Bark fuel in New South Wales forests and grassy woodlands

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Executive Summary

Bark on tree trunks contributes to bushfire behaviour in several ways. Dead bark retained on trees contributes to the overall fine fuel load of a forest; bark can ladder flames from surface fuels into the tree canopy; and certain bark types are the major contributor to the spotting process in which glowing or flaming pieces of fuel are transported by wind and convection currents to propagate new, spot fires.

We investigated bark types in NSW forests and grassy woodlands, with a view to providing estimated figures for bark fuel load, and for bark hazard, in long-unburnt vegetation and across the post-fire sequence. This information will provide input data for the Phoenix fire behaviour simulator, for Vesta spotting distance tables, and for other applications with an input requirement for bark fuel estimates.

Methods

Our analysis drew on the lists of indicative tree species provided in Keith (2004) for each vegetation class in NSW. Each tree species in the genera *Eucalyptus, Corymbia* and *Angophora* (Eucalypts) listed for classes in the wet and dry sclerophyll forest and grassy woodland formations was allocated to one of five 'bark type' categories: ironbark, stringybark, smooth, smooth with stocking, or subfibrous. An additional variable recorded the propensity of each species to produce ribbons of bark. As there was a large range in the number of species recorded for individual vegetation classes, we used the *proportion* of species exhibiting each bark type, and the proportion of species in each propensity to produce ribbons (PPR) category, to make commensurate comparisons. As an independent check on bark type proportions, we compared those generated from the Keith lists with the proportion of bark types calculated using tree species recorded in sites surveyed during a field study of fuel hazard in eight NSW forest and grassy woodland vegetation classes (Fuel Hazard Study).

Bark configuration across formations was investigated by averaging proportions across component classes. Mean proportions were also used to explore patterns across gradients in rainfall, latitude and elevation.

Methods for scoring bark fuel hazard emphasise the over-riding role of stringy bark in driving spotting behaviour. Thus for vegetation classes where the species listed in Keith (2004) included one or more with stringy bark, we allocated a maximum hazard score of either Extreme (where > 30% of listed species were classified as having stringy bark), or Very High. Maximum hazard levels for vegetation classes without stringybarks were based on the highest hazard level in the revised Victorian fuel assessment guide (Hines *et al*. 2010) for remaining bark types. As a comparison, and to inform estimation of minimum scores and post-fire trajectories, we used data and models for bark fuel hazard as a function of time-since-fire from the Fuel Hazard Study.

Estimates of bark fuel load were calculated separately. Re-analysis of bark types using revised categories including one for species which produce long or lots of ribbons, generated a second listing of the proportion of bark types in each vegetation class. A maximum bark load was allocated to each bark type, representing expected load in a hypothetical mature, very long-unburnt forest with only that bark type present. For each vegetation class, the maximum fuel load for each bark type was multiplied by its proportion; these proportions were then summed to give the estimated maximum overall bark fuel load for each class. Maximum possible bark fuel load, using this method, was 7 t/ha; this figure was in line with findings reported in the literature. A similar process was used to estimate minimum bark loads immediately post-fire. To inform estimation of minimum loads and post-fire trajectories, linear and exponential decay models were fitted, for each individual vegetation class, to data on percent char at different post-fire ages collected during the Fuel Hazard Study.

Key points and findings

- Wet and dry sclerophyll forests and grassy woodlands in NSW are rarely dominated by a single tree species. Frequently, co-occuring species differ in bark type, and it is common to find a range of bark types at class, community, stand, site and even plot level.
- Of the 39 vegetation classes considered in the report, 28 had at least one stringybark species listed by Keith (2004), while 31 had one or more species with a propensity to produce long, or lots of, ribbons.
- For the eight vegetation types surveyed during the Fuel Hazard Study, the proportion of bark types was similar whether field data or species lists in Keith (2004) were used. This finding provides confidence that our methods reflect the reality of bark types in the field.
- Flammable bark was particularly prevalent in wet sclerophyll forests. The proportion of species with a propensity to produce long ribbons was higher in these forests than in the drier vegetation types, and while the total proportion of stringy- and subfibrous-barked species was much the same in each formation, in wet sclerophyll forests a higher proportion of these rough-barked species had stringy bark; this applied particularly in shrubby WSF.
- Broad trends in bark flammability occur across environmental gradients. Most marked is the propensity for ribbon bark-producing species to occur at higher altitudes and latitudes: there was a greater proportion of long-ribbon-producing species in vegetation classes that occur primarily in the south of the state, than in those found in the north. On the other hand, the proportion of species with stringy bark was higher, overall, in the north than in the south. Forest classes of the western slopes and plains have very few species that produce either long ribbons or stringy bark.
- After a fire, bark fuel on stringy and other rough-barked trees generally develops more slowly than other fuel layers. Both linear and exponential modelling of field data from the Fuel Hazard Study showed a mean duration of char retention of over 30 years.
- Ribbon bark, however, appears to recover rapidly post-fire. Data from the Fuel Hazard Study showed little difference between time-since-fire categories in the amount of ribbon bark present. Quantity, however, was mostly very small. This applied across all classes except the wet sclerophyll forest and the grassy woodland, where ribbon bark quantity was rated ‘small’ and ‘moderate’ respectively.
- In general, we erred on the side of over-estimating rather than under-estimating bark hazard and load. Maximum values on both these fuel parameters are only likely to be attained in

mature forests that have not burnt for many years. In many NSW forests these conditions will rarely transpire, due to logging and extant fire return intervals.

- Maximum estimated bark fuel hazard ratings for individual vegetation classes ranged from Moderate to Extreme, with the maximum bark hazard for the majority of classes set at Very High. While these estimated maxima were in line with linear models fitted to field data, in most classes in the Fuel Hazard Study, these levels had not been reached in survey sites unburnt for over 9 years.
- In most cases, estimated minimum bark fuel hazard levels were set just one level below maxima, reflecting the over-riding influence of bark type (which doesn't change with time-since-fire) rather than bark condition (which can and often does change) in bark hazard scales. Where maxima were set at Extreme, however, minima were set at High. Thus for almost all vegetation classes, minimum bark hazard ratings were estimated to be High. This setting was in line with intercepts for linear models of DSE bark fuel hazard as a function of time-since-fire (attempts to fit negative exponential models were largely unsuccessful), and reflects the nature of hazard scales which require quite unusual circumstances before bark hazard in a site can be scored Moderate or Low.
- Bark fuel load estimates are presented in Table 14. Maxima ranged from 0.6 to 4.5 t/ha, with estimates for the majority of classes falling between 1.5 and 3.5 t/ha. Wet sclerophyll forests tend to carry relatively high bark fuel loads. For most vegetation classes, stringy bark was the major contributor to bark fuel load estimates.
- In calculating minimum bark fuel loads, we assumed trees would retain a proportion of their bark fuel immediately post-fire. This assumption was in line with models of bark char in Fuel Hazard Study vegetation classes, as a function of time-since-fire. In fact, bark load in the early post-fire years will be influenced by the intensity of preceding fire(s), and may be lower or higher than our estimates. Estimated minima ranged from 0.14 to 1.5 t/ha.
- Both the linear and exponential decay models provided a reasonable fit for bark char as a function of time-since-fire, in most Fuel Hazard Study classes. We used the mean k value for decline in stringy bark char, 0.10, to describe the negative exponential model trajectory of fuel load from minimum to maximum values, for all vegetation classes.
- Note that estimated fuel loads represent all bark available for consumption. While a proportion of available bark is likely to burn in the initial stages of flaming combustion, and thus could be considered 'fine fuel', combustion of bark on tree trunks may continue for some time. Particularly for rough-barked trees, including stringybarks, the concept of 'fine fuel < 6 mm' is difficult to apply. Although loose, surface bark may be 'fine' and burn rapidly, inner layers of more closely-packed bark may burn after the passage of the fire front. In applying the estimates in this report, modellers need to take this into account, perhaps by assigning a proportion of estimated fuel load values to each combustion stage.

