Research, where annual rainfall averages 584 mm (98 years of data) and elevation is 175 m asl.

8.5 Schultz *et al.* (2011)

Schultz *et al.* (2011) surveyed a series of sites in Victoria for effects of grazing on grassy ecosystems. Herbaceous 'phytomass' (live + dead plant material, *excluding* tree litter) was harvested from unburnt exclosures and adjacent heavily grazed areas. This study thus provides an indication of near-surface fuel load.

Two sites with an overstorey of trees and an understorey of *Austrodanthonia* and *Austrostipa* species were located close to the NSW border west of Echuca at Mitiamo and Pine Grove. This understorey composition is consistent with Keith's description of Floodplain Transition Woodlands.

At Pine Grove, the ungrazed plot supported 4.07 t/ha of herbaceous phytomass. This dropped to 1.15 t/ha where grazing (by sheep) had taken place. The parallel figures at Mitiamo, where tree basal area was higher and exclosure more recent, were 1.62 and 0.46 t/ha.

Rating: 3
Constraints of this study for current purposes are the restricted information on vegetation composition, and the limited exclosure time (10 years at Pine Grove and 5 years at Mitiamo): has steady state been reached?

Rainfall and elevation: Schultz *et al.* (2011) give a figure for rainfall of 381 mm per annum. Nearest weather station is probably Echuca Aerodrome, where rainfall averages 427 mm (122 years of data), and elevation is 96 m asl.

8.6 Synthesis and suggested values for Phoenix

Table 26 adds parameters for litter derived from the studies in this chapter to those in Table 23. There is little here to suggest consistent differences between the grassy woodlands of the tablelands (other than Subalpine Woodlands, which are clearly in a category of their own), and those of the western slopes and plains. Of course, available data is scant, limiting ability to identify differences which may in fact exist.

Table 26. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the grassy woodland formation in Chapters 6 to 8. ST, Southern Tableland. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4). Weighted means in last two lines are copied from previous summary tables, for comparison.

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Pressland (1982)	New England Grassy Wdlds	3.4	9.6	0.35	3
McElhinny (2005)	ST/Western Slopes Grassy Wdlds		5.6		3
Chatto (1996)	Western Slopes Grassy Wdlds		7.2		3
Adams and Attiwill (1986)	Floodplain Transition Wdlds	2.6	10.2	0.25	3
Weighted mean	**Studies above**	**3.0**	**8.1**	**0.37**	
Weighted mean	**Coastal Valley Grassy Wdlds**	**3.0**	**6.5**	**0.46**	
Weighted mean	**ACT Subalpine Wdlds**	**4.5**	**16.5**	**0.28**	

In the absence of further information I suggest parameterising all the grassy woodland classes, with the exception of Coastal Valley and Subalpine Woodlands, together. Thus, for litter, I suggest using the weighted mean values from the four available studies (Table 26), ie 8.0 t/ha for *Limit* (8.1 t/ha rounded to the nearest 0.5), and 0.35 for *k* (0.37 rounded to nearest 0.05). In the absence of data I suggest setting *Initial* at 1.0 t/ha.

What about near-surface fuel? The study by Schultz *et al.* (2011) indicates that the biomass of this fuel element can vary considerably with both tree density and grazing, ranging in the two plots in that study from approximately 0.5 to 4.0 t/ha. Wet/dry cycles may also play a role, particularly in the more westerly grassy woodland variants. Any figure chosen will therefore be approximate at best. With that caveat, I suggest adding 2.0 t/ha to *Limit* for litter alone, bringing it up to 10.0 t/ha for surface + NS fuel, and increasing *k* to 0.40.

For the grassy woodland classes on the tablelands other Subalpine Woodlands, and for grassy woodlands of the slopes and plains, data on the fuel load contributed by shrubs is non-existent. We know, however, that shrub density in these woodlands, almost by definition, is very low (Keith 2004). I suggest setting *Limit* at 0.5 t/ha, and *k* at 0.20.

Suggested parameters for grassy woodland classes on the western slopes and plains are summarized in Table 27 below, with a comparison between literature-derived and suggested models for litter fuel in grassy woodland classes other than Coastal Valley Grassy Woodlands or Subalpine Woodlands presented in Figure 7.

Table 27. Summary of suggested values for negative exponential model parameters, for classes in the grassy woodland formation on the western slopes and plains. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Fuel layer	***Initial***	***k***	***Limit***	***r***
Litter	1.0	0.35	8.0	7.0
Litter + NS	1.0	0.40	10.0	9.0
Elevated	0.0	0.20	0.5	0.5

8.7 Knowledge gaps

Data on fuel dynamics in Western Slopes and Floodplain Transition Grassy Woodlands in NSW is virtually non-existent, with suggested parameters derived from hints provided by research conducted elsewhere. This applies to all fuel elements including litter, grasses and shrubs. As for other classes in this formation, if more robust parameters for these fragmented woodland systems are wanted, substantial data collection will need to take place.

Figure 7. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in grassy woodland classes other than Coastal Valley Grassy Woodlands and Subalpine Woodlands. wm, model based on weighed means derived from the literature (line 6, Table 26), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 27; see text for explanation of crosswalk from literature to suggested model.

9. Shrub/grass dry sclerophyll forests east of the Divide

9.1 Introduction

Chapters 9 to 11 address dry sclerophyll forests (DSF) in Keith's shrub/grass subformation. Shrub/grass dry sclerophyll forests can be considered a transition between shrubby dry sclerophyll forests and grassy woodlands (Keith 2004:188). They generally occur on soils of somewhat greater fertility than their shrubby counterparts, often in rain-shadow areas. Because of their grassy component, they are often subject to grazing by domestic stock. Litter, grasses and shrubs all provide fuel for fire in this forest type.

Of the ten vegetation classes identified by Keith (2004) in the shrub/grass subformation of dry sclerophyll forests, six occur predominantly east of the Divide (Table 28). Of these, four occupy a substantial geographic area.

Table 28. Vegetation classes in the shrub/grass subformation of dry sclerophyll forests which occur predominantly east of the Great Divide.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Clarence DSF	122-3	Lowlands and foothills of the Clarence River valley in the far north-east of the state, in rainshadow areas	moderate
Northern Gorge DSF	130-1	Gorges to east of the New England tablelands, from upper Manning River to near the Queensland border	moderate
Hunter-Macleay DSF	124-5	Macleay, Manning and Hunter river valleys, in rain shadow areas.	moderate
Cumberland DSF	126-7	On tertiary soils of Western Sydney's Cumberland Plain	small
Central Gorge DSF	132-3	Gorges of the Kowmung, Wollondilly and Shoalhaven rivers in the central east of the State, on clay loam soils.	moderate
Southern Hinterland DSF	128-9	Foothills of the far south coast, south from Narooma	small

Despite the extensive area covered by the classes addressed in this chapter, I know of only one study from shrub/grass DSF east of the Divide, from a site in south-east Queensland some distance from the NSW border.

9.2 Guinto *et al.* (2001)

This study, which examined nutrient levels in three different fire frequency treatments in two long-running experiments in south-east Queensland, has already been mentioned (Section 3.7). One site, at Bauple 260 km north of Brisbane, was in shrub/grass forest dominated by *Corymbia maculata*. As this species also dominates the Clarence Dry Sclerophyll Forest class, the findings of this study may have relevance for NSW.

Litter load was but one of many parameters measured, and the description of methods is scanty. Of interest for this review is the figure for litter load in the long unburnt treatment, which had been without fire for 48 years at the time of sampling, ie long enough for steady state to be assumed. Here, litter load averaged 19.03 t/ha. No cut-off size was mentioned. Using the 0.82 adjustment factor gives an estimated fuel load for particles < 6 mm of 15.61 t/ha.

Rating: 3
While the spatial replication behind this figure appears adequate, the use of a conversion factor to arrive at an estimated figure for particles < 6 mm reduces confidence. A major disadvantage of this study, from a NSW point of view, is that it was conducted over 300 km north of the border with Queensland.

Rainfall and elevation: Guinto *et al.* (2001) give a figure of 1131 mm for annual rainfall at this site, and an altitude of 60 m asl. The weather stations most likely to be relevant are Gympie (1127 mm rainfall, 65 m asl, 140 years of data) and Maryborough (1151 mm rainfall, 10 m asl, 141 years of data).

9.3 Further information and speculation

There is limited data on which to base parameters for the six vegetation classes covered by this chapter. This is a major knowledge gap.

Analysis of data collected through the UoW (University of Wollongong) fuels project in Cumberland DSF, using hazard scores, suggests that steady state litter load in that forest type is low. From the UoW research, which involved surveying 17 sites across a range of post-fire ages, *Limit* for litter depth was around 20 mm (*Initial* = 5 mm, k = 0.16), while the asymptote for surface fuel hazard was slightly below 2.0 (surface hazard rating of Moderate, k = 0.15). Using a bulk density of 34 kg/m^3 (McCarthy 2004), 20 mm of litter depth translates to 6.8 t/ha of fuel load. Alternatively, using Tolhurst's equation for converting surface hazard scores to fuel loads gives 5.8 t/ha. These figures are considerably lower than those recorded by Guinto *et al.* (2001) at Bauple.

If *Limit* for litter was as low as 6 t/ha, and k was, say, 0.20, L would be only 1.2 t/ha, which seems rather low for a forest.

Given the paucity of information available for classes covered in this chapter, synthesis of data for the shrub/grass subformation of Dry Sclerophyll Forests will be deferred till information for all classes in this subformation has been presented - see Section 11.7.

Suggested parameters from that section, for shrub/grass Dry Sclerophyll Forest classes east of the Divide, are given in Table 29.

Table 29. Summary of suggested values for negative exponential model parameters, for classes in the shrub/grass subformation of dry sclerophyll forests east of the Divide. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Fuel layer	***Initial***	***k***	***Limit***	***r***
Litter	1.0	0.30	11.0	10.0
Litter + NS	1.0	0.30	12.0	11.0
Elevated	0.0	0.20	2.0	2.0

9.4 Knowledge gaps

The almost total lack of data for the shrub/grass DSF classes in this chapter is probably the most significant data gap in NSW with respect to fuel load. The apparent conflict between the fuel load figures from Bauple and those extrapolated from the UoW research on the Cumberland Plain highlights the extent to which these shrub/grass forests are an enigma. That these sub-coastal vegetation classes are likely to be associated with human habitation geared to both production and lifestyle makes filling this gap a particularly high priority.

10. Shrub/grass dry sclerophyll forests on the tablelands

10.1 Introduction

This category includes only one of Keith's vegetation classes: New England DSFs (Keith 2004:134-5). These forests occur at high elevation on granite soils where rainfall averages 850-1000 mm, from Tenterfield south to Wollomombi east of Armidale. Some fragmentation has occurred. Extent is moderate.

I know of one dataset relevant to this vegetation class, from the study by Watson (1977) which has already been mentioned on several occasions (Sections 2.4, 3.10, 5.2).

10.2 Watson (1977)

One of the many sites covered by this UNE Masters project was located on the New England tablelands 3 km north of the northern boundary of Styx River State Forest east of Armidale. This site falls clearly into Keith's New England DSF class. Tree species mentioned in both Watson's site description and the description in Keith (2004) include *E. calignosa*, *E. radiata*, *E. acaciiformis*, *E. pauciflora* and *Banksia integrifolia*. Watson (1977) describes the soils at this site as 'impoverished'.

Litter fall was sampled over a 12 month period, using 9 litter traps. 4.58 t/ha of litter was collected, however no size cut-off is mentioned. Applying the 0.91 conversion factor gives an estimate of 4.17 t/ha for annual accession of litter particles < 6 mm.

Watson (1977) also sampled litter on the forest floor (on a single occasion), however as time-since-fire is not mentioned, steady-state litter load cannot be assumed. Mean litter load was 7.16 t/ha. Using the 0.82 conversion factor gives a value, for litter < 6 mm in diameter, of 5.87 t/ha.

Rating: 3
The litter fall figure for this study is based on a single year of measurement. While with-in site spatial replication was reasonable, no between-site replication took place. The use of a conversion factor to arrive at an estimated figure for particles < 6 mm is a further weakness, from a fuel point of view. Lack of information on time-since-fire makes it impossible to assess whether standing litter load approximates steady state.

Rainfall and elevation: Watson (1977) gives a figure of 960 mm for annual rainfall at this site; this figure was based on measurements at a nearby property. Altitude is not reported. The nearest weather station is Jeogla (1515 mm rainfall, 1030 m asl, 43 yrs of data).

10.3 Comment

Again, data on which to base parameters for this shrub/grass forest class, are sparse. What there is, only adds to the puzzle.

If Watson's figure of 4.2 t/ha for *L* is roughly correct (Watson 1977), and *Limit* in New England DSFs is, say, 10 t/ha, then *k* would be a relatively high 0.42. If *Limit* really was as low as 6 t/ha, *k*, at 0.60, would be even higher. These figures are much higher than the *k* value suggested by the UoW work in Cumberland DSF.

Given the paucity of information available for New England DSF, synthesis of data for the shrub/grass subformation of Dry Sclerophyll Forests will be deferred till information for all classes in this subformation has been presented - see Section 11.7. Suggested parameters from that section, for New England DSF, are given in Table 30.

Table 30. Summary of suggested values for negative exponential model parameters, for New England Dry Sclerophyll Forests. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Fuel layer	***Initial***	***k***	***Limit***	***r***
Litter	1.0	0.30	11.0	10.0
Litter + NS	1.0	0.30	12.0	11.0
Elevated	0.0	0.20	2.0	2.0

10.4 Knowledge gaps

Watson's litter fall figure provides one solid piece of data in a sea of unknowns. It would be instructive to extend litter fall measurement to other years and other sites. Comparison with litter fall in coastal shrub/grass forests would be informative. Measurement of litter load across sites, years, seasons and time-since-fire is desirable in this vegetation type as well as in the coastal shrub/grass variants.

For all the shrub/grass forest types considered so far, data on near-surface and elevated fuels is entirely lacking.

11. Shrub/grass dry sclerophyll forests on the western slopes and plains

11.1 Introduction

This category includes three of Keith's vegetation classes, which are outlined in Table 31. All have suffered substantial clearing, and much of their remaining extent has been heavily grazed and/or logged (Keith 2004).

Table 31. Vegetation classes in the shrub/grass dry sclerophyll forest subformation which occur predominantly on the western slopes and plains.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
North-west Slopes Dry Sclerophyll Woodland	136-7	On hilly country with moderately fertile soils, on the western slopes in the central and northern parts of the state.	moderate
Upper Riverina DSF	138-9	Western fall of the southern tablelands and parts of the Snowy River gorge, on moderately fertile soils.	moderate
Pilliga Outwash DSF	140-1	Area bounded by the Namoi and Castlereagh Rivers, mostly between Coonabarabran, Narrabri and Coonamble.	moderate

I have found several studies addressing litter and/or fuel in this category, two from the Upper Riverina and two from the Pilliga.

11.2 March and Watson (2007)

March and Watson (2007) measured litter fall in a forest remnant near Holbrook, NSW, over a single year. Dominant trees included *Eucalyptus blakelyi*, *E. goniocalyx*, *E. polyanthemos* and *E. macrorhyncha*, all of which are mentioned in Keith's description of Upper Riverina DSF. The understorey was grassy.

March and Watson (2007) provide figures for total litter fall, including 'large twigs' (> 5 cm long and > 2 mm in diameter; upper cut-off not given), in each of six plots; the average across plots was 2.40 t/ha. Applying the 0.91 conversion factor gives an estimate for *L*, for particles < 6 mm, of 2.19 t/ha.

These authors also measured standing litter load under trees with and without mistletoe. Figures were very low: 1.91 t/ha under trees without mistletoe, 4.53 t/ha under trees with mistletoe. As sampling was not carried out randomly, these figures do not represent a mean across the landscape; as litter tends to be greater under trees than in gaps between them (Watson 2005; McElhinny *et al.* 2010), the landscape-wide figure is likely to be even lower. However as time since fire is not mentioned, we do not know whether the litter layer was at steady state.

Rating: 3
For our purposes, the usefulness of the litter fall data from this study is limited by the short timeframe over which it was collected, and by lack of spatial replication. Limitations of the litter load data are discussed above.

Rainfall and elevation: Nearest weather station may be Hume Reservoir, where mean annual rainfall is 695 mm (89 years of data) and elevation is 184 m asl.

11.3 Adams and Attiwill (1986)

This study, which has already been mentioned (Section 8.4) measured litter fall and litter load in various vegetation types around Victoria. Here we consider findings at Site RI dominated by *Eucalyptus sideroxylon* (red, or mugga, ironbark). The limited distribution of *E. sideroxylon* places this site close to the NSW border in the vicinity of Albury (Brooker and Kleinig 1999); most of its distribution is in NSW, where in the south of the state it is found in Upper Riverina DSF (Keith 2004). Site RI had remained unburned for at least 50 years.

Litter fall, which was measured over two years, averaged 2.78 t/ha. Applying the 0.91 conversion factor, since no size cut-off was specified, gives an estimated L for particles < 6 mm of 2.53 t/ha. Litter load, which was measured on a single occasion, averaged 14.56 t/ha. Using the 0.82 conversion factor gives an estimate for *Limit*, for fine fuel, of 11.94 t/ha. k can now be calculated: 2.53/11.94 = 0.21.