1 Introduction

The wet and dry sclerophyll forests and grassy woodlands of New South Wales are almost exclusively dominated by trees from the closely related genera *Eucalyptus, Corymbia,* and *Angophora* (Mytaceae), together commonly referred to as Eucalypts (Keith, 2004). Sclerophyll forests and grassy woodlands are particularly prone to fire (Gill and Catling, 2002), and as the predominant tree taxa of these formations, Eucalypts make a significant contribution to bushfire fuels (Gill, 1997). This contribution is to all fuel layers: to the surface and near-surface layers through dropped dead leaves, sticks and bark; and to the elevated and canopy fuel layers through living material and retained dead leaves, sticks, branches and bark (Gould *et al*., 2011). There is a large body of research covering the measurement, assessment and contribution of these fuels to fire behaviour (Watson, 2009), with greatest coverage and emphasis on surface fuel. Whilst bark fuel is recognised as making an important contribution to fire behaviour (Gould *et al*., 2007a), its measurement is in its infancy (Watson, 2009).

Bark is one of the most variable features across Eucalypt species. At the broadest scale Eucalypts can be divided into those that shed their dead bark annually (the smooth barks) and those that retain their dead bark, which accumulates year by year on the trunk and branches (the rough barks). Within the latter category, the persistent bark varies widely in texture, fibre length and thickness. Between these two categories are species, commonly referred to as “half-barks”, whose bark is persistent to variable heights on part, or all, of the trunk. A number of broad categories are used to describe the variation found in Eucalypt bark (Boland *et al*., 2006; Botanic Gardens Trust, 2009; Centre for Plant Biodiversity Research, 2006):

- <u>Smooth bark</u>: is usually shed annually, either in one go, as in *C. maculata* (Spotted Gum), or in patches throughout the year, as in *E. punctata* (Grey Gum).
- <u>Scribbly</u>: Some smooth barks have characteristic “scribbles”, caused by insect larvae, e.g. *E. racemosa*. The scribbly condition is also seen on the smooth-barked upper trunk and branches of some half-barks, e.g. *E. pilularis* (Blackbutt), and is therefore used as a secondary descriptor.
- <u>Ribbon bark</u>: In some species the decorticating bark typically curls longitudinally when drying, forming cylindrical pieces of “ribbon” bark, often metres long. These ribbons can accumulate on the upper trunk and in the crown through detaching incompletely or being caught in branch axils. Ribbon bark can form on different base bark types, and is rarely used as a primary bark description (except for a few very “ribbony” species, e.g. *E. viminalis*).
- <u>Stringybark</u>: is composed of long loosely intertwined fibres, which can be pulled off in long strings. It is thick, spongy and usually has deep longitudinal furrows.
- <u>Box bark</u>: is composed of short, compacted and tightly held fibres. It is thin, hard and finely flakey with narrow longitudinal fissures.
- <u>Peppermint bark</u>: is composed of short to medium fibres. It is moderately thin but usually thicker and spongier than box bark. It has narrow longitudinal fissures, often exposing finely interlaced layers below.

- Tessellated bark: retained fibrous bark which splits horizontally as well as vertically as the tree grows, resulting in bark held in small plates. These plates can be firm or spongy as in red bloodwoods (e.g. *C. gummifera*) or flakey as in yellow bloodwoods (e.g. *C. eximia*).
- Ironbark: One of the easiest of the bark types to identify and describe, ironbark is infused with kino, which hardens, resulting in very hard, thick, dark bark. As it is persistent, it has deep and wide longitudinal furrows.

There is some overlap in these categories and some species can show characteristics of more than one of the categories in a single tree, e.g. *E. pilularis* has rough bark on its trunk, smooth on the upper branches, often with scribbles, and can form long ribbons of decorticating bark (CPBR, 2006; Botanic Gardens Trust, 2009). In addition bark can vary both temporally and spatially within a species. Bark on a young *E. sieberi* is soft and flakey, whereas on a mature tree it is hard, thick and fissured, much like an ironbark (Boland *et al*., 2006). The smooth nature of Spotted Gum (*C. maculata*) bark could not be contested, yet for a couple of weeks each year before and during its annual shedding, it can have copious small, curled pieces of bark covering its bole and branches (*pers. obs*. 2011). In the southern extent of its range *E. chloroclada* has a stocking of finely fibrous, flakey to box-type bark, whereas in its northern extent it usually lacks rough bark altogether (CPBR, 2006).

Bark contributes to bush fire behaviour through three particular mechanisms. Firstly, dead bark retained on trees contributes to the overall fine fuel load of a forest (Gill, 1997) (Bark which has been completely shed is usually considered a part of the surface fuel load, in some cases making a considerable contribution (Gill *et al.*, 1986)). Secondly, bark can act as a “ladder fuel”, by carrying flames vertically from the surface into the tree canopy, leading to crown fires (McCarthy *et al*., 1999). Thirdly, certain bark types are the major contributor to the “spotting” process in which glowing or flaming pieces of fuel are transported by wind and convection currents to propagate new, spot fires beyond the fire front. For each of these mechanisms, some bark types contribute more than others.

Unlike surface fine fuel, the **fuel load** of bark held on standing trees cannot be directly measured through the established cut, dry and weigh method. Therefore, the relatively small number of studies addressing bark fuel load (e.g. Gould *et al*., 2007a) have estimated the quantity of bark consumed in fires per unit area by measuring reduction in bark thickness and combined this with figures for tree density and size-class distribution. Research by Gould *et al.* (2007a) as part of the Project Vesta experiments showed that initial bark thickness in Jarrah forest was related to time-since-fire (TSF) as well as to the season and intensity of past fires (Jarrah, *E. marginata*, has stringy bark). Post-fire calculations showed that reduction in bark thickness not only correlated with pre-fire fuel age (the length of the last interfire interval) and pre-fire bark thickness, but also significantly correlated with fire intensity. Higher intensity fires resulted in greater depth of bark removal as well as greater height of bark charring.

For bark to act as a **ladder fuel** it must be “available” to burn and continuous enough to carry fire vertically up the trunk and into the branches. The longer the bark fibres and the more loosely the bark is held, the more available it is to act as ladder fuel. This directly relates to bark type, tree age and TSF (Catchpole, 2002). The bark types most likely to act as ladder fuel are those that fall within the broad categories of stringy and subfibrous bark. If ribbons are continuous along the bole and into the crown, they too will act as ladder fuel. Flames do not 'climb' trees with smooth or iron bark (McCarthy *et al*., 1999).