Rating: 3
Litter fall data from this study are probably reasonably accurate, for the single site surveyed. Litter load data are likely to be more problematic, given the single sampling time; in addition, SE for this value was high (8.64 t/ha). Thus *Limit* and k are almost certainly less accurate than L.

Rainfall and elevation: Adams and Attiwill (1986) give a figure of 570 mm for mean annual rainfall, and 260 m for elevation. The nearest weather station may be Rutherglen Research, where annual rainfall averages 584 mm (98 years of data) and elevation is 175 m asl.

11.4 Van Loon and Love (1971)

Van Loon and Love (1971) surveyed standing litter load, together with grasses and elevated fuels in a number of sites in the Pilliga East forest. All sites were dominated by white cypress pine (then *Callitris glauca*, now *C. glaucophylla*), *Eucalyptus crebra*, and bulloak (*Casuarina leuhmannii*). A very limited number of additional species occurred in the understorey, which was dominated by pine and bulloak. This description of species composition and structure places these sites in the Pilliga Outwash DSF class.

This study had good spatial replication: 10 sites were surveyed, and three measurements taken in each of four quadrats at each site. All sites had last burnt at the same time, 20 years previously in the extensive fires of 1951.

Material collected was sorted into twigs (up to 1" = 25 mm in diameter), bark, leaves, green vegetation under 3 ft (approx 1 m) in height, cured vegetation under 3 ft, and miscellaneous decomposing matter. Understorey from 3 to 20 ft (approximately 6 m) was also cut and weighed. Van Loon and Love (1971) report fuel weights in lbs/acre; I have converted these to t/ha (1 lb/acre = 0.001121 t/ha).

Total fuel load for the component under 3 ft in height averaged 5556 lb/acre, ie 6.23 t/ha. Of this, the green and cured vegetation component made up 0.29 t/ha (4.6%); most of this was grass. The remainder, ie 5.94 t/ha was litter including particles up to 25 mm. Using the conversion factor of 0.87 (Section 1.5.1) gives an estimated 5.17 t/ha for litter particles under 6 mm in diameter.

For litter under 6 mm + near-surface fuel, the estimate would therefore be 5.17 + 0.29 = 5.46 t/ha.

Van Loon and Love (1971) note that grass was unusually abundant at the time of sampling, as rainfall had been considerably higher than average over the preceding nine months. While this may have encouraged grass growth, it may also have speeded decomposition. Leaving this speculation aside, we can probably assume that litter load 20 years after a fire would be very close to *Limit*.

Fuel load between 3 and 20 ft totaled 1501 lb/acre, ie 2.36 t/ha. Much of this, however, consisted of woody material over 6 mm. Van Loon and Love (1971) give figures for leaves, and for various size classes of woody material. From these figures it can be calculated that the fine fuel component < 6 mm made up 43.4% of this total, ie 1.02 t/ha.

Rating: 2
Spatial replication was excellent, as is the detail in which results are reported. Questions remain however over whether fuel loads had reached steady state, and whether the unusually high rainfall in the nine months prior to sampling had affected decomposition, somewhat lowering fuel load.

Rainfall and elevation: Van Loon and Love (1971) do not provide figures for these parameters. Nearest weather station may be Narrabri West where average annual rainfall is 656 mm (82 years of data, 212 m asl).

11.5 Hawkins (1966)

Hawkins (1966) collected litter fall in a managed stand of white cypress pine in Yuleba State Forest east of Roma in southern Queensland. This study involved a small number of traps some of which were in an area burnt by a wildfire two years previously. I have used data from four of Hawkins' six traps, two in unburnt forest and two in forest that experienced moderate fire severity. While spatial replication was low, temporal replication was high, with litter collections continuing over five years.

Mean annual litter fall averaged 1485 lb/acre, which is 1.66 t/ha. Applying the 0.91 conversion factor gives an estimated *L* of 1.51 t/ha for particles under 6 mm.

Hawkins (1966) provides little information on the vegetation in his study site. The dominance of white cypress pine, and the fact that rainfall in the area is above the limit of the semi-arid range, suggests that Pilliga Outwash DSF may be the closest equivalent.

Rating: 3
While spatial replication was low, temporal replication was excellent. The need to apply a conversion factor adds uncertainty. The extent to which Hawkins' forests resemble the Pilliga Outwash forests in NSW is unclear.

Rainfall and elevation: Hawkins (1966) does not provide figures for these parameters. Nearest weather station may be Sarat where average annual rainfall is 579 mm (130 years of data, 246 m asl).

11.6 Curtis (1975) cited by Bevege (1977)

Bevege (1977) cites a UNE honours thesis by Curtis (1975), which apparently has litter load data for cypress pine woodland in the Pilliga. According to Bevege (1977), litter load was 7.3 t/ha. Assuming steady state and no cut-off, this gives an estimate of 5.9 t/ha for *Limit*, for litter particles < 6 mm.

Rating: 4
I have not yet accessed this thesis, which is not available for loan. Information on location, methods and size cut-off is presently lacking.

11.7 Synthesis and suggested values for Phoenix

Figures for litter in shrub/grass DSF, from all the studies outlined in the three chapters covering this subformation, are summarized in Table 32. Because so little data is available for classes in this formation, particularly east of the Divide, I have included the figure for fuel load in Cumberland DSF extrapolated from litter depth data collected as part of the UoW fuel hazard study (Section 10.3). I've given this study a confidence rating of 3, as fuel load was not measured directly.

Table 32. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation in the shrub/grassy DSF formation. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Van Loon and Love (1971)	Pilliga Outwash DSF		5.2		2
Hawkins (1966)	Pilliga Outwash DSF	1.5			3
Curtis (1975)	Pilliga Outwash DSF		5.9		4
Weighted mean	**Pilliga Outwash DSF**	**1.5**	**5.4**	**0.26**	
Guinto *et al.* (2001)	Clarence DSF		15.6		3
UoW fuel hazard project	Cumberland DSF		6.8		3
Watson (1977)	New England DSF	4.2			3
March and Watson (2007)	Upper Riverina DSF	2.2			3
Adams and Attiwill (1986)	Upper Riverina DSF	2.5	11.9	0.21	3
Weighted mean	**Shrub/grass DSF, all except Pilliga Outwash DSF**	**3.0**	**11.4**	**0.28**	
Weighted mean	**Shrub/grass DSF, all**	**2.6**	**9.0**	**0.29**	

There is some indication in Table 32 of reduced litter fall as rainfall declines from east to west, and trees other than eucalypts increase in abundance. On the other hand, *k* values across the formation appear fairly consistent. If *k* holds steady across classes, *Limit* will increase with *L*. It may therefore be appropriate to designate more than one fuel type within this subformation. Needless-to-say, lack of data make it difficult to decide how best to do this.

Data availability is greatest in the most western of the shrub/grass DSF classes, Pilliga Outwash DSF. It seems likely that standing litter load in this forest type is low. Both existing datasets, Curtis (1975) cited by Bevege (1977) and Van Loon and Love (1971), are in close agreement. Van Loon and Love (1971) mention that the fuel on their sites would be insufficient to support a running fire except under conditions of very high to extreme fire danger. This analysis concurs with other reports of the dampening effect of cypress pine on flammability (Cohn *et al.* 2011). That major fires can occur, however, is attested by events in 1997 and 2006.

In the absence of further information, I suggest parameterising the Pilliga Outwash forests separately to the rest of the shrub/grass subformation. Using figures from the weighted means for this class, and rounding, gives a value for *Limit* of 5.5 t/ha, with *k* = 0.25. This is for litter alone. In the absence of data on fuel remaining after a fire, I suggest setting *Initial* at 0.5 t/ha.

As to near-surface fuel, Van Loon and Love (1971) recorded an average of 0.29 t/ha of grass in their study plots, in a year when grass growth was particularly prolific. I suggest increasing *Limit* to 6.0 t/ha, for litter + near-surface fuel together, and leaving *Initial* and *k* unchanged.

Elevated fuel load in Pilliga Outwash DSF is likely to vary depending on the state of cypress pine and bulloak regeneration. Referring again to Van Loon and Love (1971), suggested parameters are: *Initial* = 0 t/ha, *Limit* = 1.0 t/ha, *k* = 0.20.

Until more data becomes available, I suggest, for all other classes in the shrub/grass DSF subformation, using figures for litter close to those of the weighted mean derived from studies other than those in Pilliga Outwash DSF in Table 32: *Limit* = 11.0 t/ha, *k* = 0.30. Again in the absence of data on fuel remaining after a fire, I suggest setting *Initial* at 1.0 t/ha.

Empirical data on near-surface and elevated fuel, for classes in this subformation other than Pilliga Outwash DSF, is so far entirely lacking. I suggest increasing *Limit* by 1.0 t/ha to account for near-surface fuel, and again leaving *Initial* and *k* unchanged.

Assuming somewhat higher shrub density in these classes relative to Pilliga Outwash DSF, suggested parameters for elevated fuel are: *Initial* = 0 t/ha, *Limit* = 2.0 t/ha, *k* = 0.20.

Suggested parameters for all vegetation classes in the shrub/grass subformation of dry sclerophyll forests are summarized in Table 33, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 8.

Table 33. Summary of suggested values for negative exponential model parameters, for both the shrub/grass subformation of dry sclerophyll forests in general, and for the classes in this subformation on the western slopes and plains in particular. NS, near-surface. *r = Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	**Fuel layer**	***Initial***	***k***	***Limit***	***r***
Pilliga Outwash DSF	Litter	0.5	0.25	5.5	5.0
	Litter + NS	0.5	0.25	6.0	5.5
	Elevated	0.0	0.20	1.0	1.0
Other shrub/grass DSF classes	Litter	1.0	0.30	11.0	10.0
	Litter + NS	1.0	0.30	12.0	11.0
	Elevated	0.0	0.20	2.0	2.0

11.8 Knowledge gaps

Of the three vegetation classes addressed in this chapter, data can only be considered adequate for one, Pilliga Outwash DSF. No studies in North-west Slopes Dry Sclerophyll Woodland were located. And while some data for Upper Riverina DSF does exist, the very different values for litter load reported by March and Watson (2007) and Adams and Attiwill (1986) point to a need for further research across the range of this forest type in NSW.

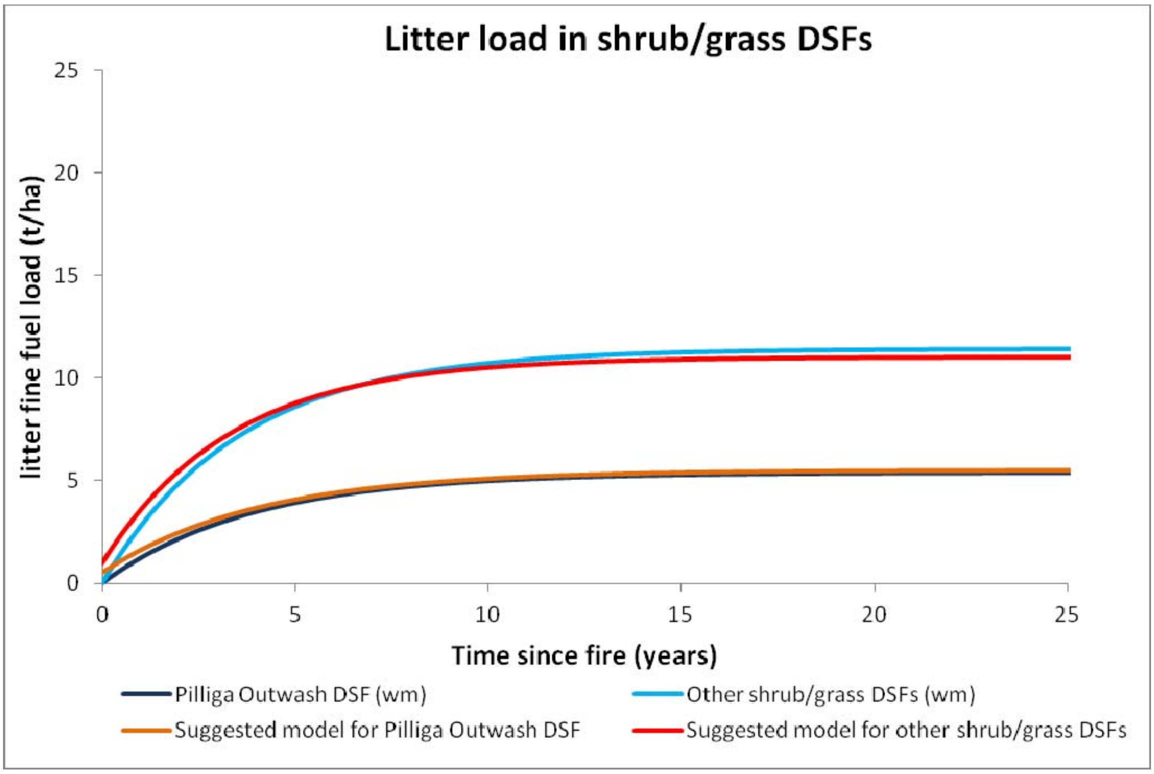

Figure 8. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in Pilliga Outwash and other shrub/grass Dry Sclerophyll Forest classes. wm, model based on weighed means derived from the literature (Table 32), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested models are given in Table 33; see text for explanation of crosswalk from literature to suggested models.

12. Shrubby dry sclerophyll forests east of the Divide

12.1 Introduction

This chapter and the two that follow address dry sclerophyll forests in Keith's shrubby subformation. Shrubby dry sclerophyll forests occur on relatively infertile soils. These may be shallow soils of rocky areas, such as those derived from Sydney's Hawkesbury sandstone. Or they may be the deeper sandy soils of coastal dune-fields or alluvial plains. I have divided these forests into three categories: those occurring primarily east of the Great Divide (this chapter), those found on the tablelands (Chapter 13), and those on the western slopes and plains (Chapter 14).

Table 34. Vegetation classes in the shrubby dry sclerophyll forest subformation, which occur predominantly east of the Great Divide.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Coastal Dune DSF	142-3	Coastal dune fields north from Jervis Bay, including in coastal reserves eg Yuraygir, Bundjalung and Broadwater	moderate
North Coast DSF	144-5	Sandstone-derived soils of coastal ranges mostly between Coffs Harbour and Ballina	moderate
Sydney Coastal DSF	146-7	Sandstone-derived soils in areas of relatively high rainfall (> 950mm) around Sydney, up to 700 m asl	large
Sydney Hinterland DSF	148-9	Sandstone-derived soils in the greater Sydney region where rainfall falls below 950 mm.	large
Sydney Sand Flats DSF	150-1	Sandy alluvial soils in the vicinity of Sydney and Newcastle	small
South Coast Sands DSF	152-3	Young coastal dunes south of Sydney	small
South East DSF	154-5	Dominant vegetation type of coastal lowlands, ranges and escarpment of southern NSW. Occurs on shallow, infertile soils derived from sedimentary or granitic substrates.	large
Southern Wattle DSF	156-7	Small patches in two disjunct locations: on coastal foothills in south-east of the state, and around Byadbo.	small

Of the 14 shrubby DSF vegetation classes identified by Keith (2004), eight occur predominantly east of the Divide (Table 34). Of these, five occupy a substantial geographic area:

- In the north-east: Coastal Dune and North Coast DSF
- Around Sydney: Sydney Coastal and Sydney Hinterland DSF
- In the south-east: South East DSF

Quite a few studies provide insight into fuel dynamics in these forests.

Three curves for dry sclerophyll forest around Sydney have been developed (Van Loon 1977; Conroy 1993; Morrison *et al.* 1996). All include shrubs, and all were derived from surveying sites at a range of times after fire. For Sydney Coastal DSF, supplementary data can be found in studies by Denham *et al.* (2009) and Bewick (1994). Additionally, a study by Lamb (1985) illuminates litter dynamics in two vegetation communities near Narrabeen Lakes on Sydney's northern beaches.

North of Sydney, Fox *et al.* (1979) studied litter load in coastal forest near Seal Rocks, fitting the Olson curve to data from various times-since-fire, while Chaffey and Grant (2000) measured fuel load of litter and standing vegetation. To augment understanding of what may occur in coastal dry sclerophyll forest in the north of the state, several studies from south-east Queensland are also summarized in this chapter.

To the south, Bridges (2005) and Turner *et al.* (1992) provide figures for standing litter load and litter fall in South East DSF, while supplementary information from studies across the border in East Gippsland also provide clues.

12.2 Conroy (1993)

Conroy's study of fuel development in a range of vegetation types around Sydney has already been described (Sections 2.3, 3.2). Conroy (1993) called his second group of sites with an overstorey of sclerophyll trees 'woodland', a category which included sites with trees > 10 m high and canopy cover of 10 - 30%. I have allocated this curve to the Sydney Coastal DSF class because this is the common dry sclerophyll forest type of the Sydney area in general, and in Ku-ring-gai Chase National Park, where many of Conroy's sites were located, in particular. However it is possible that some data were collected in other vegetation classes. Shrubs up to 4 m were included, and a 6 mm cut-off for fine fuel was used.

Conroy (1993) provides summary figures for six time-since-fire categories: 0-1 year, 1-3 years, 3-6 years, 6-10 years, 10-20 years and >20 years. Presumably these points represent mean values for a number of sites in each category; 23 'woodland' sites were assessed overall. However raw data for individual sites is not provided.