Stringy and ribbon bark are recognised as the major contributors to **spotting**. This is because they are often loosely attached, are of relatively low terminal velocity (i.e. light enough to be lifted by the convection plume and descend slowly in the wind field), and have sufficient combustion times to remain alight till they land on suitable fuel to start a spot fire (Gould *et al*., 2007a). Stringy bark is renowned for intense short-distance spotting, whilst ribbon bark is know to cause occasional spotting tens of kilometers beyond the fire front (Ellis, 2011). Spotting is a major cause of suppression effort failure (Gould *et al*., 2007a).

All in all, the contribution of bark to fire spread, fire intensity and suppression difficulty, is significant. Recognition of this fact is reflected in recent methods for predicting fire behaviour and its consequences in Australian forests, which require bark fuel loads and/or hazard scores as inputs:

- The empirically-based 'Vesta' tables for spotting distance in forests require input of 'hazard scores' for bark fuel together with those for surface and near-surface fuel. Guidelines for determining these scores are outlined in Gould *et al.* (2007b; the 'Vesta guide'), along with spotting distance tables.
- The fuel hazard assessment system developed by the Victorian Department of Environment and Sustainability in 1999 (the 'DSE guide'; McCarthy *et al*., 1999) and updated in 2010 (the 'Revised DSE guide'; Hines *et al*., 2010), likewise has an input requirement for a bark hazard rating; this is combined with hazard ratings for surface and elevated fuel to rate overall fuel hazard. DSE overall fuel hazard scores have been empirically linked with probability of first attack success (McCarthy and Tolhurst 1998, Plucinski *et al.* 2007).
- The 'Phoenix' fire behaviour simulator developed in Victoria uses the same three fuel layers as the DSE guide to characterise fuel development with TSF, requiring, for each layer, parameters for 'Initial' (fuel load immediately after fire), 'Limit' (steady state fuel load), and *k*, the rate at which fuel develops, according to the negative exponential model.

The ability to measure and model the contribution of bark fuel to fire behaviour on a landscape scale, however, is complex for a number of reasons:

- <u>Mixed (Eucalypt) species pattern</u>: In NSW, sclerophyll forests and woodlands typically contain a number (typically two or three, but up to ten) of co-occurring Eucalypt species (Florence, 1996), resulting in most stands comprising a mixture of bark types. The indicative tree species listed for each vegetation class in Keith (2004) reflect this pattern. Additionally, the relative abundance of each bark type within each vegetation class is variable and has rarely been directly measured. Manuals for determining fuel hazard scores generally provide inadequate guidance as to how to rate bark fuel hazard in a site with a variety of different tree species and bark types, although the Revised DSE guide does address this issue to some extent. If at least 10% of trees in an assessment plot have fine fibrous bark, this guide (Hines *et al.* 2010) directs assessors to use the table for "fine fibrous bark types including stringybarks." If less than 10%

of trees have stringybark, assessors are directed to two additional rating tables, covering "ribbon or candle" and "other" bark types.

- Impact of time since fire (TSF), fire intensity and tree age: In the absence of fire, bark thickness is a function of tree diameter (with different regression equations for different species; Vines, 1968), and therefore tree age (Chatto *et al.*, 2003). During fires of a certain minimum flame height, stringy and subfibrous bark is consumed, thus reducing bark thickness (Gould *et al.*, 2007a). Therefore TSF has a direct impact on the amount of available bark fuel. In addition bark quantity is closely related to the intensity and season of past fires, with higher intensity fires at dryer times consuming greater thicknesses of bark to greater bole heights (Chatto *et al.*, 2003; Gould *et al.,* 2007a). Using bark thickness as a proxy, the amount of bark fuel on a subfibrous or stringybark tree at any one time will therefore be a function of its age, of the time since the previous fire, and of the intensity and season of previous fires.

2 Aim

A report on fuel load dynamics in NSW forests and woodlands has recently been prepared by Watson (2011) to provide a scientific basis for fuel development models which may be of use to fire and land management authorities in NSW. The report synthesised scientific studies which address parameters relevant to determining the trajectory with TSF of fuel load in the litter, near-surface and elevated fuel layers. However as very little empirical work has been done in NSW on bark fuel load or hazard, this fuel layer was not addressed. The aim of the current study, therefore, is to complement the previous report by estimating, for NSW forest and grassy woodland vegetation classes:

- maximum and minimum hazard scores / ratings for bark fuel; and
- maximum and minimum bark fuel loads, in tonnes/hectare (t/ha).

We also aimed to determine appropriate model types to describe the development of bark fuel hazard and load across the post-fire sequence, and to identify:

- appropriate post-fire ages to step hazard from minimum to maximum values;
- for fuel load, an indicative value for *k* for input into the Phoenix fire behaviour simulator.

Note that hazard ratings and scores are directly interchangeable in this report, with scores simply being the numerical equivalent of the ratings, as follows:

Hazard Rating		Hazard Score
L	=	1
M	=	2
H	=	3
VH	=	4
E	=	5

This scale follows previous practice (McCarthy and Tolhurst, 1998; Plucinski *et al.*, 2007; Tolhurst *et al.*, 2007) and is the scale used in Phoenix. The hazard-rating-to-score scale conversion differs slightly in the Vesta system: for bark it is simply an integer range from 0 (L) to 4 (E).

3 Methods

3.1 Determining bark types in vegetation classes

3.1.1 Vegetation classes addressed

Of the 99 vegetation classes described by Keith (2004), this study addressed those with a tree canopy of Eucalypts in three formations − wet sclerophyll forests (WSF), dry sclerophyll forests (DSF) and grassy woodlands (GW) − paralleling the scope of the Watson (2011). Rainforests were omitted due to their limited distribution, dominance by species other than Eucalypts and tendency not to carry fire. One class in the DSF formation, Southern Wattle DSF, was excluded from the analysis as it has no Eucalypt species in its canopy. Thirty-nine vegetation classes were analysed in all (Table 1).

Table 1: Summary of vegetation classes analysed in study

Vegetation formation	Vegetation subformation	No. Vegetation classes
Wet sclerophyll forests	wet sclerophyll forests (shrubby)	4
	wet sclerophyll forests (grassy)	5
WSF Subtotal		***9***
Dry sclerophyll forests	dry sclerophyll forests (shrub / grass)	10
	dry sclerophyll forests (shrubby)	13
DSF Subtotal		***23***
Grassy woodlands	(no subformations)	7
TOTAL		**39**

3.1.2 Initial bark classification

For each vegetation class, all Eucalypt (*sens. lat*.) tree species recorded in Keith (2004) as "indicative" were listed. Using a number of key sources (Boland *et al.*, 2006; Centre for Plant Biodiversity Research, 2006; Botanic Gardens Trust, 2009) each Eucalypt species was initially allocated to one of the following ten bark categories, as follows:

- **Ironbark:** As this is such a distinctive bark type, most bark descriptions simply listed it as "ironbark" with the occasional added descriptor such as: "hard", "deeply furrowed / fissured", "thick".
- **Stringybark:** long fibred bark, which can be pulled off the tree in strips. Descriptors of stringybark included: "stringy", "long fibred", "thick, firm, furrowed", "deep longitudinal fissures". The shorter fibred "stringybarks", e.g. *E. planchoniana* (Needlebark Stringybark), and the white mahoganies (e.g. *E. umbra*) were categorised as "Subfibrous – stringy" (see below).
- **Smooth:** included only those species that usually have no persistent dead bark on the whole trunk and branches, e.g. *E. racemosa*. Those that are mostly smooth but usually retain some rough bark at the base of the trunk, or more extensively, were categorised under "Smooth –

short sock" or "Half barks". As the scribbly nature of some Smooth-barks has little bearing on flammability, those species primarily described as "Scribbly" were simply allocated to the "Smooth" bark type category.

- **Smooth – short sock (to 4m):** species that are smooth on their upper trunk and branches, but usually retain a stocking of rough persistent bark on the lower part of the trunk, typically between 1 – 4 metres high. A typical description read: "smooth with a short stocking of persistent rough bark", or "rough and flakey on basal 1–4 m of trunk, smooth above". Descriptions of the persistent bark of the sock included: "loose basal slabs", "hard platy slabs", "shortly fibrous, compact", "fibrous-flakey", "corky", "scaly".
- **Half barks (whole trunk or >4m):** species whose bark (generally of the rough subfibrous type) is usually persistent for most, or all, of the trunk and sometimes even to the larger branches. Descriptions always mentioned it being "smooth above". Given the partly decorticating nature of these trees, they often form ribbons. Descriptions included: "rough and persistent on the major part of the trunk", "stocking of finely fibrous, flakey to box-type bark", "persistent on full trunk, shortly fibrous to stringy, smooth above", "rough and compact to larger limbs, fibrous".
- **Subfibrous – box-like:** descriptions usually specifically referred to "box-type" bark, which is shortly fibrous and thin compared to the bark of other rough-barked Eucalypts. Descriptions included: "shortly and closely fibrous", "finely fibrous, and slightly flakey", "irregularly ridged and cracked", "often becoming finely tessellated".
- **Subfibrous – peppermint-like:** as with box-type, descriptions usually explicitly referred to "peppermint-like" bark, which has short to medium-length fibres and is thicker and more spongy than box-type bark. Additional descriptors included: "fibres medium length, moderately thin, underlayers criss-crossed", "subfibrous with interlaced strands", "finely fibrous with shallow longitudinal fissures".
- **Subfibrous – stringy:** In reality there is a continuum between the very coarse stringy bark of the "true stringybarks" (e.g. *E. macrorhyncha*) and the softer, shorter fibred bark of the mahoganies (e.g. *E. carnea*); indeed there can be an age continuum within a species. Subfibrous – stringy barks are often able to be "peeled" off in fibrousy strips, however these tend to be softer and shorter than those of the true stringybarks. Some descriptions even made the distinction of bark being "held in flattish strips rather than typical stringybark". Descriptions for this bark type included: "thick, shortly fibrous", "fibrous, spongy", "stringy or fibrous, with shallow longitudinal fissures".
- **Subfibrous – tessellated:** Descriptions of this bark type always had the word "tessellated" in them, with other descriptors providing further detail including: short-fibred, friable, fibrous-flakey, spongy.
- **Subfibrous – rough:** a necessarily broad category ranging from the soft, fibrous, corky bark of *A. bakeri* to the compact, thick, longitudinally furrowed bark of mature *E. sieberi*. The unifying feature of this category would be that it looks quite rough without being "stringy", i.e. when detached, it comes away in uneven spongy or rough pieces. Species categorised at "Subfibrous – rough" included those whose bark was described using any combination of: "rough", "corky", "fibrous – flakey", "thick, fibrous, spongy", "shortly fibrous and friable"

“thick, elongated, slabs”, “coarse and thick, fibrous, furrowed”, “sometimes longitudinally fissured”, “coarsely platy and fissured”. An archetype of “Subfibrous – rough” would be *E. botryoides*.

3.1.3 Bark type classification used for most analyses

Since there were as few as two species listed for a particular vegetation class, it became apparent that the above categories were too numerous to indicate trends. Bark types were therefore distilled into five categories by the following process:

- **Ironbark:** Category was not changed due to the distinctive nature of this bark type.
- **Stringybark:** Species originally categorised as Subfibrous – stringy were added to this category.
- **Smooth:** Category left as is.
- **Smooth with stocking:** This category was simply a renaming of the former Smooth – short sock category.
- **Subfibrous:** This category was a compilation of all four remaining Subfibrous bark categories, plus the Half barks.

3.1.4 Classification of species by propensity to produce ribbons

Because ribbon formation can occur on a number of base bark types, the propensity of a species to form ribbons was recorded as a separate variable to bark type. This field was divided beyond the binary yes / no. Species which consistently form long ribbons along the smaller and larger branches in the crown were classified as "Ribbon - long / lots"; these ribbons either do not detach completely or get caught in bunches in the branch axils and remain hanging in the crown (e.g. *E. viminalis*). Some species, however, form shorter ribbons, often seasonally and / or inconsistently, which tend not to remain hanging in the crown (e.g. *E. punctata*). These were classified as “Ribbon – short / some”. When assigning each species to one of the three "propensity to produce ribbons" categories, a combination of sources was used (Boland *et al.*, 2006; Centre for Plant Biodiversity Research, 2006; and Botanic Gardens Trust, 2009), as different sources placed more or less emphasis on this feature as a descriptor for a species’ bark.

3.1.5 Initial analysis of bark characteristics in vegetation classes

As there was a large range in the number of Eucalypt species recorded for individual vegetation classes (between 2 and 13), we used the *proportion* of species exhibiting each bark type, and the proportion of species in each propensity to produce ribbons (PPR) category, to make commensurate comparisons. For each vegetation class, the number and proportion of species displaying each bark type was tabulated. The same process was then carried out for “propensity to produce ribbons” (PPR).

3.2 Comparison with field data

As an independent check on bark type proportions calculated using the species lists in Keith (2004), we drew on data collected as a part of a field study of fuel hazard (University of Wollongong Fuel Hazard Study, FHS). This included lists of tree species in multiple survey sites for eight vegetation types: four dry sclerophyll forest (shrubby) classes; two dry sclerophyll forest (shrub / grass) classes; a grassy woodland; and a wet sclerophyll forest (Watson *et al*., 2012). The complete species list for each vegetation class was used to calculate bark type and PPR proportions, using the methods described above. For methods used in the FHS, see Watson *et al.* (2012).

The wet sclerophyll forest surveyed as a part of the FHS was a combination of two intergrading classes described by Keith (2004). These were North Coast WSF and Northern Hinterland WSF. In order to perform a commensurate comparison, the Keith (2004) data for these two classes was pooled: we merged the species lists for the two classes, removing duplicates (species listed for both classes), and recalculated bark type and PPR numbers and proportions. Although not strictly accurate given this situation for the WSF, we have used the term “class” when referring to the eight vegetation types surveyed in the FHS, through this report.

The FHS proportions were compared with those derived from the Keith (2004) species lists (including the pooled WSF data described above) for the eight surveyed vegetation classes.