The model fitted by Conroy (1993), presumably to the raw data, does not include a term for *Initial*. The values for total fine fuel (litter, herbs, and shrubs all in together) were: *Limit* = 23.57, $k = 0.19$ (Conroy 1993:83).

Separate figures for litter, herbs, and shrubs, for each time-since-fire category, are also given (Conroy 1993:83), but curves for individual components are not. I have used these figures to fit curves for litter only, for litter + herbs, for shrubs only, and for herbs only, as well as for total fine fuel. To link fuel load figures to time since fire, I have used category mid-points for the first five categories (eg 8 years for the 6-10 year category). For the >20 year category I used a time-since-fire of 25 years. Both versions of the negative exponential model were fitted. Results are shown in Table 35.

Table 35. Parameters for negative exponential model fitted to data for 'woodland' in Appendix to Conroy (1993:83). Top half of table: model assumes no fuel remains immediately after the passage of a fire. Bottom half of table: model includes a term for fuel remaining immediately after fire. SE in brackets. Significance codes: *** = <0.001; ** = < 0.01; * = < 0.05; . = < 0.1.

	Initial	***Limit***	***k***	**R^2**
Total fine fuel	Not included	22.5 (1.8)***	0.23 (0.06)*	0.92
Litter only	Not included	15.7 (1.3)***	0.22 (0.06)*	0.91
Litter + herbs	Not included	17.7 (1.4)***	0.23 (0.06)*	0.92
Shrubs only	Not included	4.9 (0.7)**	0.24 (0.11)	0.77
Herbs only	Not included	2.0 (0.2)**	0.35 (0.15)	0.82
Total fine fuel	3.8 (2.0)	23.3 (1.8)**	0.17 (0.05)	0.96
Litter only	3.0 (1.0)	16.6 (1.2)***	0.14 (0.04)*	0.98
Litter + herbs	3.2 (1.3)	18.6 (1.3)***	0.15 (0.04)*	0.97
Shrubs only	0.7 (1.2)	4.9 (0.9)*	0.20 (0.16)	0.79
Herbs only	0.0 (0.6)	2.0 (0.3)**	0.34 (0.24)	0.82

Note that:

- For all variables which include litter, the version of the model that includes a term for *Initial* returns a higher R^2 value than the version without this term. However the standard errors around the terms for *Initial*, are high.

- Model fit for shrubs, and to a lesser extent for herbs, is not as good as that for components which contain litter. *k* values for shrubs and herbs are not significant.

- Figures for *Limit* are fairly consistent, whichever form of the model is used, and SE is low.

- Inclusion of a term for *Initial* lowers *k*. SEs for *k* are moderately high.

- Input figures used here, from the appendix of Conroy (1993), are not the same as those shown in the bar chart on p77. I have assumed the figures in the appendix are correct, as they accord with those shown in the graph on p79, and those in Conroy (1996).

Taking the values for litter only from fitting equation (1), ie *Limit* = 15.7 t/ha, *k* = 0.22, average annual litter fall (*L*) would be 3.5 t/ha. Taking the values from fitting equation (3), ie *Limi*t = 16.6 t/ha, *k* = 0.14, average annual litter fall (*L*) would be 2.3 t/ha. I have used the equation (3) parameters in Table 37.

For litter + herbs, equation (3) gives the following values: *Initial* = 3.2 t/ha, *Limit* = 18.6 t/ha, *k* = 0.15. For shrubs, *Initial* = 0.7 t/ha, *Limit* = 4.9 t/ha, *k* = 0.20.

Rating: 2
The number of points in this study is impressive, as is the thoroughness of methods used to collect data at each site. However in my reworking I have used averages for six time-since-fire categories, rather than the original data. There is also some uncertainty about whether all sites are from the one vegetation class.

Rainfall and elevation: See Section 2.3.

12.3 Van Loon (1977)

Van Loon (1977) carried out this fuel load study in the Blue Mountains, in five widely-dispersed areas. Information on species composition, which is supplied in an appendix, is insufficiently detailed to allocate sites between the two possible DSF vegetation classes, Sydney Coastal DSF and Sydney Montane DSF, which is considered in the next chapter. All sites were dominated by eucalypts, and had a diverse shrubby understory. From mapping in Keith (2004) it seems likely that Sites 2, 3 and 5 (at Lawson and Woodford) supported Sydney Coastal DSF, while Sites 1 and 4 (Shipley Plateau, Bells Line of Road near Mt Wilson) may have supported the latter vegetation type.

Sites were surveyed twice, in 1970 and 1974, giving data for 10 times-since-fire ranging from 1.8 to 22.8 years. Samples included litter, herbs and shrubs, with particles up to 25 mm in diameter collected. Van Loon (1977) provides figures for various components, allowing calculation of values for litter alone, for "grasses, ferns, and low herbaceous vegetation" up to 0.9 m ('herbs'), and for understorey vegetation ('shrubs'). Because the weight of the 6-25 mm component is identified separately, that of the component < 6mm can also be identified. Although graphs showing development of fuel load with time-since-fire are provide in Van Loon's paper, models are not explicitly fitted. Raison *et al.* (1983) took this step, for particles < 25 mm.

I have extracted data for fuel elements < 6 mm and fitted both versions of the model for total fine fuel, litter only, litter plus herbs, herbs only, and shrubs (Table 36). Initially, I used all 10 points outlined in Van Loon (1977), however I also fitted the models to a 9-point data set, omitting one point that Van Loon (1977) considered 'anomalous' because fuel load at this site was lower in 1974 than in 1970.

Table 36. Parameters for negative exponential model fitted to data for fuel elements <6 mm in diameter, in Van Loon (1977). Top half of table: model assumes no fuel remains immediately after the passage of a fire. Bottom half of table: model includes a term for fuel remaining immediately after fire. Lines in plain type fitted to 10 data points; lines in italics fitted to 9 data points (see text). SE in brackets. Significance codes: *** = <0.001; ** = < 0.01; * = < 0.05; . = < 0.1.

	Initial	***Limit***	***k***	R^2
Total fine fuel	Not included	18.0 (2.2)***	0.14 (0.04)**	0.79
	Not included	*18.5 (1.4)****	*0.15 (0.03)****	*0.92*
Litter only	Not included	11.4 (0.13)***	0.17 (0.05)**	0.77
	Not included	*11.8 (1.0)****	*0.17 (0.03)***	*0.88*
Litter + herbs	Not included	13.2 (1.4)***	0.20 (0.06) *	0.71
	Not included	*14.0 (0.8)****	*0.19 (0.03)****	*0.91*
Herbs only	Not included	2.0 (0.4)***	0.49 (0.44)	0.10
	Not included	*2.3 (0.4)****	*0.34 (0.20)*	*0.28*
Shrubs only	Not included	Neg exp model	not appropriate	
	Not included	*Couldn't fit it*		
Total fine fuel	5.1 (2.0)*	34.7 (39.8)	0.03 (0.05)	0.85
	3.2 (1.8)	*21.1 (3.4)****	*0.08 (0.04)*	*0.94*
Litter only	1.8 (2.3)	12.6 (2.8)**	0.11 (0.08)	0.78
	- 0.2 (2.3)	*11.8 (1.1)****	*0.17 (0.07)**	*0.88*
Litter + herbs	3.4 (2.8)	15.6 (4.4)**	0.09 (0.08)	0.73
	0.3 (2.3)	*14.1 (1.0)****	*0.19 (0.06)**	*0.91*
Herbs only	Couldn't fit it			
	0.5 (1.8)	*2.4 (0.5)***	*0.25 (0.37)*	*0.29*
Shrubs only	Couldn't fit it			
	Couldn't fit it			

For all variables which included litter, removing the anomalous point from the data set resulted in better model fit. And while adding a term for *Initial* gave marginal improvements in R^2 values, standard error for this term was generally high. SEs for *Limit* were also higher under equation (3) than equation (1), particularly for the 10-point version of total fine fuel. For litter only, and litter + herbs, the 9 and 10 point versions of both equations (1) and (3) were consistent, in part because values for *Initial* approximated 0 in equation (3), which of course is the assumption in equation (1).

Choosing the 9-point version of equation (1) to exemplify parameters for litter load < 6 mm gives a value for *Limit* of 11.8 t/ha, and a value for *k* of 0.17. Thus the estimated value for *L* would be 2.0 t/ha.

How do these values compare with those derived from Conroy's data? *Limit* and *L* are somewhat lower, while Van Loon's *k* falls between the values derived from the two different forms of the models using Conroy's data points.

For litter + herbs, the 9-point version of equation (3) gives: *Initial* = 0.3 t/ha (cf 3.2 t/ha from Conroy), *Limit* = 14.1 t/ha (Conroy's value was 18.6 t/ha), *k* = 0.19 (Conroy's value was 0.15).

For shrubs and herbs alone, the model either could not be fitted, or if it was, R^2 values were very low. Van Loon (1977:8) fits two straight lines to his shrub data, the first one, to about 5 years post-fire, dropping, and the second rising steadily after that. "It can be seen that after a 'settling down' period of about 5 years in which the weight of mainly killed understorey is reduced, a virtually linear increase in understorey weights occurs with time, at least for the period under review." Patterns in the herb data were difficult to discern. The one parameter which appears relatively clear is *Limit*, which was modelled as 2.0 - 2.4 t/ha.

Rating: 2
Data were carefully collected and reported. However the number of points was not large, and fuel load on one site was considerably lower in 1974 than 1970, suggesting either a problem with measurement, or unrecorded site disturbance.

Rainfall and elevation: Van Loon (1977) does not provide information on rainfall or elevation. I've used figures for Mt Victoria, where mean annual rainfall is 1061 mm (119 years of data), and elevation is 1064 m asl.

12.4 Denham *et al.* (2009)

Denham *et al*. (2009) measured litter load in four dry sclerophyll forest/woodland sites between Colo Vale and Bargo in NSW, on two occasions two years apart. Measurements covered the early post-fire years (0.5 to 5.0 years after fire). Prominent plant species included *Corymbia gummifera, Banksia serrata, Banksia spinulosa, Persoonia levis* and *Telopea speciosissima*. Species complement and location place these sites in either the Sydney Coastal or Sydney Hinterland DSF class.

While the data collected during this study is insufficient to fit a curve, the points can be compared with the curves for litter derived from the work of Conroy (1993) and Van Loon (1977); see Figure 9. As Denham *et al.* (2009) do not specify a size cut-off, the 0.82 conversion factor has been applied. Points for sites surveyed by Denham *et al.* (2009) mostly fall either very close to the Conroy curve, or between this curve and the one generated from Van Loon's data.

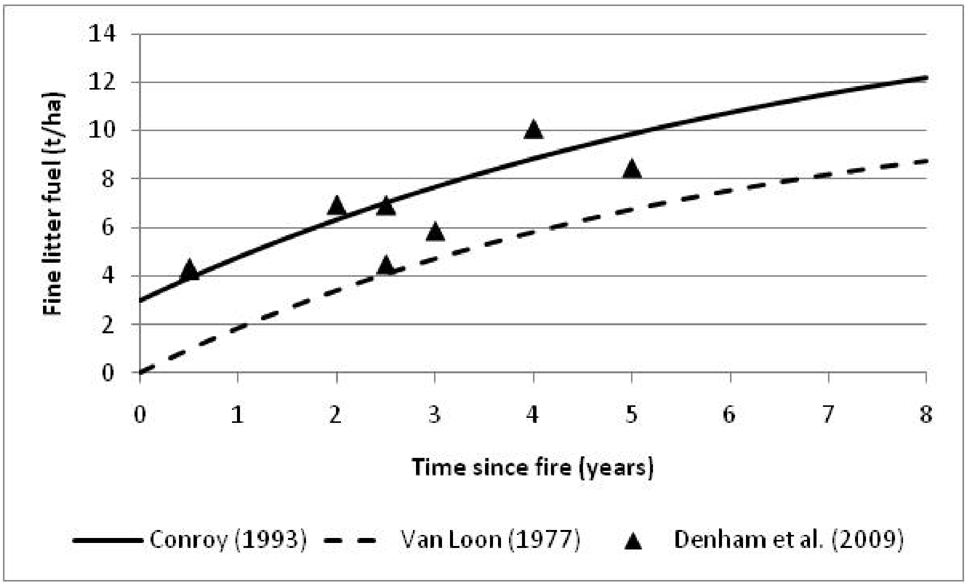

Figure 9. Comparison of litter load figures (particles <6 mm) derived from dry sclerophyll forest/woodland sites sampled by Denham *et al.* (2009), and curves for litter accumulation derived from work by Conroy (1993) and Van Loon (1977). The Denham *et al.* (2009) point at 0.5 years post-fire is in fact two points very close together, from two different sites.

Rating: 3
The greatest limitation of this study, for current purposes, is the lack of a size cut-off. It may be that the 0.82 conversion factor over-estimates fine fuel in recently-burnt sites where remaining particles may be larger, on average, than those in the later post-fire years.

Rainfall and elevation: Denham *et al.* (2009) do not provide information on rainfall or elevation. Nearest weather station is probably Mittagong (Beatrice Street) where mean annual rainfall is 892 mm (111 years of data), and elevation is 635 m asl.

12.5 Morrison *et al.* (1996)

In an article which examined conflicts between fire regimes for biodiversity and property protection, Morrison *et al.* (1996) present yet another curve for fuel development in woodland on sandstone-derived soils near Sydney. The location of this study, in Ku-ring-gai Chase National in Sydney's north, places the sites with trees (Morrison *et al.* surveyed both woodland and heath) in the Sydney Coastal DSF class.

The curve derived by Morrison *et al.* (1996) is very different to those presented by Conroy (1993) and Van Loon (1977): the value for *Limit* in Morrison *et al.* (1996) is 43.1 t/ha, for all fuel elements together (6 mm cut-off), *Initial* is 6.8 t/ha and *k* is 0.08. However when fitting their curve these authors omitted two points, from sites unburnt for about 30 years, which would have brought the asymptote down considerably. The highest value recorded in any of the sites surveyed by Morrison *et al.* (1996) was approximately 30 t/ha, at 15 years post-fire, while the two points at around 28 and 29 years post-fire returned values of approximately 18 and 22 t/ha. The authors themselves note that their data "suggest that the fine fuel load in woodland communities never reaches a steady state, the maximum load being 30-35 $t.ha^{-1}$ approximately 20 years after a fire, which is then followed by a decline in fuel load through time... presumably due to senescence and non-replacement of adults of the shorter-lived species."

The twelve sites surveyed by Morrison *et al.* (1996:168) were all on ridgetops or plateaus, from "a vegetation mosaic of intergrading closed-scrub/scrub-heath/low woodland/low open-woodland", after low intensity fires. Ten replicate quadrats were surveyed at each site, in each of two vegetation classes, woodland and shrubland (only the woodland curve is considered here). This suggests that the woodland sites were all towards the small tree/high shrub cover end of the considerable spectrum encompassed by the Sydney Coastal DSF class (Keith 2004:146).

Break-down by components is not given in the paper.

Morrison *et al.* (1996) also present equations for fuel accumulation after fires of moderate and high intensity. Each of these curves is based on five sampling times all within seven months of a wildfire, at two sites. Curve fit is poor (R^2 values of 0.48 and 0.53 for moderate and high intensity fires respectively). Each has a value for *Limit* of around 30 t/ha, and *k* values of 0.07 and 0.06.

Rating: 4
The fact that points were omitted when fitting this curve, which reaches an asymptote greatly in excess of the highest fuel load recorded in study sites, strongly suggests that the equation as it stands is not realistic.

Rainfall and elevation: Morrison *et al.* (1996) do not provide information on rainfall or elevation. Nearest weather station is probably Pennant Hills where mean annual rainfall is 1070 mm (70 years of data), and elevation is 173 m asl.

12.6 Bewick (1994)

Bewick (1994), one of the authors of the study by Morrison *et al.* (1996) above, studied fuel load in Ku-ring-gai Chase National Park shortly after a wildfire. Sites burnt at moderate intensity were compared with those burnt at high intensity, determined from vegetation condition after the fire.

While Bewick (1994) presents a chart showing post-fire fuel load (data from samples taken at 2 and 3 months post-fire was combined), extracting information on elements < 6 mm in diameter is difficult. However figures on the percentage of fine fuel removed by the fire can be used to calculate this quantity.

In sites burnt at high intensity, remaining material was almost all classified as 'charcoal', which included "both settled ash and chunks of charcoal from the remains of burnt sticks, logs, and branches" (Bewick 1994:48). Presumably much of this was over 6 mm; in calculating proportion removed, Bewick (1994) does not consider it fine fuel. In patches burnt at high intensity, 99.9% of fine fuel was removed.

In sites burnt at moderate intensity, remaining material included a wider range of components. 87.9%, or 2.24 t/ha, of pre-fire fine fuel remained.

Bewick (1994) also gives a figure for total fine fuel prior to the fire, in woodland burnt approximately 28 years previously. This figure, which included litter, herbs and shrubs together, was 18.5 t/ha.

Rating: 2
This study provides useful information on values taken by *Initial*. Some questions about the identity of 'fine fuel' slightly limits the usefulness of this study for current purposes.

Rainfall and elevation: This study was located in the same patch of vegetation as Morrison *et al.* (1996); see Section 12.5.

12.7 Lamb (1985)

Lamb (1985) measured litter fall, litter decomposition, and steady state litter load in two adjacent communities near Narrabeen Lagoon in Sydney. Although measurements included particles up to, and over, 26 mm in diameter, the breakdown given in Lamb's paper allows calculation of parameters for particles < 6 mm.