3.3 Bark types across formations and environmental gradients

To explore potential trends in bark fuel, bark type and PPR proportions were compare between vegetation subformations and across broad environmental gradients. For all groupings of vegetation classes, bark type and PPR proportions were calculated by averaging proportion figures across component classes. The comparison of average bark type and PPR proportions across broad environmental gradients was carried out by grouping classes in relation to the following three environmental characteristics (Appendix 3):

- **Rainfall**: classes were divided into those occurring primarily in regions where mean annual rainfall exceeds 800 mm (*high* rainfall) and those found where rainfall is generally below this figure (*low* rainfall), as per the Keith (2004) descriptions. Comparison was limited to the two DSF subformations as no WSF classes fell in the low rainfall category and only one grassy woodland class was classified as occurring in the high rainfall zone.
- **Latitude**: classes were divided into those that occur predominantly in the *North* of the state of NSW and those that occur predominantly in the *South* of the state, as per the Keith (2004) descriptions. Classes with a fairly even State-wide north-south distribution (e.g. Coastal Valley Grassy Woodlands) and those that occur fairly centrally (e.g. several classes found around Sydney) were allocated to a *Central* group. We compared:
    - Wet sclerophyll forests (by subformation) in the North and South of the state (there were no WSF classes in the Central group);
    - Dry sclerophyll forests (by subformation) across all three groups (North, Central and South).

Grassy woodlands were not included in the latitudinal comparisons, as almost all classes were classified into the Central group.

- **Elevation:** classes were initially divided into those that occur predominantly above 600 m asl and those that occur predominantly below this elevation, as per the Keith (2004) descriptions. As the low elevation classes encompassed a broad range of compounding environmental factors, rainfall in particular, it was decided to further split this group into those found east of the Great Dividing Range and those that occur on the western slopes and plains. We compared:
    - Wet sclerophyll forests (by subformation) found on the escarpment and tablelands (high elevation) with those found on the coast (WSF classes do not extend west of the Great Dividing Range);
    - Grassy woodlands found on the escarpment and tablelands (high elevation) with those found predominantly on the western slopes and plains (the coastal group was excluded as only one GW class occurred east of the Great Dividing Range); and
    - Dry sclerophyll forests (by subformation) across the three elevation groups.

3.4 Estimating bark hazard scores for vegetation classes

3.4.1 Maximum bark hazard scores

The starting point for determining bark fuel hazard scores for NSW forest and woodland vegetation classes across the post-fire sequence was to estimate the maximum bark hazard score a particular class might be expected to reach. Maximum bark fuel in a forest patch will depend on tree species present, and will occur where the forest is long-unburnt and trees are of maximum girth. We used the bark types and proportions described above to derive an estimate of maximum bark hazard score in long-unburnt forests and woodlands of mature trees.

Methods for scoring bark fuel hazard emphasise the over-riding role of stringy bark in driving spotting behaviour (Hines *et al*., 2010; Gould *et al*., 2007b; McCarthy *et al*., 1999). Even in a stand with a mixture of bark types, if trees with stringy bark are present, the condition of this bark type determines hazard ratings (this is somewhat nuanced in the DSE guides, where stands with < 10% of trees with stringy bark are scored somewhat differently); this is presumably because even a single stringybark tree has the potential to produce embers and cause spot fires. Maximum hazard scores for stands with stringybark trees are at the top end of the bark hazard rating scale, reaching Extreme where bark is uncharred and loose (Hines *et al*., 2010; Gould *et al*., 2007b; McCarthy *et al*., 1999).

Thus for vegetation classes where the species listed in Keith (2004) included one or more with stringy bark, we allocated a maximum hazard score of either Extreme (where > 30% of listed species were classified as stringybark), or Very High (Table 2).

For vegetation classes in which none of the species listed in Keith (2004) were categorised as having stringy bark, the maximum hazard score was based on the other bark types, using the scale in Table 2. The maximum hazard score values for these additional bark types reflect maximum hazard ratings in Hines *et al*. (2010).

Table 2: System of allocating maximum hazard scores to vegetation classes

Bark type	% of trees listed in Keith (2004)	Hazard score (rating)
Stringybark	>30%	5 (E)
	>0 and <=30%	4 (VH)
*If no stringybark present in vegetation class then take the **highest** score from the following:*		
Ribbons – long / lots	>30%	4 (VH
	>0 and <=30%	3 (H)
Ribbons – short / some	>30%	3 (H)
	>0 and <=30%	2 (M)
Subfibrous bark OR	>30%	3 (H)
Smooth with stocking	>0 and <=30%	2 (M)
Ironbark	>30%	2 (M)
	>0 and <=30%	1 (L)
Smooth (entirely)	100%	1 (L)

3.4.2 Models from field data

To provide a comparison for estimated maximum hazard scores, and to inform estimation of minimum scores and post-fire trajectories, models were fitted to data on bark fuel hazard collected as part of the FHS, using TSF as the predictor variable. In each vegetation class, data on fuel condition was collected from at least 16 sites across a range of post-fire ages, in multiple plots (usually seven) per site. For the current modelling exercise, we used site-level mean bark fuel hazard scores assessed in plots using the DSE guide. Linear and negative exponential models were fitted, for each individual vegetation class. The negative exponential model describes a situation where fuel accumulates rapidly in the early post-fire years, and then levels off; rate of development is defined by the parameter *k*. Data were pooled across classes, and linear models fitted for:

- all sites;
- sites in which > 50% of plots contained at least one tree with stringy bark; and
- sites in which < 50% of plots contained least one tree with stringy bark.

As an additional data source, mean bark fuel hazard scores for sites in three TSF categories were calculated for each of the eight FHS vegetation classes; post-fire age categories were: 0 – 6 years, 6 - 9 years, and greater than 9 years.

3.4.3 Comparison with field data

For the vegetation classes surveyed as a part of the FHS, estimated maximum fuel hazard scores derived using the methods described in Section 3.4.1 were compared with:

- fuel hazard scores derived using the same methods applied to the species lists from the FHS;
- fuel hazard scores derived from the modelling described in Section 3.4.2; and
- mean fuel hazard scores in sites unburned for over 9 years.

3.4.4 Minimum bark hazard scores and time-since-fire trajectory

Minimum bark hazard ratings for each of the 39 vegetation classes addressed in this study were then determined, using results and models from the FHS (Section 3.4.2), and an examination of hazard tables in Hines *et al.* (2010). Results and models from the FHS were also used to determine the points at which bark hazard ratings should be stepped up from minimum through to maximum values.

3.5 Estimating bark fuel load for vegetation classes

Both the Vesta and DSE fuel assessment guides provide figures linking fuel hazard scores to fuel load, in t/ha, for each of the fuel layers. Watson (2009) outlines these fuel load equivalents and highlights some issues in their derivation. In the case of bark, fuel load may not be directly convertible from hazard scores due to the emphasis on bark types which contribute to spotting in the determination of hazard scores. For example a site with trees with ribbon bark may score highly in terms of hazard due to the significant role of ribbons in spotting. However the majority of species that produce ribbon bark are smooth or smooth with a short rough-barked stocking, and thus are almost certain to have less bark fuel on trunk and branches than (long-unburnt) stringybark species. Also, as noted above, a site whose tree complement includes only a small proportion of stringybark trees would attract a bark hazard rating of Extreme or Very High, if that bark were uncharred and loose, even though the bark fuel *load* (mass per unit area) would be small relative to that in a forest composed entirely of stringybarks. Therefore calculations of bark fuel load need to take into account the proportion of all bark types present, including ribbons, with differing weightings applied to different bark types based on their relative contribution to fuel load.