Litter load was sampled twice, in 1976 and in 1981. Figures for each of the two years were very similar, indicating that steady state had almost certainly been reached. *k* was derived in two ways: by direct measurement, and from *L* and *Limit*. Again, very similar figures were obtained.

This study did not address fuel components other than litter.

Community 1 was located on a hillside in sandy soil. Dominant trees were *Angophora costata*, *Eucalyptus gummifera* and *E. umbra*, placing this site in Keith's Coastal Dune DSF class. In this community, for litter particles < 6 mm, *Limit* averaged 18.15 t/ha, *L* was 5.1 t/ha and *k* was 0.28.

Community 2, which occupied an old sandy alluvial fan below Community 1, was dominated by *E. botyroides* and *A. floribunda*, placing it in Keith's South Coast Sands DSF class. In this community, for litter particles < 6 mm, *Limit* averaged 15.6 t/ha, *L* was 6.5 t/ha and *k* was 0.42.

Lamb (1985) attributes the higher *k* value in Community 2 relative to Community 1 to greater water availability, due perhaps to greater soil depth, and a water table close to the surface. Nutrient status in the two communities was similar.

Rating: 1
Parameters arising from this study were measured or derived in ways which allowed their accuracy to be checked. Agreement was remarkable.

Rainfall and elevation: Lamb (1985) does not provide figures for rainfall or elevation. Mean annual rainfall in Manly, on the coast approx 10 km south of Narrabeen, is 1219 mm (49 years of data). Here, elevation is "unknown" – I've used a nominal value of 25 m for this coastal site.

12.8 Fox *et al.* (1979)

Fox *et al.* (1979) sampled litter load < 25 mm in sites with varying times-since-fire in shrubby forest on a sand mass inland from Seal Rocks. Dominant trees were *Angophora costata* and *Eucalyptus pilularis*, putting this vegetation type in Keith's Coastal Dune DSF class.

This study did not address fuel components other than litter. No break-down into size-classes is given.

Equation (1), which was fitted to the data (for particles > 25 mm) by the authors, gave clear parameters with low SEs: *Limit* was 16.8 (± 0.2) t/ha, while *k* was 0.31 (± 0.01). From these figures, the authors used equation (2) to estimate *L*, at 5.2 t/ha.

Using the conversion factors outlined above, estimated values for particles < 6 mm in diameter become: *Limit* = 16.8 x 0.87 = 14.6 t/ha, *L* = 5.2 x 0.94 = 4.9 t/ha. Calculating *k* from these values gives 0.33.

Rating: 2
The number of points used in this study was considerable, and SEs for model parameters were low. However some error has probably been introduced in the conversion process (< 26 mm to < 6 mm).

Rainfall and elevation: Mean annual rainfall given in the paper was 1390 mm. Nearest weather station on the coast is Nelson Bay, where annual rainfall averages 1351 mm (110 years of data), and elevation is 25 m asl.

12.9 Chaffey and Grant (2000)

Chaffey and Grant (2000) measured fuel load of litter, and also of standing vegetation to 2.5 m, in a series of sites in Coastal Dune DSF north of Newcastle. While most sites were in various stages of rehabilitation after sand mining, one site was located in intact forest last burnt 17-19 years previously. Total fuel load at this site averaged around 17 t/ha; of this, 13.5 t/ha was litter.

Applying the 0.87 conversion factor (these researchers used a 25 mm cut-off), and assuming steady state, gives an estimate for *Limit*, for litter particles < 6 mm, of 11.8 t/ha. Chaffey and Grant's figures also tell us that near-surface plus elevated fuel averaged 3.5 t/ha. As this included stems between 6 and 25 mm, fine fuel load would have been something less than 3.5 t/ha.

Rating: 3
Only a single point from this study was relevant for current purposes. My assumption that the site had reached steady state cannot be confirmed. Use of a conversion factor adds uncertainty.

Rainfall and elevation: Chaffey and Grant (2000) do not include figures for these parameters. Nearest weather station is probably Williamtown RAAF, where rainfall averages 1121 mm per annum (63 years of data) and elevation is 9 m asl.

12.10 Rogers and Westman (1977)

Rogers and Westman (1977) measured litter fall at a single sandmass site on North Stradbroke Island in south-east Queensland. Litter load was also assessed, once, at what was probably seven years post-fire. To calculate fuel curve parameters the authors assumed the site had reached steady state. This study did not include a size cut-off.

I have classified this site as Coastal Dune DSF: Keith (2004:142) notes that large areas of this vegetation class occur on North Stradbroke. Dominant trees were *Eucalyptus signata* and *E. umbra* as well as smaller numbers of *Tristania conferta* (now *Lophostemon confertus*), *Angophora* species including *A. costata*, and *Banksia aemula*. The understorey consisted of sclerophyll shrubs, herbs and bracken. Canopy foliage projective cover was 52% (Rogers and Westman 1977).

Total litter load was 27.0 t/ha, 32% (8.6 t/ha) of which was classified as 'wood', a category which presumably included twigs < 6 mm. Using the 82% conversion factor (Section 1.5.1) gives a value of 22.1 t/ha for fine fuel < 6 mm.

Litter fall was collected for over two years. Mean annual litter fall was 6.43 t/ha, when all components were included; of this, 25% was "twigs and wood." Using the 0.91 conversion factor (Section 1.5.2) gives a value of 5.85 for *L* < 6 mm.

Dividing *L* by *Limit* gives a value for *k* of 0.26.

Rating: 3
This rating reflects the assumption of steady state fuel load, and the limited sampling involved in identifying *Limit* (one site only, one time only). The lack of clear identification of the components of both litter fall and litter load < 6 mm also limits confidence in the figures extrapolated from this study.

Rainfall and elevation: Rogers and Westman (1977) give a figure of 1650 mm for mean annual rainfall, for Point Lookout on the island's east coast: the study site was also on that side of the island. The figure for Point Lookout on the BoM website is 1435 mm, however this is based on only 12 years of data (1977 to 2009). The nearest weather station with a longer dataset is Dunwich, on the island's western shore, where the figure for annual average rainfall is 1604 mm (57 years of data). The authors also provide a figure for elevation of 100 m asl.

12.11 Sandercoe (1989, 1992)

These two papers by Sandercoe report on a fuel sampling program carried out in Cooloola National Park north of Noosa in south-east Queensland in the 1980s. One of several vegetation types surveyed falls neatly into Keith's Coastal Dune DSF class. The overstorey dominant was *Eucalyptus signata* (scribbly gum), with *Corymbia intermedia* (pink bloodwood) also present; the understorey contained a range of sclerophyll species (Sandercoe 1989). Canopy cover was 20% (Sandercoe 1992). Keith (2004) specifically notes that large areas of the northern variant of Coastal Dune DSF occur at Cooloola.

Sampling was carried out at a limited number of sites spread across the catchment, with the same sites resampled each year. All material up to 1.5 m above the ground, and less than 10 mm in diameter, was harvested. Results are reported for all fuel, and for the dead fraction only. Sandercoe (1989) notes that much of the dead material is suspended in the understorey, rather than forming a typical litter layer on the ground.

In Sandercoe (1992) negative exponential models are fitted to points up to 7 years post-fire. In Sandercoe (1989), which is actually the more recent of the two papers, a longer run of post-fire data (to 10 years post-fire) is presented, but models are not fitted. I have therefore re-fitted equation (1) to the data presented in Sandercoe (1989). This form of the negative exponential model is appropriate, as Sandercoe (1992:371) reports that "fuel reduction in most fires at Cooloola is close to 100%."

For all fuel, live and dead, *Limit* is 8.87 t/ha. Using the 0.97 conversion factor gives an estimate for particles < 6 mm of 8.60 t/ha. k is 0.39, with $R^2 = 0.97$.

For dead matter only, *Limit* is 7.45 t/ha, giving an estimate of 7.23 t/ha for particles < 6 mm. k is 0.19, R^2 is 0.94.

Rating: 3
Methods used in the study appear sound, with good spatial replication. Curve fits were good. However restriction of the data to less than 10 years post-fire may mean *Limit* has yet to be attained and may be higher than implied by the available data. Additionally, as Cooloola is approximately 250 km north of the border, relevance to NSW is questionable.

Rainfall and elevation: Sandercoe (1992) notes that the rainfall in Cooloola is approximately 1500 mm. Nearest appropriate weather station may be Toolara Forestry, where mean annual rainfall is 1303 mm (40 yrs of data), and elevation is 49 m asl. I've used these figures as Sandercoe's sites are not coastal, suggesting the 1500 mm figure for annual rainfall may be too high.

12.12 Birk (1979)

Birk (1979) measured litter fall in sandstone-derived North Coast DSF dominated by *Eucalyptus umbra*, *E. baileyana* and *Angophora woodsiana*, in the grounds of Griffith University in Brisbane. Litter collection continued for 18 months. Various types of litter trap were used. Ground-based traps caught an average of 3.2 t/ha of litter per year. There was no size cut-off in this study.

Using the conversion factor of 0.91 gives a value for *L* of 2.91 t/ha.

Rating: 3
Spatial replication involved 13 traps distributed across 3 sites, which is reasonable. However 18 months is not a particularly long time for a litter fall study.

Rainfall and elevation: Mean annual rainfall given in the paper is 1145 mm. Nearby weather stations are Brisbane Regional Office with an annual rainfall of 1150 mm (145 years of data), and Archerfield Airport with 1060 mm (77 years of data). Elevation is given in the paper as 100 m asl.

12.13 Bridges (2005)

Bridges (2005) reports fuel load measurements at various times, over various treatments, in the Eden Burning Study Area experiment carried out by State Forests over 30 years, inland from Eden on the NSW south coast. Vegetation in the experimental area falls into Keith's South East DSF class. Dominant tree species include *E. consideniana*, *E. sieberi*, *E. agglomerata* and *E. muelleriana*, while *Allocasuarina littoralis*, *Epacris impressa*, *Acacia terminalis* and *Platysace lanceolata* feature in the understorey (Bridges 2005).

From the point of view of the current exercise, the most informative fuel load figure is that for unburnt, unlogged forest (UN treatment in Bridges 2005), in 1993. While not guaranteed to represent steady state fuel load, fire in this treatment had been excluded for many years (no wildfire for approximately 20 years, no planned burning for 12 years, and then the burn had been very patchy). I am making the assumption that by this stage, litter load approximated *Limit*.

Fuel was collected in two zones: the more relevant one for current purposes went from ground level to 0.9 m; all material to 25 mm was included. Fuel load was 16.5 ± 1.4 t/ha (Bridges 2005:42, Table 19).

A break-down into components is given graphically. Unfortunately, attempts to extrapolate figures from the graph were not successful as they did not add to 16.5 t/ha. As a proportion, however, litter components < 6 mm (twig06, bark, leaves, misc, charcoal) made up 61% of fuel load in this zone. Using this figure as a conversion factor gives a litter load < 6 mm of 16.5 x 0.61 = 10.1 t/ha.

Data quality: 4
The mismatch between component and overall fuel weights is disconcerting. The figure derived for litter < 6 mm is based on the assumption that the component figures represent correct proportions, which may not be the case. Additionally, steady state has been assumed, but not confirmed.

Rainfall and elevation: Bridges (2005) gives mean annual rainfall as 886 mm. Nearby weather station is Green Cape Lighthouse: average annual rainfall here is 747 mm (61 years data). Elevation is given in the paper, and ranges from 180-440 m, mid-point 310 m asl.

12.14 Turner *et al.* (1992)

This study, which was concerned with estimating biomass turnover, included figures for a single year of litter fall in Yambulla State Forest in the far south-east of NSW. Vegetation in the study catchment falls clearly into the South East DSF class. *E. sieberi* was the dominant tree species, while the understorey included *Acacia falciformis*, *A. terminalis*, *Banksia serrata* and *Persoonia linearis*.

Litter fall over the 12 month period averaged 1.57 t/ha. Although the authors do not mention a size cut-off, ‘twigs' made up only 8% of the total; I have therefore assumed this is all fine fuel. Turner *et al.* (1992) believe, on the basis of previous unpublished estimates, that the figure of 1.57 t/ha is low relative to the average across years, and note that it represents litter fall in a very dry year.

Rating: 3
The main difficulty with this study is the short time over which litter fall was measured. Also although I have assumed all material collected was fine fuel, this may not have been the case.

Rainfall and elevation:
Turner *et al.* (1992) give a figure of 940 mm for average annual rainfall. Elevation in the study catchment ranged from 210 – 471 m, giving a mean of 340 m. The study site lies between Cape Green Lighthouse weather station (738 mm ave annual rainfall, 64 years of data, 20 m asl) and Nalbaugh SF (1184 mm, 39 years of data, 675 m asl, closed in 1977).

12.15 Fogarty (1993)

Fogarty (1993) developed curves (equation (1)) for fuel accumulation using data collected after a range of low intensity fires in what he describes as a wiregrass fuel type, 30 km east of Orbost in East Gippsland, Victoria. Dominant trees were *E. sieberi* and the stringybarks *E. globoidea*, *E. baxteri* and *E. muellerana*. Understorey species included *Tetrarrhena juncea* (wiregrass), bracken, *Hakea sericea* and *Acacia terminalis*. This species complement gives these forests an affinity with Keith’s South East DSF class. Forests were 25-40 year regrowth.

Fogarty (1993) used a 6 mm cut-off, and distinguished elevated from surface fuels. Identifying the boundary between these two categories was sometimes difficult, as much litter was suspended. Where this was the case, surface fuels were sampled to a depth of 10 cm only.

Curves were:

- Surface fine fuel load: *Limit* = 10.1 t/ha, *k* = 0.19
- Elevated fine fuel load: *Limit* = 5.9 t/ha, *k* = 0.19
- Total fine fuel load: *Limit* = 16.1 t/ha, k = 0.19

Taking the figures for surface fine fuel, *L* can be estimated as 10.1 x 0.19 = 1.92 t/ha.

Rating: 2
This study included a large number of data points (69) across 11 time-since-fire categories, covering a good spread of post-fire years. Use of the 6 mm cut-off precluded the need for conversion factors. Standard errors for model parameters were reasonably low, particularly for the total fine fuel model. However this was not a NSW study so its applicability here is uncertain.

Rainfall and elevation:
Fogarty (1993) does not give figures for these variables. Nearest weather station would be Orbost, where rainfall averages 845 mm per annum (127 years of data), and elevation is 41 m.

12.16 Additional data for South East DSF

Several studies provide additional information on fuels in South East DSF, though data is insufficient to extrapolate curve parameters.

Raison *et al.* (1983) list two data points for *E. sieberi* country around Eden, from a report by Newman (1977). Fuel particle size was < 25 mm. Litter load at 3.0 years post-fire was reportedly 8.8 t/ha, which equates to an estimated 7.66 t/ha for particles < 6 mm when the 0.87 conversion factor is used. Fuel load at over 20 years post-fire was 10.0 t/ha, or 8.7 t/ha for fine fuel.

Relative to the curve for litter particles < 6 mm defined by Fogarty (1993), Newman's value for three years post-fire is high (7.66 versus 4.39 t/ha), while his value for long unburnt country is low.

Buckley (1990) also reports fuel loads from two sites dominated by *E. sieberi* and various stringybarks across the Victorian border near Bemm River. Time-since-fire is not given but was presumably fairly high. A 6 mm cut-off was used. Across the two sites, litter on the forest floor averaged 13.2 t/ha, while elevated fuel averaged 7.6 t/ha. Of the latter, approximately 5 t/ha was contributed by living shrubs while the rest was made up of dead material (eg suspended litter).

The litter load on the forest floor in Buckley's study exceeds the value for *Limit* derived by Fogarty (1993), and is higher than any of his data points.

Buckley (1994) measured fuel load in a 'wiregrass fuel type' near Orbost, Victoria dominated by *Eucalyptus consideniana*, *E. globoidea* and *E. baxteri*. *Banksia serrata* and a mixture of bracken, *Gahnia*, coral fern, shrubs and wire-grass made up the understorey. Tree density was low, due to logging. Time since fire was 24 years. Total fuel load < 6 mm across surface, near-surface and elevated fuel layers averaged 14.4 t/ha. 10.1 t/ha of this total was allocated to elevated fuel; 3 t/ha of this was dead.

12.17 Synthesis and suggested values for Phoenix

Parameters for litter (< 6 mm) are summarized in Table 37; studies which do not clearly distinguish the litter layer from total fuel load (Sandercoe 1989; 1992; Morrison *et al.* 1996) have been omitted. Even within this shrubby dry sclerophyll forest subformation, in the coastal/subcoastal zone, considerable differences are apparent.

The three studies listed at the top of Table 37 were all conducted on sandstone substrates with shallow soils. Here, litter fall at 2-3 t/ha is relatively low, as are *k* values (weighted mean 0.16). Coastal communities on deep sand have considerably higher values for both litter fall (weighted mean 5.6 t/ha) and *k* (0.34). Values for *Limit* tend to be slightly higher than in the sandstone-based communities, although there is overlap: higher litter fall on deep sand tends to push steady state fuel load figures up, while higher decomposition rates push it down. Figures for *Limit*, *L* and *k* in South East DSF appear to have more in common with classes on sandstone-derived substrates, than with those on deep sand, though both litter fall and *Limit* appear to be even lower here than in the more northerly sandstone forests. South East DSF occurs on “shallow, infertile soils derived from sedimentary or granitic substrates” (Keith 2004:155).