3.5.1 Merging bark type and ribbon data

Even though a tree that produces ribbon bark is not likely to have as high a bark fuel load as a tree with stringy bark, in cases where it produces lots of long ribbons which accumulate on the trunk and branches it will contribute to bark fuel load to a greater extent than a smooth barked tree. A number of the species classified as "smooth", or "smooth with stocking" (Section 3.1.3), produce long ribbons of bark. We therefore created an additional bark type category, for the fuel load calculations, called “long ribbon”. The decision rule was to reassign all listed species in the "smooth" or "smooth with stocking" bark type categories that had "ribbons – long / lots" listed as their PPR category to the new “long ribbon” bark type category. Species with a PPR type of "ribbons – short / some" were not reclassified as the vast majority of these are 'gums' which only seasonally produce short ribbons during their annual bark shed.

To summarise, categories in this merged bark type classification were:

- Stringybark
- Long ribbons
- Subfibrous
- Smooth with stocking
- Ironbark
- Smooth

3.5.2 Maximum bark fuel loads

Bark type proportions were re-calculated using the revised 6-category bark type classification (Appendix 11 gives species numbers and proportions for the 39 vegetation classes, using this new classification). A maximum bark hazard score was allocated to each individual bark type (Table 3); these maximum values were taken from the bark hazard tables in Hines *et al*. (2010). Equivalent fuel load values for each bark type (Scale 1, Table 3) were initially derived from these maximum hazard scores, using Table 9.2 in Hines *et al*. (2010); these maximum fuel load values represent what one might expect in a long-unburnt forest of mature trees of species with one bark type only.

Evaluation of these figures for equivalent fuel load in the light of the limited literature confirmed that the figure for stringybark, 7 t/ha, was reasonable. Tolhurst *et al.* (1992) assessed bark loss during a fire in long-unburnt *E. obliqua* forest at 7 t/ha, while Gould *et al.* (2007a) estimated the maximum amount of jarrah bark likely to be consumed in an intense fire in long-unburnt fuels, at 8.4 t/ha. The low fuel load figures for smooth bark, ironbark, smooth with stocking and subfibrous bark also seem realistic, although validation data are not available. The figure of 5 t/ha for ribbon bark, however, was judged excessive, and was therefore scaled back to 2 t/ha (Scale 2, Table 3). This change was consistent with the explanation above, that the maximum hazard rating of VH given by Hines *et al.* (2010) to ribbon bark is predominantly based on the capacity of ribbon bark to 'spot', rather than on its contribution to fuel load. It is also consistent with findings from the FHS, which generally found ribbon quantity in survey sites to be low, even when trees from species in the "ribbon – long / lots" PPR category were relatively abundant.

For each vegetation class, the maximum fuel load for each bark type (Scale 2) was multiplied by its proportion, giving an estimated fuel load for each individual bark type. The sum of the individual bark type fuel loads gave the estimated maximum overall bark fuel load for each class. Maximum possible bark fuel load, using this method, was 7 t/ha.

Table 3: Parameters used in developing a method for estimating maximum bark fuel loads for NSW forests and grassy woodlands. * From Hines *et al.* (2010).

		Equivalent bark fuel load (t/ha)	
Bark Type	**Max Haz Score***	**Scale 1***	**Scale 2**
smooth	1	0	0
ironbark	2	1	1
smooth with stocking	3	2	2
subfibrous	3	2	2
long ribbons	4	5	2
stringybark	5	7	7

3.5.3 Models from field data

To inform estimation of minimum scores and post-fire trajectories, models were fitted to data on bark char collected as part of the FHS, using TSF as the predictor variable. Linear and negative exponential models were fitted, for each individual vegetation class, to two variables which involved estimating the percentage of char on tree trunks up to a height of 5 m, for two bark types: stringy, and subfibrous. In the case of bark char, the negative exponential model implies a more rapid drop in char in the early post-fire years, than later in the post-fire sequence; here, 3/*k* gives the number of years till only 5% of char remains.[1]

3.5.4 Minimum bark fuel loads

Minimum bark hazard scores were likewise drawn from the bark hazard tables in Hines *et al.* (2010); fuel load equivalents once again were taken from Table 9.2 in this guide (Scale 3, Table 4). For most bark types the minimum hazard score was 2 (M), with a fuel load equivalent of 1 t/ha. Smooth and iron barked trees were assumed to contribute nothing to bark fuel loads, immediately post-fire. These minimum fuel load values represent what one might expect in a recently-burnt forest of mature trees of species with one bark type only.

Table 4: Parameters used in developing a method for estimating minimum bark fuel loads for NSW forests and grassy woodlands. *From Hines *et al.* (2010).

		Equivalent bark fuel load (t/ha)	
Bark Type	**Mim Haz Score***	**Scale 3***	**Scale 4**
smooth	1	0	0
ironbark	1	0	0
smooth with stocking	2	1	1
subfibrous	2	1	1
long ribbons	2	1	1
stringybark	2	1	2

[1] This form of the negative exponential model is also called an exponential decay model, or curve.

Evaluation of these figures in the light of the limited information available suggested that for most bark types, fuel load values in Scale 3 were reasonable. For the smooth with stocking, subfibrous and long ribbon bark types they imply a loss of 50% of pre-fire bark (assuming maximum levels have been reached); this was judged to be appropriate. For stringy bark, the quantity consumed by fire will vary with fire intensity, however data from the FHS strongly suggests that after many fires, a reasonable proportion of bark will remain. We therefore set the minimum bark load, for a forest of only stringybark trees, at 2 t/ha. Values used to calculate minimum bark fuel loads are summarised in the final column of Table 4 (Scale 4). The process used to determine total minimum bark loads for each vegetation class paralleled that used to derive estimates for maximum fuel loads (Section 3.5.2).

3.5.5 Time-since-fire trajectory for fuel load

The relative fit of the linear and negative exponential models to the bark char data from the FHS was used to determine how best to characterise the trajectory between minimum and maximum fuel loads. Suggested values for use in the Phoenix fire behaviour simulator were also informed by these models.

4 Results

4.1 Bark types in vegetation classes and formations

For each vegetation class the number and proportion of Eucalypt species in the Keith (2004) lists, for each bark type (Section 3.1), are tabulated in Appendix 1, along with the number and proportion of species in each PPR category. The maximum number of stringybark species listed for a single vegetation class was 4, while the highest proportion of stringies was 50%. Eleven of the 39 vegetation classes covered by this study had no stringybark species at all. The maximum number of species with a propensity to produce long/lots of ribbons listed for a single vegetation class was 7, the maximum proportion 80%. Seven vegetation classes had no species in this category.

The mean proportions of each bark type across the five forest and grassy woodland subformations are illustrated in Figure 1, while Figure 2 shows proportions in each PPR category. While the total proportion of stringy- and subfibrous-barked species was much the same in each grouping, in wet sclerophyll forests a higher proportion of these rough-barked species had stringy bark; this applied particularly in shrubby WSF. The proportion of stockings at the base of smooth-barked species was also greater in WSF (Figure 1). The proportion of species with ribbons of any sort was greater in WSF and grassy woodlands than in DSF. The proportional representation of species with long / lots of ribbons was particularly high in wet sclerophyll forests (Figure 2).