Table 37. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies addressing vegetation classes in the shrubby subformation of dry sclerophyll forests which occur predominantly east of the Divide. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4). Weighed mean for Shrubby DSF on deep sand includes Coastal Dune and South Coast Sands DSF.

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R’g
Conroy (1993)	Sydney Coastal DSF	2.3	16.6	0.14	2
Van Loon (1977)	Sydney Coastal DSF	2.0	11.8	0.17	2
Birk (1979)	North Coast DSF	2.9			3
Weighted mean	**Shrubby DSF on sandstone**	**2.3**	**14.2**	**0.16**	
Lamb (1985)	Coastal Dune DSF	5.1	18.2	0.28	1
Fox *et al.* (1979)	Coastal Dune DSF	4.9	14.6	0.33	2
Chaffey and Grant (2000)	Coastal Dune DSF		11.8		3
Rogers and Westman (1977)	Coastal Dune DSF	5.8	22.1	0.26	3
Weighted mean	**Coastal Dune DSF**	**5.2**	**16.8**	**0.31**	
Lamb (1985)	South Coast Sands DSF	6.5	15.6	0.42	1
Weighted mean	**Shrubby DSF on deep sand**	**5.6**	**16.5**	**0.34**	
Bridges (2005)	South East DSF		10.1		4
Turner *et al.* (1992)	South East DSF	1.6			3
Fogarty (1993)	South East DSF	1.9	10.1	0.19	2
Weighted mean	**South East DSF**	**1.8**	**10.1**	**0.18**	

These differences suggest that the vegetation classes addressed in this chapter could profitably be divided into at least three fuel types:

- Shrubby DSF communities on shallow, sandstone-derived soils: Sydney Coastal DSF, Sydney Hinterland DSF, and North Coast DSF

- Shrubby DSF communities on deep sandy soils: Coastal Dune DSF, South Coast Sands DSF, and Sydney Sand Flats DSF

- Shrubby DSF communities of the south-east: South East DSF and Southern Wattle DSF.

Note that this allocation includes two vegetation classes, Sydney Sand Flats DSF and Southern Wattle DSF, for which no fuel load data is available. When data for these communities, which both occupy a limited area, becomes available, this allocation may change.

We turn now to suggested fuel parameters for Phoenix and other management applications, starting with shrubby DSF communities on shallow, sandstone derived soils.

For litter alone, weighted mean values are 14.2 t/ha for *Limit*, and 0.16 for *k* (Table 37); I therefore suggest setting *Limit* at 14.5 t/ha and *k* = 0.16. As to *Initial*, the study by Bewick (1994) suggests just over 2.0 t/ha of litter fuel remain after a fire of moderate intensity, in Sydney sandstone woodland, while after a high intensity fire virtually no litter remains. These quantities are in the same ball-park as figures for *Initial* derived through fitting equation (3) to data from Conroy (1993) and Van Loon (1977), which range from zero to 3.0 t/ha. I suggest setting *Initial* for litter between these figures, at 1.5 t/ha.

Curves for litter + herbs in sandstone-based Sydney forests and woodlands can be derived from the work of Conroy (1993) and Van Loon (1977) (Sections 12.2 and 12.3). For *Limit*, Van Loon's data gives a value of 14.1 t/ha, where Conroy's gives 18.6 t/ha. I suggest using a mean of 16.4 t/ha (this adds 1.9 t/ha for herbs to the figure for litter alone). For *k*, Van Loon's data gives a value of 0.19, where Conroy's gives 0.15. Again I suggest using the mean of 0.17. For *Initial*, Van Loon's data gives a value of 0.3 t/ha, where Conroy's gives 3.2 t/ha; the mean is 1.7 t/ha, adding 0.2 t/ha to the figure for litter alone, which seems reasonable.

Turning to elevated fuel: this element of the fuel array was also measured by both Van Loon (1977) and Conroy (1993). Attempts to fit a negative exponential model to Van Loon's data were unsuccessful. The weight of shrubs per unit area tended to fall over the initial post-fire years, then rise in a linear fashion. This may be a common occurrence in shrubby DSF, as the dead stems and twigs remaining immediately after a fire progressively collapse into the surface and near-surface layers, to be replaced by live regrowth. In using the negative exponential model for elevated fuel, Phoenix is modelling the situation in simplified form. I suggest using the figures derived from fitting equation (3) to the Conroy data, even though fit is not all that good: *Initial* = 0.7 t/ha, *Limit* = 4.9 t/ha, *k* = 0.20.

With *Limit* for litter + herbs at 16.4 t/ha, and for shrubs at 4.9 t/ha, the total for fine fuel in both these layers would be 21.3 t/ha. While this is somewhat lower than the highest values recorded by Morrison *et al.* (1996), which were around 30 t/ha, it accords well with the value for *Limit* calculated from Conroy's data, while being somewhat higher than that derived from Van Loon (1977), and the figure in Bewick (1994), for all fuel layers in long unburnt sites in Ku-ring-gai Chase National Park, of 18.5 t/ha.

We now move on to the very different deep sand communities, with their higher levels of litter fall and decomposition.

For litter alone, weighted mean values, for equation (1), are:

- for *Limit*, 16.8 t/ha for Coastal Dune DSF, falling slightly to 16.5 t/ha when the single study in South Coast Sands is added.

- For *k*, 0.31 for Coastal Dune DSF, rising slightly to 0.34 when the South Coast Sands DSF study is added.

While we have no direct measurements of *Initial* in the deep sand classes, the excellent fit of equation (1) in the study by Fox *et al.* (1979) suggests that it is not high. I suggest: *Initial* = 1.0 t/ha, *Limit* = 17.0 and *k* = 0.32.

The only clue to fuel load of herbs and shrubs in the deep sand communities comes from the study by Chaffey and Grant (2000), which suggests that these components, together, do not exceed 3.5 t/ha. If we allocate 1.0 t/ha of this amount to herbs, and 2.5 t/ha to elevated fuel, we can estimate values for the Phoenix surface fuel parameter, which includes near-surface as well as litter fuels. Thus *Limit* becomes 18.0 t/ha. I suggest using the same value for *Initial* as for litter alone (1.0 t/ha). As we have no information as to whether *k* will rise or fall with the addition of near-surface fuel in this forest type, I suggest leaving it at 0.32.

For elevated fuel, in the absence of substantial data, I suggest using: *Initial* = 0.5 (this is slightly lower than the figure for the sandstone communities, as elevated fuel load appears to be lower), *Limit* = 2.5 t/ha (from Chaffey and Grant 2000), and *k* = 0.25 (this is slightly higher than the *k* value for the sandstone communities, as the deep sand vegetation classes are clearly more productive).

It is interesting to observe that these values almost reach those recommended for shrubby wet sclerophyll forests. Litter fall, too, is only slightly lower in the deep sand DSFs (weighted mean 5.6 t/ha) than it is in shrubby WSF (weighted mean 6.7 t/ha). The value for *k*, for surface fuels in coastal deep sand dry sclerophyll forests, is almost double that for shrubby DSF on sandstone-derived soils. This means that fuel load is predicted to rise much more rapidly in deep sand sites.

Note that while I have allocated the Sydney Sand Flats class to this group on the basis of substrate, this allocation may not be appropriate. Sydney Sand Flats forests grow on old alluvial sand deposits in rainshadow areas where both nutrients and precipitation are relatively low. Litter fall may well be lower, and decomposition slower, than in the coastal deep sands sites. Litter depth in a single long-unburnt site in this forest class near Windsor averaged 27 cm; using the figure of 34 kg/m^3 from McCarthy (2004), this translates to a fuel load of 9.2 t/ha, much lower than the recommended value for *Limit* for the deep sands group.

One further comment on fuel dynamics in deep sand shrubby dry sclerophyll forests: both Sandercoe (1989, 1992) and Rogers and Westman (1977) address similar vegetation types in the south-east Queensland region, however the figures for *Limit* arising from these two studies are quite different. While some of the discrepancy almost certainly reflects limitations of and differences between the methods used in the two studies, the canopy also appears to differ. Rogers and Westman (1977) report a canopy foliage projective cover of 52% in their North Stradbroke Island site, while in the Cooloola woodlands studied by Sandercoe (1992) it was only 20%. It may be that litter dynamics vary within these communities.

Finally, what can we say about fuel parameters in the shrubby dry sclerophyll forests of the south-eastern NSW?

For litter alone, weighted mean values, for equation (1), are 10.1 t/ha for *Limit*, and 0.18 for *k*. Again, we have no direct measure of *Initial*; I suggest using a value of 1.0 t/ha, and leaving *Limit* and *k* approximately as for equation (1): *Limit* = 10.0 t/ha, *k* = 0.18.

Data from three Victorian studies, Fogarty (1993), Buckley (1990) and Buckley (1994) suggest that fuel load in the near-surface and elevated layers in the forests of the south-east can be quite high (5.9, 7.6 and 10.1 t/ha in these three studies, respectively). The extent to which these Victorian findings can be generalized to NSW is unknown. In the absence of data I suggest using similar values for *Limit* in the near-surface and elevated layers as used above for the sandstone forests, ie 2 t/ha for herbs, and 5 t/ha for shrubs.

Thus for litter + herbs, I suggest: *Initial* = 1.0 t/ha, *Limit* = 12.0 t/ha, and *k* = 0.19. For elevated fuel I suggest: *Initial* = 0.7, *Limit* = 5.0 t/ha, and *k* = 0.19. The *k* value for both surface and elevated fine fuel in Fogarty's study was 0.19.

Suggested parameters for vegetation classes in the shrubby subformation of dry sclerophyll forests east of the Divide are summarized in Table 38, with a comparison between literature-derived and suggested models for litter fuel presented in Figure 10.

Table 38. Summary of suggested values for negative exponential model parameters for the shrubby subformation of dry sclerophyll forests east of the Divide. NS, near-surface. *r* = *Limit* - *Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	Fuel layer	*Initial*	*k*	*Limit*	*r*
Sydney Coastal DSF, Sydney Hinterland DSF, North Coast DSF	Litter	1.5	0.16	14.5	13.0
	Litter + NS	1.7	0.17	16.4	14.7
	Elevated	0.7	0.20	4.9	4.2
Coastal Dune DSF, South Coast Sands DSF, Sydney Sand Flats DSF	Litter	1.0	0.32	17.0	16.0
	Litter + NS	1.0	0.32	18.0	17.0
	Elevated	0.5	0.25	2.5	2.0
South East DSF, Southern Wattle DSF	Litter	1.0	0.18	10.0	9.0
	Litter + NS	1.0	0.19	12.0	11.0
	Elevated	0.7	0.19	5.0	4.3

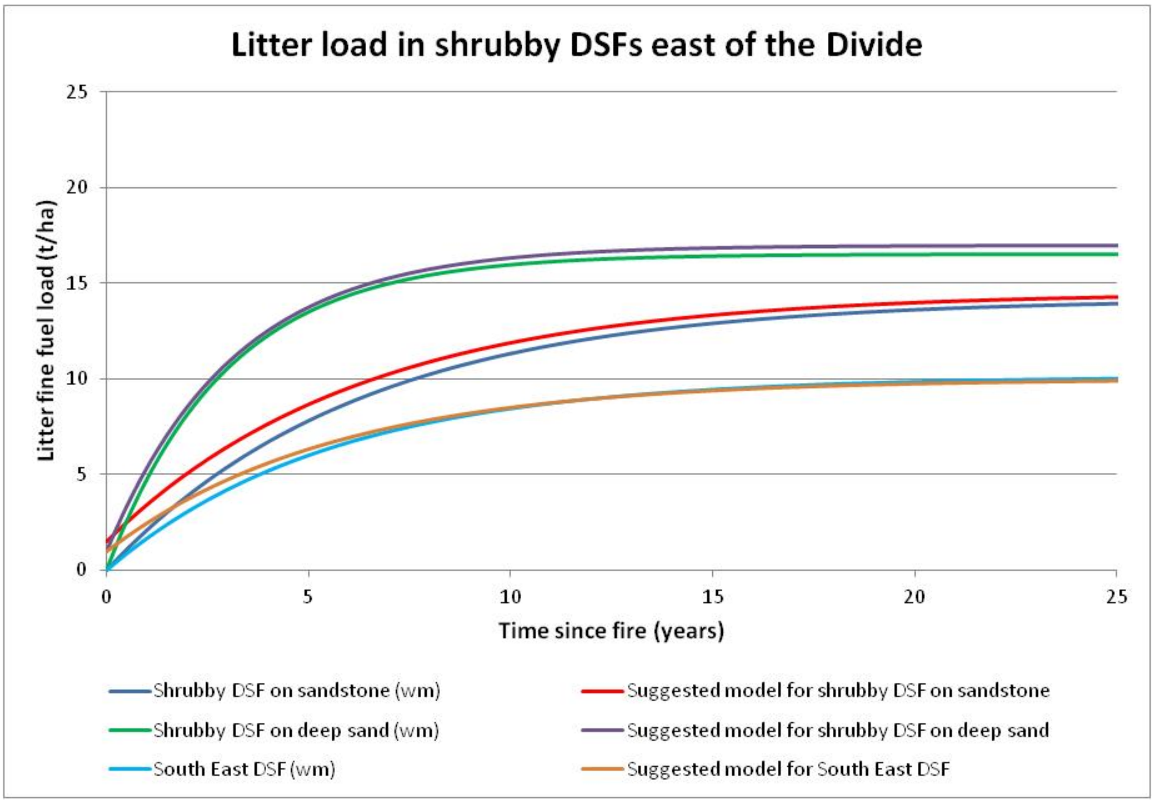

Figure 10. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in shrubby Dry Sclerophyll Forests east of the Divide. wm, model based on weighed means derived from the literature (Table 37), here, *Initial* is assumed to be zero. Values for *Initial*, *Limit* and *k* in the suggested models are given in Table 38; see text for explanation of crosswalk from literature to suggested models.

12.18 Knowledge gaps

Although quite a few studies addressing fuel dynamics in shrubby DSFs east of the Divide have been located, some gaps still exist.

- Forests on sandstone. While the picture for Sydney Coastal DSF is reasonably clear, it would be interesting to confirm the figures for litter fall derived from the time-since-fire studies of Conroy (1993) and Van Loon (1977) through direct measurement over several years. Differences between the two Sydney sandstone DSF classes in this group may also be worth exploring. The slightly higher litter fall figure in the North Coast DSF suggests that there may be some differences between this class and those around Sydney; this could be checked through a time-since-fire study.

- Coastal forests on deep sand. Here, questions remain about variability within the Coastal Dune and South Coast Sands DSF classes. Values for near-surface and elevated fuel are currently based on a single study; it would be useful to confirm whether the relatively low fuel loads in these layers are universal across these classes.

- Sydney Sand Flats DSF. While I have grouped this forest class with the coastal deep sands, no data specific to Sydney Sand Flats DSF currently exists, and there is reason to suspect that litter dynamics in these forests may be less extreme than those in their coastal counterparts. As the Sydney variants of this class occur in areas where urban development pressures are high, research into fuel development in this forest type should be a priority.

- Forests in the south-east. While data on litter load in the South East DSF class may be adequate, NSW studies addressing near-surface and elevated fuels are needed, to test whether the high fuel loads measured in similar vegetation in Victoria also occur here. No data for Southern Wattle DSF currently exists.

13. Shrubby dry sclerophyll forests on the tablelands

13.1 Introduction

This category includes four of Keith's vegetation classes, which are outlined in Table 39. All occur on rocky, infertile substrates.

Table 39. Vegetation classes in the shrubby dry sclerophyll forest subformation which occur predominantly on the tablelands.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Northern Escarpment DSF	158-9	In rocky infertile granite country north from Werrikimbe National Park (west of Port Macquarie), where rainfall exceeds 850 mm.	moderate
Sydney Montane DSF	160-1	On sandstone plateaux of the upper Blue Mountains, Illawarra escarpment and Budawang Mountains.	moderate
Northern Tableland DSF	162-3	Drier, western parts of the northern tablelands, on silica-rich infertile soils	moderate
Southern Tableland DSF	164-5	Rocky, infertile soils of the central and southern tablelands, south from Mudgee	large

Several studies have measured litter in Southern Tableland DSF, while two studies throw light on fuel dynamics in Sydney Montane DSF.

13.2 Crockford and Richardson (1998)

Crockford and Richardson (1998) measured litter fall and litter load in a dry sclerophyll forest near Canberra. The dominant tree species *E. rossii*, *E. mannifera* and *E. macrorhyncha* place this site clearly in the Southern Tableland DSF class. The forest had been unburnt for over 40 years.

Litter fall was collected over two years, with adequate spatial replication. Only particles under 10 mm in diameter were retained. Litter fall averaged 3.29 t/ha. Using a conversion factor of 0.99 gives a figure of 3.26 t/ha for particles under 6 mm.

Standing litter load was sampled twice, in 1978 when it averaged 21.0 t/ha, and again in 1994, after nine years of average rainfall, when a figure of 22.2 t/ha was obtained. No size cut-off is mentioned. Taking the latter figure as the one more likely to represent steady state fuel load, and assuming collection of particles up to 10 mm, fuel load < 6 mm can be estimated as 22.2 x 0.97 = 21.5 t/ha.

The decomposition constant *k* can be estimated as 3.26/21.5 = 0.15.

Rating: 2
This study involved adequate sampling, and figures from different years were in substantial agreement. There is some doubt however about the size cut-off used when measuring fuel load.

Rainfall and elevation: Mean annual rainfall given by the authors, who are hydrologists, is 640 mm. Nearest weather station may be Cavan; here, annual rainfall averages 679 mm (89 years of data), although this station is only at 457 m asl, whereas the altitude given by the authors is 'around 800m'.

13.3 McElhinny (2005)

This study of structural complexity has already been mentioned (Sections 7.10 and 8.2). As well as measuring litter load in grassy woodlands, McElhinny (2005) measured this parameter in 32 dry sclerophyll forest sites across the southern and central tablelands. All were part of either a *Eucalyptus dives* - *E. mannifera* - *E. macrorhyncha* or a *E. rossii* - *E. macrorhyncha* association. Their geographic location and overstorey composition locates them clearly in the Southern Tableland DSF class. Sites varied in their degree of modification.

In each site, all dead organic matter below 10 cm (100 mm) in diameter was collected from 15 quadrats. The average load, across the 32 sites, was 14.3 t/ha (12.5 percentile, 8.9 t/ha; 87.5 percentile, 19.6 t/ha). Using the 0.82 conversion factor gives an estimated mean, for fine fuel, of 11.7 t/ha.

McElhinny (2005) does not provide information on time since fire in his study sites, although he does note that many of them have not been burnt for a long time. Thus although steady state cannot be assumed, this figure is probably approaching *Limit*, across study sites.

Rating: 3
This study has the great advantage of having surveyed multiple sites across a wide geographic area. Its downsides, for current purposes, are the lack of explicit information on post-fire age, and the focus on litter < 10 cm rather than fine fuel.

Rainfall and elevation: Sites were selected through stratification into rainfall bands of 600-700 and 700-800 mm. Altitude ranged from 500 - 1100 m (mean 800 m). Yass (Linton Hostel) is the most centrally-located weather station given study site distribution. Here, rainfall averages 651 mm per year (112 years of data) and elevation is 520 m asl.

13.4 Gill *et al.* (1986)

Although this study does not contain sufficient data to generate a curve, it does provide supplementary information about fuel in Southern Tableland DSF. This work was carried out on a ridge adjoining Black Mountain in the ACT, in a site dominated by *E. macrorhyncha* and *E. rossii*. Presumably this site, where bark on the stringybarks was loose and thick, had not burnt for many years.

Litter loads next to trees were estimated, using litter depth measurements and “a locally developed relationship between litter depth and fine fuel weight” (Gill *et al.* 1986:2). Estimates averaged 22 t/ha around stringybarks, and 26 t/ha around scribbly gums. Note that these figures are almost certainly higher than landscape means including canopy gaps.

The authors also report that “shrubby fuels were light” (Gill *et al.* 1986:2), suggesting that elevated fuel load will be lower than that in coastal forests. Also, “fine fuels in general were completely consumed by the fires” (Gill *et al.* 1986:3) suggesting that *Initial* may be close to zero, even after planned burns.

The primary aim of this study was to document the effects of fire on bark on tree trunks. Initial bark depth on *E. macrorhyncha* trees averaged 20 mm. Bark depth on initially uncharred trees declined, at 0.55 m above ground level, by an average of 7.8 mm after experimental fires.

Rating: 3
Methods used in this study were carefully thought out. However the accuracy of fuel load figures is dependent on the accuracy of the litter depth to fine fuel conversion equation, which is not given in the paper. For current purposes, fuel load figures are of limited use as they do not represent a landscape-wide mean.

Rainfall and elevation: Nearest weather station may be Canberra Forestry, at 581 m asl, where rainfall averages 654 mm per annum (54 years of data, station closed in 1981).

13.5 Davis (1976) cited in Raison *et al.* (1983)

Raison *et al.* (1983) cite two figures for litter accumulation in *E. rossi – E. macrorhyncha* forest in the ACT: 13.5 t/ha at 5.6 years post-fire, and 15.0 t/ha at 30 years post-fire. Size cut-off is listed as “< 6mm?” (Raison *et al.* 1983:296). These figures, from an internal CSIRO report by Davis (1976), can be compared with expected values if the parameters derived from the paper by Crockford and Richardson (1998) are applied (Section 13.2). These are 12.2 t/ha (for 5.6 years post-fire) and 21.3 t/ha (for 30 years post-fire, when fuel load would be expected to be very close to *Limit*). Thus the Davis figure for 5.6 years is marginally higher than that predicted using the parameters in Section 13.2, while his figure for 30 years is quite a bit lower than expected from Crockford and Richardson's work. This lower figure for long unburnt sites is more in line with the mean from McElhinny (2005).

It may be that *Limit* varies with environmental factors such as altitude and aspect.

13.6 Adams and Simmons (1996)

Adams and Simmons (1996) measured litter load in a Victorian dry sclerophyll forest site dominated by *Eucalyptus macrorhyncha*, *E. goniocalyx* and *E. polyanthemos*. This site, which had a shrubby understorey, is reminiscent of Southern Tableland DSF. Samples of litter particles up to 6 mm in diameter were taken at various times after fire in a single site burnt at two different intensities (low and moderate). Applying equation (1) to the data from this study (equation (3) could not be fitted) returned a value for *Limit* of 23.0 t/ha, and for *k* of 0.16 (R^2 = 0.61).

We can now derive *L* by multiplying *Limit* by *k* = 23.0 x 0.16 t/ha = 3.68 t/ha.

A second study by these authors in similar country (Simmons and Adams 1999) returned readings, for total fuel load < 6 mm, of 18.1 and 20.2 t/ha (mean 19.2 t/ha). These sites, both near Christmas Hills, had burnt approximately 14 years previously. Understorey was sparse. The predicted value for this time-since-fire, using the parameters from the above model, would be 20.5 t/ha, so these points are roughly congruent.

Rating: 3
This study used the same definition of fine fuel as the current paper. However the extent to which vegetation dynamics in this Victorian forest mirror those in NSW forests is unknown. Model fit was reasonable but not impressive.

Rainfall and elevation: According to Adams and Simmons (1996), mean annual rainfall at their study site was approximately 700 mm. Nearest weather station may be Coldstream, where annual average rainfall is 714 mm (16 years of data), and elevation is 83 m asl. However Adams and Simmons' site is probably higher. Elevation at Healesville is 131 m.

13.7 Williams and Wardle (2007)

As part of a study of the effects of invasion by exotic pine, Williams and Wardle (2007) measured leaf fall in uninvaded eucalypt 'woodland' dominated by *E. oreades* and *E. sieberi*. This site on the Newnes Plateau north-east of Lithgow falls into Keith's Sydney Montane DSF class.

Litter was collected for a two-year period; only leaves were retained for measurement. Leaf fall averaged 1.37 t/ha. Assuming the proportion of leaves in the litter fall was the same as that recorded by Crockford and Richardson (1998, 57%) gives an estimate of 2.38 t/ha for *L*, for particles < 6 mm.

Rating: 4
Unfortunately, this study did not measure litter fall of particles other than leaves, so extrapolation has been necessary. While replication across time was attempted, spatially only a single site was involved. Williams and Wardle (2007) do provide figures for additional, nearby areas subject to pine invasion, which had similar amounts of eucalypt leaf fall, adding confidence from a spatial perspective.

Rainfall and elevation: The authors provide figures for mean annual rainfall (1072 mm) and altitude (1000-1170 m, average 1085 m). Nearest relevant weather station may be Lithgow (Newnes Forest Centre), where mean annual rainfall is 1073 mm (60 years of data) and elevation is 1050 m (though note that this station closed in 1999).

13.8 Van Loon (1977)

The data presented by Van Loon (1977) are discussed and analysed in Section 12.3. While much of the vegetation sampled in this study would have fallen into the Sydney Coastal DSF class, two of the five sites, representing four of ten data points, are mapped by Keith (2004) as Sydney Montane DSF. While information on species composition presented in Van Loon (1977) is insufficient to confirm this, neither of these two sites contained the Sydney Coastal DSF signature tree *Angophora costata*.

Values for Van Loon's Sydney Montane DSF data points are given in Table 40. These figures are drawn from the table in Appendix 1 to Van Loon (1977). Modelled values for litter use the parameters derived in Section 12.3, ie *Limit* = 11.8 t/ha, *k* = 0.17. Actual values are all within 1.3 t/ha of modelled values, with no trend for actual values to fall disproportionally above or below the modelled line. Thus the litter-based parameters derived from the Van Loon (1977) study are probably appropriate for Sydney Montane DSF.

For litter + herbs, those values were: *Initial* = 0.3 t/ha, *Limit* = 14.1 t/ha and *k* = 0.19

Although it proved impossible to fit a model to Van Loon's data for shrubs (Section 12.3), it is interesting to note the figures for Site 1, which had not burnt for 18.6 years at first sampling, and 22.8 years at the second. By 22.8 years post-fire shrub fuel load (< 6 mm) on this site exceeded 4.5 t/ha.

Table 40. Fuel load in t/ha for litter, litter + herbs, herbs alone, and shrubs, in Sydney Montane Dry Sclerophyll Forest sites surveyed by Van Loon (1977). All figures are for particles < 6 mm in diameter. Modelled values for litter are from negative exponential model with *Limit* = 11.8 t/ha and *k* = 0.17.

Site number	Time-since-fire (yrs)	Litter (actual)	Litter (modelled)	Litter + herbs	Herbs alone	Shrubs
4	5.0	7.3	6.8	10.3	3.0	0.6
4	9.2	8.3	9.3	10.8	2.5	2.0
1	18.6	10.9	11.3	12.8	2.0	2.8
1	22.8	12.8	11.6	15.5	2.6	4.7

13.9 Synthesis and suggested values for Phoenix

Relative to their equivalents east of the Divide (Chapter 12), shrubby dry sclerophyll forests on the tablelands are poorly-researched when it comes to fuel dynamics. While several studies provide figures for Southern Tableland DSF, there is no data for the two shrubby DSF classes on the northern tablelands. For Sydney Montane DSF one study of litter fall (Williams and Wardle 2007) augments the data collected by Van Loon (1977). Almost all the studies summarized in this chapter are concerned only with litter, with clues as to fuel load in other layers coming only from Van Loon (1977) and Gill *et al.* (1986).

Let us first consider Sydney Montane DSF. These forests occur on sandstone-derived soils and, at least in the Blue Mountains, intergrade with the lower-altitude sandstone forest classes, particularly Sydney Coastal DSF (Keith 2004). Data from Van Loon (1977) covers both Sydney Montane and Sydney Coastal DSF, with no trend for litter loads in Sydney Montane DSF sites to stand out from the wider data set (Table 40). As Van Loon's data has already been used in parameterising the lower altitude sandstone classes (Section 12.17), I suggest integrating the Sydney Montane DSF class into this fuel type. The litter fall figure from the study by Williams and Wardle (2007), 2.4 t/ha, falls within the range for sandstone forests in Table 37 (2.0 – 2.9 t/ha), again suggesting that this upland sandstone forest class exhibits similar dynamics to other classes in the group. The values for *Limit* proposed for this group (14.5 t/ha for litter alone, 16.4 t/ha for litter + near-surface fuel, and 4.9 t/ha for elevated fuel) sit just above the values in Table 40 for Sydney Montane DSF unburnt for 22 years.

We turn next to Southern Tableland DSF. Parameters for litter (< 6 mm) for this forest class are summarized in Table 41. The weighted mean figures suggest that both *L* and *Limit* may be greater in Southern Tableland DSF than in the other shrubby DSF classes on infertile, rocky soils reviewed so far (see paragraph above and Table 37). *Limit* may also exceed that in the coastal deep sand communities (Table 37), despite the fact that *L* in Southern Tableland DSF is clearly lower; this is, of course, because *k* is much lower in the cool, rocky, low rainfall environment which supports Southern Tableland DSF than it is in the coastal deep sand communities. Thus Southern Tableland DSF appears to warrant a fuel type of its own.

What parameters are appropriate for litter accumulation in this forest type? It is noteworthy that values for *Limit* derived from studies of litter in Southern Tableland DSF cover a wide range, from 11.7 to 23.0 t/ha (Table 41). This may in part reflect within-class variability; certainly sites in this class carry a range of tree sizes (Keith 2004), and litter depth in long unburnt sites can vary widely (UoW fuels project unpub data). The relatively low figure for litter load at 30 years post-fire cited by Raison *et al.* (1983;15.0 t/ha) is congruent with this interpretation. Taking the weighted mean values from Table 41 and adding 1.0 t/ha for *Initial* (I have set this figure low in line with the observation by Gill *et al.* (1986) that fire generally consumes almost all the fuel in this forest type), I suggest setting *Limit* at 19.0 and *k* at 0.15. This *k* value is in line with the value derived from the study by Crockford and Richardson (1998).

Table 41. Values for *L, Limit* and *k*, for litter particles < 6 mm, derived from studies in Southern Tableland DSF. R'g, rating for confidence level and relevance. Weighted mean, weighted average values for *L* and *Limit, k* derived from these two values (see Section 1.5.4).

Source	Class	*L* (t/ha)	*Limit* (t/ha)	*k*	R'g
Crockford and Richardson (1998)	Southern Tableland DSF	3.3	21.5	0.15	2
McElhinny (2005)	Southern Tableland DSF		11.7		3
Adams and Simmons (1996)	Southern Tableland DSF	3.7	23.0	0.16	3
Weighted mean	**Southern Tableland DSF**	**3.5**	**19.1**	**0.18**	

How should these values change to account for near-surface fuel? As near-surface cover in Southern Tableland DSF is low (UoW fuels project unpub data), I suggest adding 1.0 t/ha to *Limit*, and leaving *Initial* and *k* unchanged from their values for litter alone.

Turning to elevated fuel: Gill *et al.* (1986) describe the shrub layer as 'light', and perusal of the shrub species listed in the description of this vegetation type in Keith *et al.* (2004) suggests that the understorey is likely to be of lower stature than that in the coastal DSF types. While we do not have data on shrub fuel biomass in this vegetation class, we do know that a number of common shrub species tend to be relatively short-lived (Purdie and Slatyer 1976), so shrub biomass may well fall in the later post-fire years, after an initial rise. So again, the negative exponential model will provide a rough fit, at best, for elevated fuel in this vegetation class. I suggest halving the figures for *Initial* and *Limit* in shrubby coastal DSF, to *Initial* = 0.3 t/ha, *Limit* = 2.5 t/ha. For *k*, I suggest using a somewhat lower value, 0.15 rather than 0.20, as low temperatures in the highlands are likely to reduce shrub growth rates.

What about the two remaining tablelands shrubby dry sclerophyll forest classes? Northern Escarpment DSF can develop a thick shrub layer (pers. obs. 1999-2003). In the absence of data specifically on this forest type, I suggest grouping it with the sandstone forests. Northern Tableland DSF, which occurs in the drier western parts of the northern tablelands, may have more common with Southern Tableland DSF. In the absence of data specific to this forest type, I suggest grouping it with Southern Tableland DSF.

Suggested parameters for vegetation classes in the shrubby subformation of dry sclerophyll forests are summarized in Table 42, with a comparison between literature-derived and suggested models for litter fuel in Southern Tableland DSF presented in Figure 11.

Table 42. Summary of suggested values for negative exponential model parameters for classes in the shrubby subformation of dry sclerophyll forests on the tablelands. NS, near-surface. *r* = *Limit* - *Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	Fuel layer	*Initial*	*k*	*Limit*	*r*
Sydney Montane DSF, Northern Escarpment DSF	Litter	1.5	0.16	14.5	13.0
	Litter + NS	1.7	0.17	16.4	14.7
	Elevated	0.7	0.20	4.9	4.2
Southern Tableland DSF, Northern Tableland DSF	Litter	1.0	0.15	19.0	18.0
	Litter + NS	1.0	0.15	20.0	19.0
	Elevated	0.3	0.15	2.5	2.2

13.10 Knowledge gaps

The major gap in terms of the classes addressed in this chapter is the total lack of data on fuel dynamics in Northern Escarpment and Northern Tableland DSF. There is also scope for documenting fuel accumulation in Sydney Montane DSF more thoroughly. In Southern Tableland DSF, questions remain as to levels attained by shrub fuels. The considerable differences in steady state litter load derived from work by different authors points to a need for additional survey work in long unburnt sites across the range of this forest type, to better understand within-class variability.