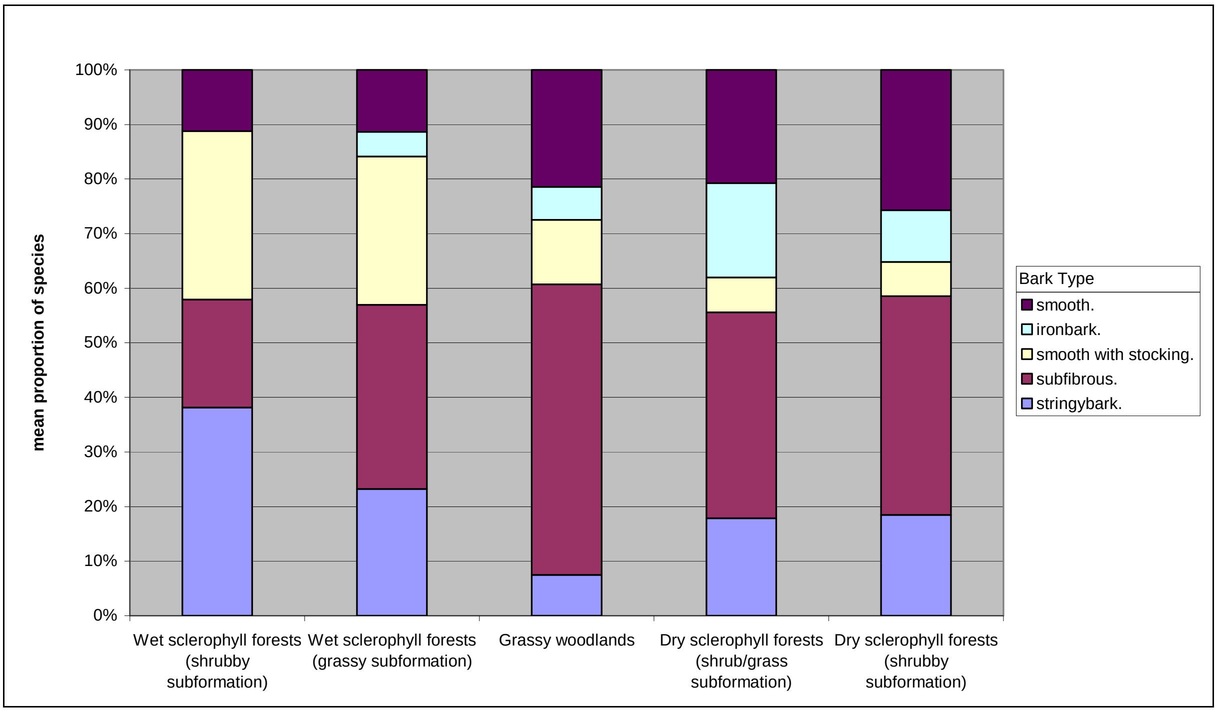

Figure 1: Mean proportion of listed species (Keith 2004) with five different bark types, in five vegetation subformations.

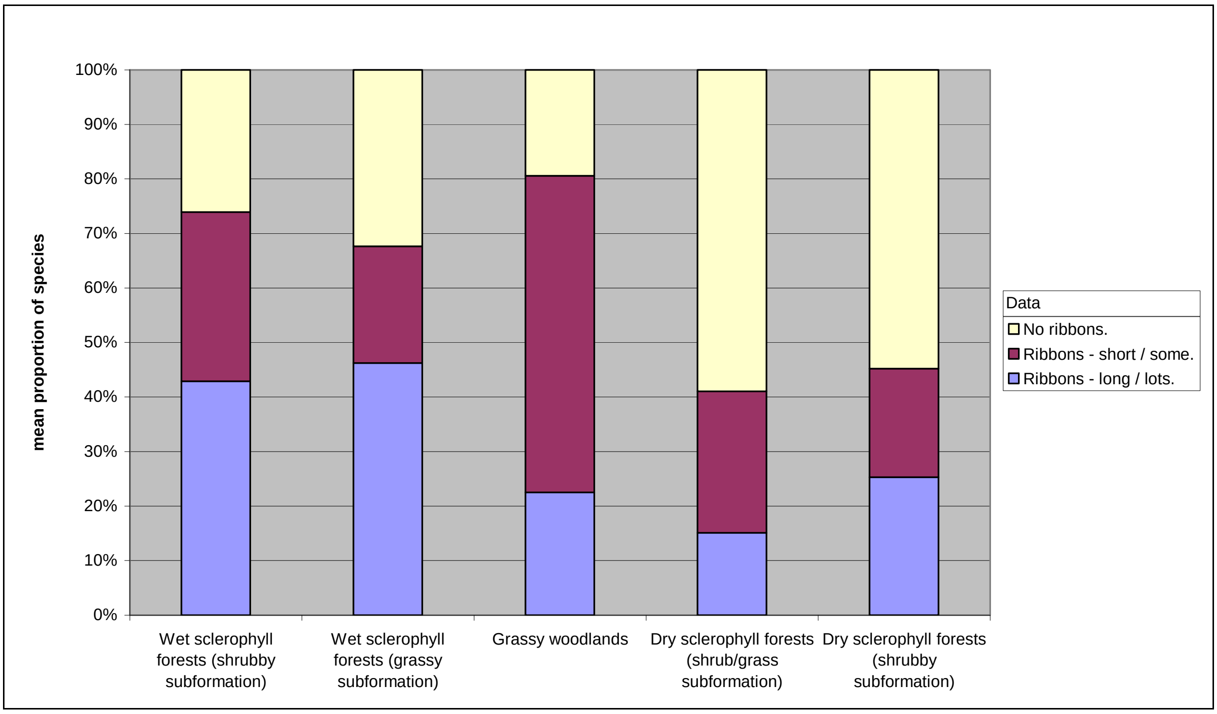

Figure 2: Mean proportion of listed species (Keith 2004) having differing propensities to produce ribbons, in five vegetation subformations.

4.2 Comparison with field data

For the eight vegetation classes surveyed as a part of the FHS, the number and proportion of Eucalypt species recorded for each bark type (Section 3.1) are tabulated in Appendix 2, along with the number and proportion of species in each PPR category. FHS bark type proportions were similar to those calculated using the species lists in Keith (2004) (Figure 3), with 75% of vegetation class X bark type combinations being within 10% of each other. The PPR proportions, likewise, were similar within each vegetation class (Figure 4) whether the species lists in Keith (2004) or the FHS field data were used. Less than 15% of the vegetation class X PPR category combinations showed a difference greater than 10% between the two data sources. The percentage of tree species in the "ribbon (long / lots)" category was within 10% in all eight classes.