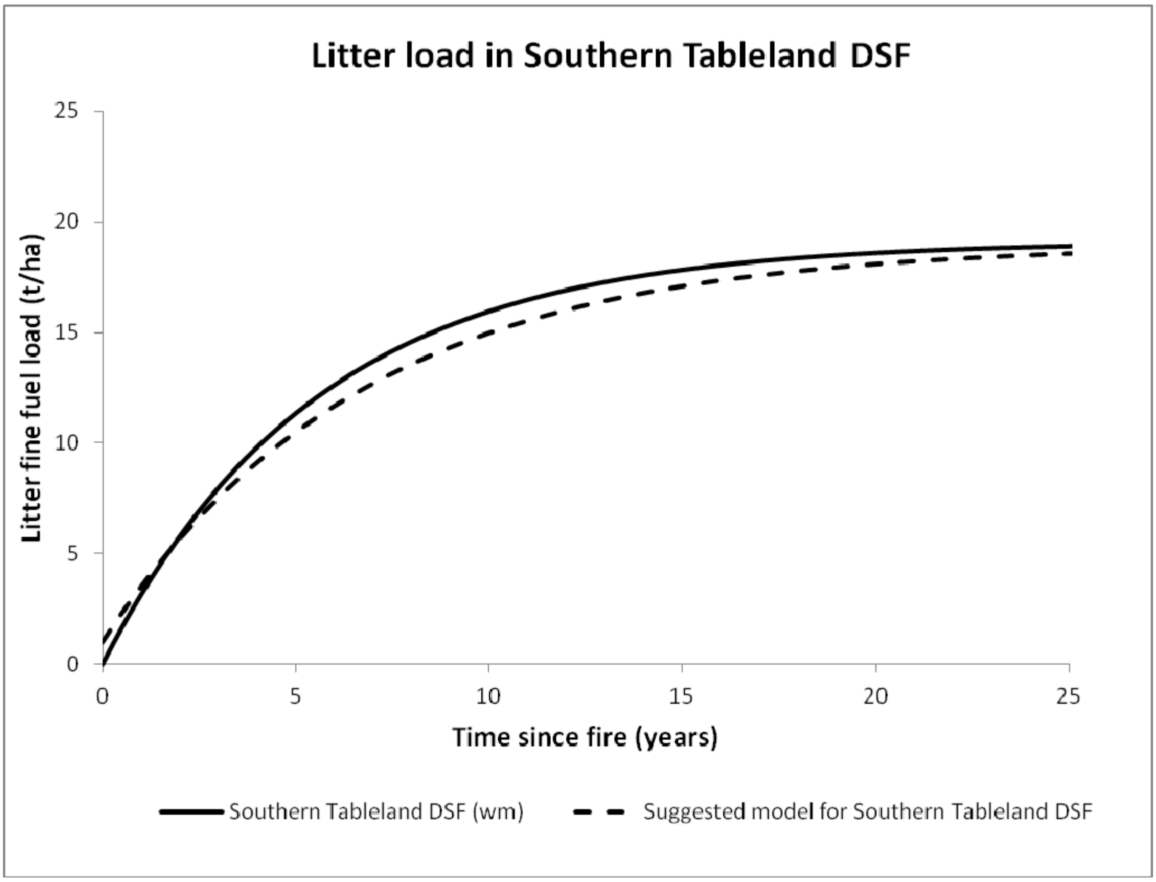

Figure 11. Comparison of literature-derived and suggested models, for accumulation of fine litter fuel < 6 mm, in Southern Tableland DSF. wm, model based on weighed means derived from the literature (Table 41), here, *Initial* is assumed to be zero. Values for *Initial, Limit* and *k* in the suggested model are given in Table 42; see text for explanation of crosswalk from literature to suggested model.

14. Shrubby dry sclerophyll forests on the western slopes

14.1 Introduction

Two shrubby dry sclerophyll forest classes occur on the western slopes (Table 43). Both feature ironbark eucalypts along with black and white cypress pine (*Callitris* spp). Shrubby dry sclerophyll forests do not occur on the Plains, as rainfall is insufficient.

Table 43. Vegetation classes in the shrubby dry sclerophyll forest subformation which occur predominantly on the western slopes.

Vegetation class	Pages in Keith (2004)	Where does it occur?	Relative extent
Western Slopes DSF	166-7	On infertile sandy soils of the western slopes, across the length of NSW but particularly in the northern and central parts of the state, eg Pilliga Forest, and around Dubbo.	large
Yetman DSF	168-9	On sandstone in the far north of the state, from west of Inverell to southern Queensland	moderate

One study of litter dynamics in Western Slopes DSF has been located (Hart 1995).

14.2 Hart (1995)

Hart (1995) measured litter fall, litter load, and litter decomposition in several vegetation types in the Pilliga. His ‘forest’ site was dominated by *E. crebra* (narrow-leaved ironbark) and *Callitris glaucophylla* (white cypress pine), and had a shrub layer containing *Acacia tindaleae*.

Litter fall was adequately sampled with collections over three years. Average annual litter fall figures are given for various components, including twigs > 10 mm and twigs < 10 mm. Excluding twigs over 10 mm gives an annual average litter fall of 2.05 t/ha. Using a conversion factor of 0.99 gives an estimated annual litter fall of particles under 6 mm of 2.03 t/ha.

Litter load was sampled on two occasions four years apart, at the same site in which litter fall was collected. Time since-fire was 36 years at first sampling in 1987, and 40 years at the second in 1991. Total fuel load averaged 11.08 t/ha in 1987 and 12.35 in 1991. A further site, unburnt for 39 years, produced a fuel load of 17.31 t/ha. Taking the average of the two longest unburnt sites gives a fuel load figure of 14.83 t/ha. As no cut-off was specified for litter load, I have used a conversion factor of 0.82 (Section 1.5.1), giving an estimated 12.16 t/ha for *Limit*, for fuel particles < 6 mm.

Using this figure, together with the figure of 2.03 for *L*, gives a *k* value of 2.03/12.16 = 0.17.

Hart (1995) also assessed *k* directly, using litter bags. The value from this procedure was 0.16.

Rating: 3
This study employed good temporal replication, and reasonable within-site spatial replication. However only one site was surveyed, plus an additional site for litter load measurement. Results from inclusion of this second site, which yielded quite a different value for litter load, suggest variability in litter parameters across the landscape.

Rainfall and elevation: Hart (1995) gives a figure of 'around 625 mm'. Nearest weather station may be Baradine where average annual rainfall is indeed 625 mm (65 years of data), and elevation is 302 m.

14.3 Synthesis and suggested values for Phoenix

For litter, Hart (1995) provides figures of around 2.0 t/ha for *L*, 12.2 t/ha for *Limit*, and 0.16-0.17 for *k*. The class in Chapters 12 and 13 with litter parameters most closely resembling these is South East DSF (Section 12.17). However while shrub fuel load in South East DSF appears to reach quite high levels, this is unlikely to be the case in Western Slopes DSF with its dry inland location. To adequately represent the differences between Western Slopes DSF and the shrubby dry sclerophyll forests reviewed in the previous two chapters, an additional fuel type is recommended.

For litter, I suggest setting *Initial* at 1.0 t/ha, *Limit* at 12.0 t/ha, and *k* at 0.16. Near-surface fuel may add little; while we have no direct data for Western Slopes DSF, we do know that grass load in the neighbouring shrub/grass Pilliga Outwash DSF class was only 0.29 t/ha (Van Loon and Love 1971:Section 11.4). I suggest, for litter + near-surface fuel, raising *Limit* to 12.5 t/ha and leaving *Initial* and *k* as for litter alone. For elevated fuel, I suggest using the same parameters as for Southern Tableland DSF, ie *Initial* = 0.3 t/ha, *Limit* = 2.5 t/ha, *k* = 0.15.

In the absence of data on Yetman DSF, I suggest using the same parameters as for Western Slopes DSF.

Suggested parameters for vegetation classes in the shrubby grass subformation of dry sclerophyll forests on the western slopes are summarized in Table 44.

Table 44. Summary of suggested values for negative exponential model parameters for classes in the shrubby subformation of dry sclerophyll forests on the western slopes. NS, near-surface. r = *Limit - Initial*. *Initial* equates to *c* in Phoenix. *Limit, Initial* and *r* in t/ha.

Classes	**Fuel layer**	***Initial***	***k***	***Limit***	***r***
Western Slopes DSF, Yetman DSF	Litter	1.0	0.16	12.0	11.0
	Litter + NS	1.0	0.16	12.5	11.5
	Elevated	0.3	0.15	2.5	2.2

14.4 Knowledge gaps

The study by Hart (1995) provides useful insight into litter dynamics in Western Slopes DSF. However data gaps in relation to grasses and shrubs remain. Even for litter, sampling across a wider range of sites is desirable. For Yetman DSF, data is totally lacking.

15. Summary and conclusion

15.1 Summary tables

This report has outlined studies pertaining to post-fire development of fine fuel load in NSW forests and grassy woodlands. On the basis of these studies, values for populating the negative exponential model for classes in these formations have been suggested. Values for all formations and classes are summarized in Tables 45-47 and illustrated in Figures 12-15.

- Table 45: *Initial*, *Limit* and *k* for litter, litter + near-surface, and elevated fuel load.
- Table 46: Phoenix parameters *c*, *k* and *r* for surface and elevated fuel load. Note that surface fuel in Phoenix equals litter + near-surface fuel.
- Table 47: Phoenix parameters *c* and *r* expressed as hazard scores.

15.2 Fuel load to hazard score conversions and their limitations

To populate Table 47, I have reformatted equations given in Tolhurst (2005), and used them to convert *Initial* and *Limit* from fuel load into hazard scores.

- For surface fuel, I've allowed *Initial* to take a hazard score value below 1, even though the lowest hazard score level in the DSE guide is Low, which is scored 1. This is because Phoenix allows for values below 1, and to express fuel loads less than 2.6 t/ha a hazard score < 1 must be employed.
- For elevated fuel, I've set *Initial* at a minimum hazard score of 1, which is the score for Low in the DSE guide. This equates to 0.061 t/ha, using the equation from Tolhurst (2005), which of course is very close to 0. This slight adjustment is reflected in values for elevated fuel load in column 6 of Tables 45 and 46.

I have then subtracted the hazard score for *Initial* from the hazard score for *Limit*, to give a value for *r* in hazard score terms.

Note that the hazard score values for *Initial*, *Limit* and *r* given in Table 47 assume that the formulae given in Tolhurst (2005) are the basis for determining fuel load/hazard score conversions in Phoenix today.

Note, too, that if the hazard score *r* value in Table 47 is converted back to a fuel load, it **will not** equate to the difference between *Limit* and *Initial* in fuel load terms. This is because the conversion equations in Tolhurst (2005), and thus the equations used to create the values in Table 47, are not linear. The differences are particularly noticeable for elevated fuel.

Note also that the fuel development trajectory between *Initial* and *Limit* in Phoenix may or may not align with the curves for fuel load given in this paper. This will depend on how the interface between hazard scores and fuel loads operates in Phoenix. Values between *Initial* and *Limit* will only be the same as those in this document if Phoenix makes the conversion to fuel load at the point where *c* and *r* are read in. If accumulation is modelled in hazard score terms, *then* converted to fuel load for input to the fire behaviour models, values at any given time since fire – particularly in the early and middle post-fire years – will be different to, and generally lower than, their equivalents when fuel load accumulation is modelled directly. For this reason, *k* values are not included in Table 47.

It is recommended that the RFS work with those involved in the development of Phoenix to ensure fuel inputs to fire behaviour models generated by Phoenix accurately reflect fuel load curves. Matters to do with the internal workings of Phoenix are outside the scope of this document, and outside the scope of the University of Wollongong's fuels project.

To make maximum use of the fuels data available in NSW, and summarized in this document, fire behaviour simulation would ideally operate directly on fuel load without using hazard scores as intervening variables.

15.3 Variability across and within vegetation types

For litter, values for *Limit* vary widely across and within formations, ranging from 5.5 t/ha in Pilliga Outwash DSF to 24.0 t/ha in Montane WSF. *k* values, too, vary widely, from 0.75 in rainforests to 0.15-0.18 in dry sclerophyll forests on rocky, infertile substrates. Within subformations, cold, high altitude classes tend to have lower *k* values, and thus higher steady state litter loads, than classes with similar rates of litter fall growing in more benign climatic conditions. Where *k* is low, litter builds up more slowly than when it is high. Thus in shrubby wet sclerophyll forests where *k* is around 0.45, 95% of quasi steady state litter loads will be achieved in under 7 years. By contrast, in a dry sclerophyll forest with a *k* value of 0.15, 20 years will need to elapse before litter load reaches 95% of its eventual *Limit*.

The amount of elevated fine fuel also varies widely across, and to some extent within, formations. High values for elevated fuel load occur in the shrubby dry sclerophyll forests on sandstone around Sydney and in the north of the state. Shrub fuel load is also high in the shrubby dry sclerophyll forests in the south-east of the state, if results from studies in similar vegetation in Victoria apply across the border. As might be expected, elevated fuel levels are relatively low in grassy woodlands and grassy forests, and in forests with high canopy cover.

Of course, the accuracy of the values suggested here is limited by the data available. Note too that even where good data exists, values suggested here may be an approximation at best for any particular site within a forest or woodland class.

Vegetation classification inevitably imposes artificial boundaries on naturally occurring variation across the landscape. Within each class, there will be a range in terms of vegetation composition and structure, and in characteristics of trees linked to litter fall, such as basal area (Fox *et al.* 1979; Turnbull and Madden 1983; Turner and Lambert 2002), canopy cover (Walker 1981) and bark type (Gill *et al.* 1986). Some management practices, such as recent logging, will also have an impact. Data on which recommended figures for particular classes are based may have been collected in sites near the centre of the range of variability found across a class, or at one end of the spectrum. The use of weighted means from multiple studies should guard again bias to some extent, however where studies are few or all from around the same area, it may still be an issue.

The only way to ensure values for fuel accumulation parameters accurately reflect reality is to continue to accumulate data, across and within NSW vegetation classes. Ideally, we would have sufficient information, across each vegetation class, to clearly define mean values for *Initial*, *Limit* and *k*, together with measures of variability. Although extant data is sufficient to discern general patterns, we are still a fair way from this goal.

15.4 Priorities for filling knowledge gaps

Of the knowledge gaps identified in this document, I believe some merit more urgent attention than others. Factors to consider when prioritizing vegetation classes for future research include the extent to which data is currently available, geographic extent, location relative to assets, and flammability. Keeping these points in mind, suggested priorities are:

- Classes in the shrub/grass subformation of dry sclerophyll forests. Research into fuels in these forests is scant, they occur in landscapes where people live and where rural production takes place, they are definitely flammable. What little data currently exists suggests the assumption that these grassy forests closely resemble their shrubby counterparts in fuel terms is almost certainly flawed. Data on fuel accumulation through time, in at least a sample of the ten classes in this subformation, is urgently needed.

- Elevated and near-surface fuels. Relative to studies of litter dynamics, studies which provide a clear picture of post-fire development in near-surface and elevated fuel load are limited. For many vegetation groupings, suggested figures for *Limit* are very rough estimates based on data gathered in other vegetation type. Attention to near-surface and elevated fuels as well as to litter, in future fuel load surveys, is recommended.

- Shrubby dry sclerophyll forest classes in the north of the state. Shrubby dry sclerophyll forests are highly flammable, with substantial litter loads some years after fire, and high levels of elevated fuel. While data for some shrubby DSF classes is quite good, no fuel load data exists for the four variants in the north of the state: North Coast DSF, Northern Escarpment DSF, Northern Tableland DSF and Yetman DSF.

- Shrubby dry sclerophyll forests around Sydney. Gaps in relation to shrubby dry sclerophyll forests around Sydney centre on Sydney Sand Flats DSF. While of limited extent, this forest type occurs in semi-urban parts of western Sydney subject to development pressure. The provisional grouping of this forest class with coastal deep sands forests may not reflect reality. The second sandstone variant, Sydney Hinterland DSF, is also worthy of further investigation. Here too, urban fringe issues are likely to increase as Sydney grows.

- Two grassy wet sclerophyll forest types are currently unstudied: Northern and Southern Tableland WSF.

- Two shrubby wet sclerophyll forest types have limited data: Northern and Southern Escarpment WSF. This also applies to South Coast WSF, though its extent is more limited.

- Grassy woodlands are very poorly studied. This applies to Coastal Valley Grassy Woodlands beyond the Sydney region, to all classes on the tablelands except Subalpine Woodlands, and to most classes on the western slopes. Even Subalpine Woodlands present some mysteries, as most existing studies, which are from the ACT, appear to be from one extreme of the range of this relatively extensive woodland type. Despite lack of data, I have given this formation a low priority because fragmentation generally means that the bushfire risk presented by woodlands is low.

- Data for some rainforest types is lacking. However small extent plus low flammability suggest that research into this formation does not need to be given a high priority.

As further research enhances knowledge of fuel load levels and their rates of development, the figures suggested here can be refined. The studies and analysis presented in this report should provide a transparent and readily-available platform for further enhancements to fuel classification and parameterisation in NSW.

Table 45. Summary of suggested values for negative exponential model. *Initial*, fuel load immediately after a fire; *Limit*, steady state fuel load. *Initial* and *Limit* in t/ha. All values for fine fuel < 6 mm.

Formation/subformation	Class	Litter fuel load			Litter + NS fuel load			Elevated fuel load		
		Initial	*k*	*Limit*	*Initial*	*k*	*Limit*	*Initial*	*k*	*Limit*
Rainforests	All	0.0	0.75	8.0	0.0	0.75	9.0	0.1	0.30	1.0
Wet sclerophyll forests (shrubby)	All	1.0	0.45	17.0	1.0	0.35	19.0	0.1	0.15	3.0
Wet sclerophyll forests (grassy)	Montane WSF	1.0	0.20	24.0	1.0	0.20	24.0	0.1	0.15	2.0
	All other grassy WSF classes	1.0	0.35	18.0	1.0	0.35	18.0	0.1	0.15	2.0
Grassy woodlands	Coastal Valley Grassy Wooodlands	0.5	0.40	6.5	1.0	0.45	8.0	0.1	0.30	2.0
	Subalpine Woodlands	2.0	0.25	15.0	2.0	0.30	16.0	0.1	0.20	2.0
	All other grassy woodland classes	1.0	0.35	8.0	1.0	0.40	10.0	0.1	0.20	0.5
Dry Sclerophyll Forests (shrub/grass)	Pilliga Outwash DSF	0.5	0.25	5.5	0.5	0.25	6.0	0.1	0.20	1.0
	All other shrub/grass DSF classes	1.0	0.30	11.0	1.0	0.30	12.0	0.1	0.20	2.0
Dry Sclerophyll Forests (shrubby)	Sydney Coastal DSF, Sydney Hinterland DSF, Sydney Montane DSF, North Coast DSF, Northern Escarpment DSF	1.5	0.16	14.5	1.7	0.17	16.4	0.7	0.20	4.9
	Coastal Dune DSF, South Coast Sands DSF, Sydney Sand Flats DSF	1.0	0.32	17.0	1.0	0.32	18.0	0.5	0.25	2.5
	South East DSF, Southern Wattle DSF	1.0	0.18	10.0	1.0	0.19	12.0	0.7	0.19	5.0
	Southern Tableland DSF, Northern Tableland DSF	1.0	0.15	19.0	1.0	0.15	20.0	0.3	0.15	2.5
	Western Slopes DSF, Yetman DSF	1.0	0.16	12.0	1.0	0.16	12.5	0.3	0.15	2.5

Table 46. Summary of suggested values for negative exponential model parameters used in Phoenix, expressed as fine fuel load < 6mm. *c*, fuel load immediately after a fire; *r*, (steady state fuel load – *c*). *c* and *r* in t/ha. Surface fuel includes litter + near-surface fuel.

Formation/subformation	Class	Surface fuel load			Elevated fuel load		
		c	*k*	*r*	*c*	*k*	*r*
Rainforests	All	0.0	0.75	9.0	0.1	0.30	0.9
Wet sclerophyll forests (shrubby)	All	1.0	0.35	18.0	0.1	0.15	2.9
Wet sclerophyll forests (grassy)	Montane WSF	1.0	0.20	23.0	0.1	0.15	1.9
	All other grassy WSF classes	1.0	0.35	17.0	0.1	0.15	1.9
Grassy woodlands	Coastal Valley Grassy Wooodlands	1.0	0.45	7.0	0.1	0.30	1.9
	Subalpine Woodlands	2.0	0.30	14.0	0.1	0.20	1.9
	All other grassy woodland classes	1.0	0.40	9.0	0.1	0.20	0.4
Dry Sclerophyll Forests (shrub/grass)	Pilliga Outwash DSF	0.5	0.25	5.5	0.1	0.20	0.9
	All other shrub/grass DSF classes	1.0	0.30	11.0	0.1	0.20	1.9
Dry Sclerophyll Forests (shrubby)	Sydney Coastal DSF, Sydney Hinterland DSF, Sydney Montane DSF, North Coast DSF, Northern Escarpment DSF	1.7	0.17	14.7	0.7	0.20	4.2
	Coastal Dune DSF, South Coast Sands DSF, Sydney Sand Flats DSF	1.0	0.32	17.0	0.5	0.25	2.0
	South East DSF, Southern Wattle DSF	1.0	0.19	11.0	0.7	0.19	4.3
	Southern Tableland DSF, Northern Tableland DSF	1.0	0.15	19.0	0.3	0.15	2.2
	Western Slopes DSF, Yetman DSF	1.0	0.16	11.5	0.3	0.15	2.2

Table 47. Summary of suggested values for negative exponential model parameters used in Phoenix, expressed as hazard scores. *c*, hazard score immediately after a fire (= *Initial*); *Limit*, hazard score at steady state (= *r* + *c*); *r*, (*Limit* – *c*). Surface fuel includes litter + near-surface fuel.

Formation/subformation	Class	Surface fuel hazard score			Elevated fuel hazard score		
		c	*Limit*	*r*	*c*	*Limit*	*r*
Rainforests	All	0.00	2.77	2.77	1.00	2.62	1.62
Wet sclerophyll forests (shrubby)	All	0.41	4.43	4.02	1.00	3.35	2.36
Wet sclerophyll forests (grassy)	Montane WSF	0.41	4.99	4.58	1.00	3.06	2.07
	All other grassy WSF classes	0.41	4.30	3.89	1.00	3.06	2.07
Grassy woodlands	Coastal Valley Grassy Wooodlands	0.41	2.55	2.13	1.00	3.06	2.07
	Subalpine Woodlands	0.79	4.03	3.23	1.00	3.06	2.07
	All other grassy woodland classes	0.41	2.99	2.57	1.00	2.20	1.20
Dry Sclerophyll Forests (shrub/grass)	Pilliga Outwash DSF	0.21	2.05	1.83	1.00	2.62	1.62
	All other shrub/grass DSF classes	0.41	3.37	2.96	1.00	3.06	2.07
Dry Sclerophyll Forests (shrubby)	Sydney Coastal DSF, Sydney Hinterland DSF, Sydney Montane DSF, North Coast DSF, Northern Escarpment DSF	0.68	4.08	3.40	2.40	3.77	1.37
	Coastal Dune DSF, South Coast Sands DSF, Sydney Sand Flats DSF	0.41	4.30	3.89	2.20	3.22	1.02
	South East DSF, Southern Wattle DSF	0.41	3.37	2.96	2.40	3.79	1.39
	Southern Tableland DSF, Northern Tableland DSF	0.41	4.56	4.14	1.91	3.22	1.31
	Western Slopes DSF, Yetman DSF	0.41	3.46	3.05	1.91	3.22	1.31

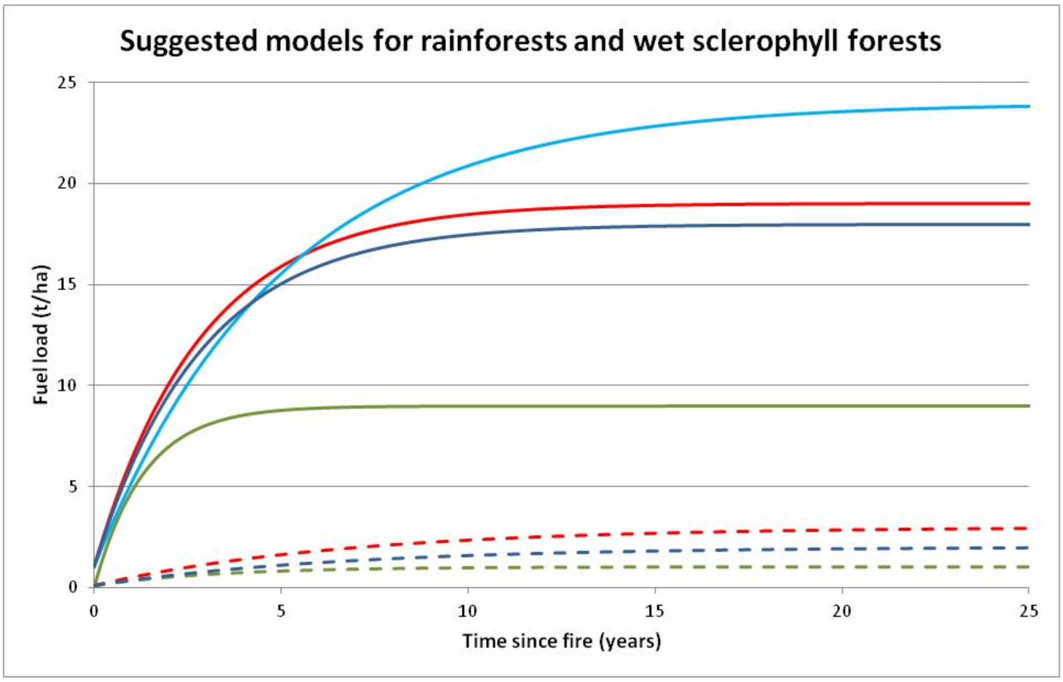

Figure 12. Suggested models for accumulation of fine fuel load in rainforests (all classes, green), shrubby wet sclerophyll forests (all classes, red), and grassy wet sclerophyll forests (Montane WSF, light blue; all other classes, dark blue). Solid lines, surface fuel (litter + near-surface). Dotted lines, elevated fuel. Suggested model for elevated fuel in grassy WSF is the same for Montane WSF as for all other classes.

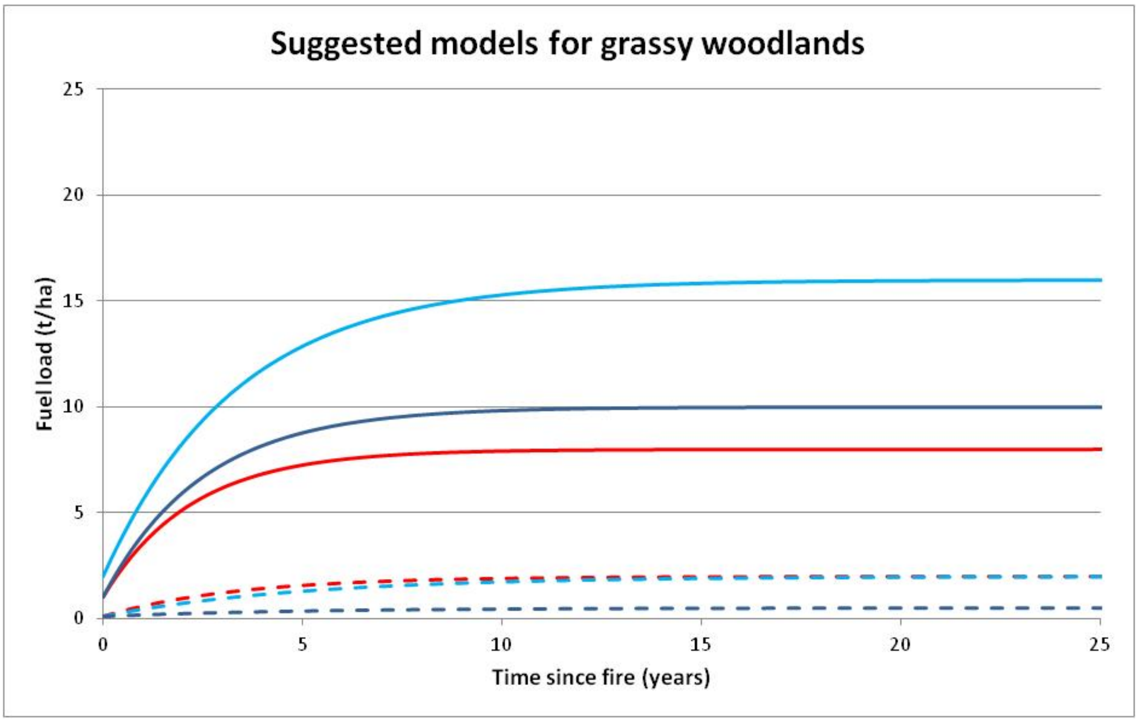

Figure 13. Suggested models for accumulation of fine fuel load in grassy woodlands. Red, Coastal Valley Grassy Woodlands; light blue, Subalpine Woodlands; dark blue, all other grassy woodland classes. Solid lines, surface fuel (litter + near-surface). Dotted lines, elevated fuel.

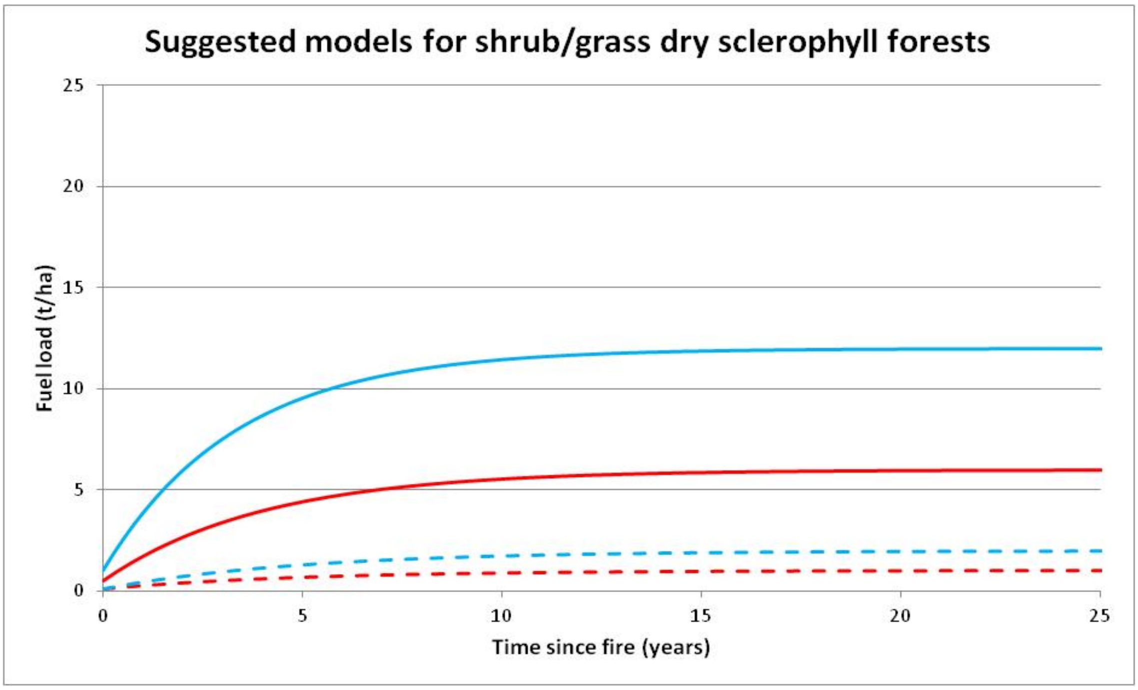

Figure 14. Suggested models for accumulation of fine fuel load in shrub/grass dry sclerophyll forests. Red, Pilliga Outwash DSF; light blue, all other shrub/grass DSF classes. Solid lines, surface fuel (litter + near-surface). Dotted lines, elevated fuel.

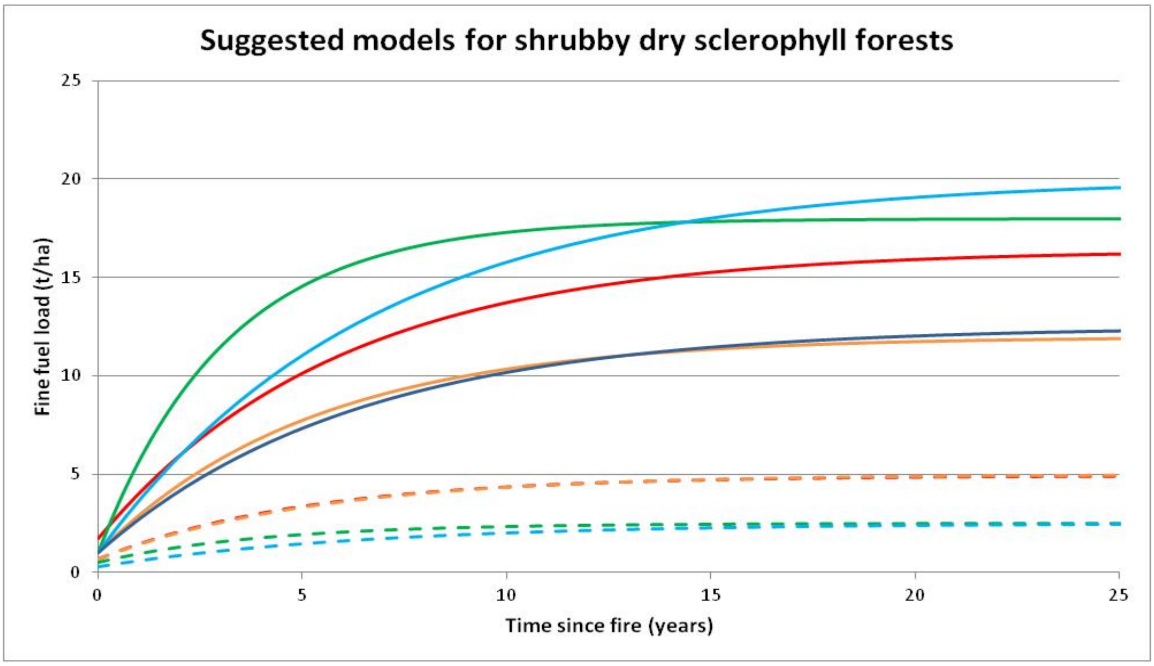

Figure 15. Suggested models for accumulation of fine fuel load in shrubby dry sclerophyll forests. Red, Sydney Coastal DSF, Sydney Hinterland DSF, Sydney Montane DSF, North Coast DSF, Northern Escarpment DSF; green, Coastal Dune DSF, South Coast Sands DSF, Sydney Sand Flats DSF; orange, South East DSF, Southern Wattle DSF; light blue, Southern Tableland DSF, Northern Tableland DSF; dark blue, Western Slopes DSF, Yetman DSF. Solid lines, surface fuel (litter + near-surface). Dotted lines, elevated fuel. Suggested model for elevated fuel in Western Slopes and Yetman DSF is the same as that for Southern Tableland DSF (light blue dotted line); suggested model for elevated fuel in Sydney Coastal DSF etc (red dotted line) is almost coincident with suggested model for South East DSF (orange dotted line).

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