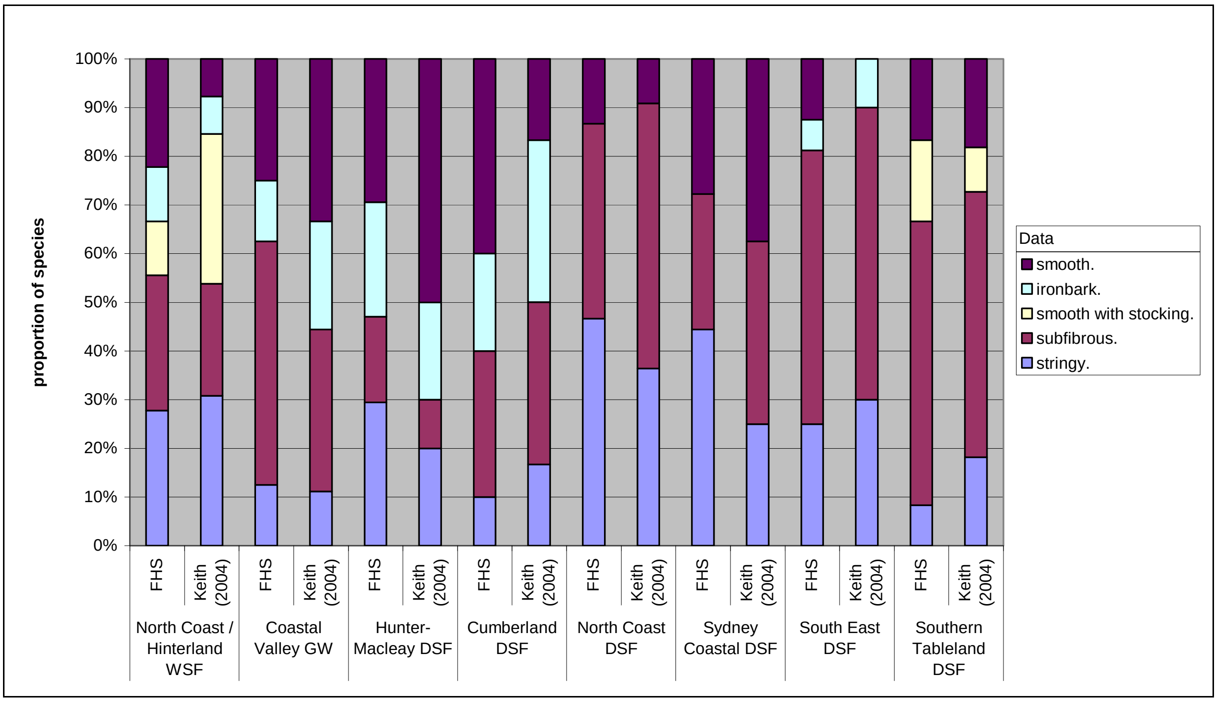

Figure 3: Comparison of bark type proportions in eight vegetation classes, using tree species lists from two sources: a field study of fuel hazard (FHS – Watson *et al*., 2012) and Keith (2004).

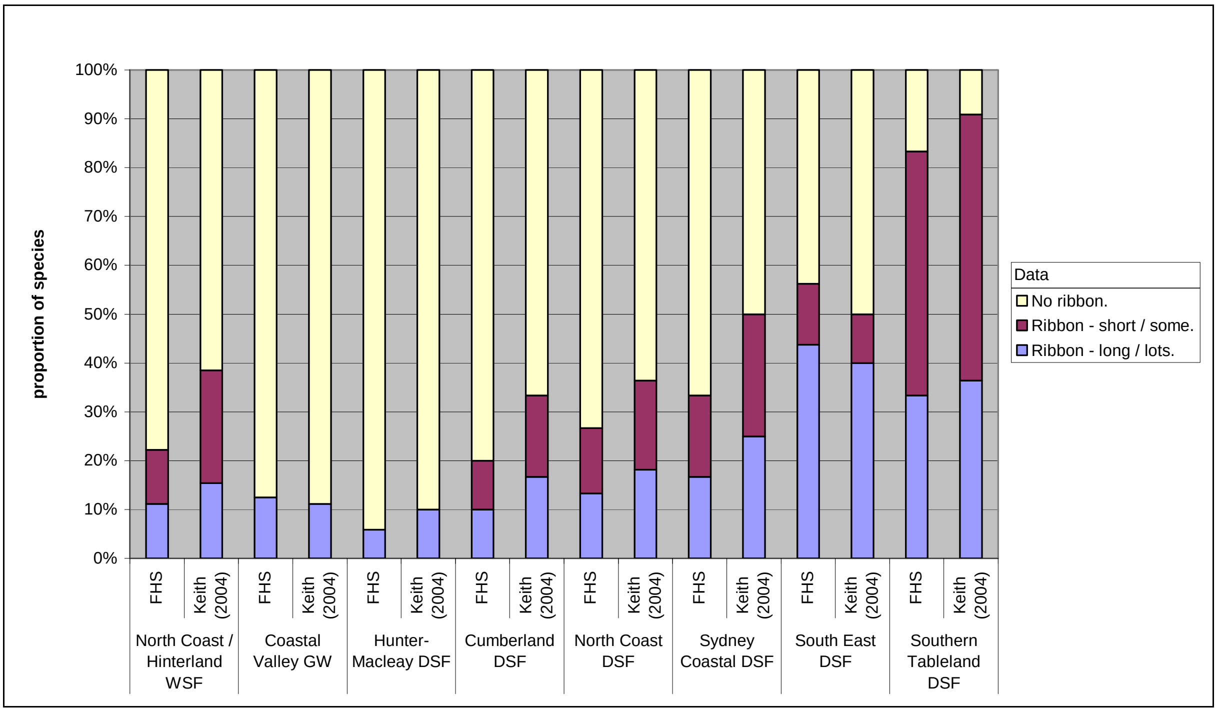

Figure 4: Comparison of propensity to produce ribbons (PPR) proportions in eight vegetation classes, using tree species lists from two sources: a field study of fuel hazard (FHS – Watson *et al*., 2012) and Keith (2004).

4.3 Bark types across environmental gradients

When vegetation classes were grouped, within their corresponding vegetation subformation, into categories based on broad environmental gradients, a number of trends in bark type and PPR proportions became apparent:

- Rainfall: In each of the two DSF subformations, the mean proportion of both stringybark species and species with a propensity to produce long ribbons was greater in the high rainfall (>800mm) group than in the group of classes occurring in areas of lower rainfall. Conversely, the mean proportion of ironbarked species was consistently higher in the low rainfall group (Appendix 4).
- Latitude: For both WSF subformations the mean proportion of species with a propensity to produce long / lots of ribbons was markedly greater in the South group, whilst the mean proportion of stringybark species was higher in the North group (Appendix 5). Both these trends were repeated in the shrubby subformation of dry sclerophyll forests (Appendix 6), but not in the shrub / grass subformation, where there was little differentiation in bark types and propensity to produce ribbons between latitude groups.
- Coast, High country and Western slopes and plains: In each WSF subformation there was a much greater mean proportion of species that produce long / lots of ribbons – and ribbons in general − in the high country classes than in those at low elevation on the coast (Appendix 7). There was also a corresponding altitudinal increase in the mean proportion of "Smooth with stocking" species, a bark type often associated with ribbon-production. The trend for increasing (long / lots) ribbon production with altitude was particularly marked in the Grassy Woodland (Appendix 8) and both DSF subformations (Appendix 9), where there were no listed species in the western slopes and plains group classified as producing long / lots of ribbons. In each of the Grassy Woodland and DSF subformations, stringybark proportion was also very low in the western group, and reached its maximum in the high country group. By contrast, the proportion of ironbarks in the two DSF subformations was much higher in the western group than in the other two groups (high country and coast).

To summarise, the broad trends in bark fuel appear to be increasing propensity to produce ribbons with altitude and latitude, whilst the proportion of stringy bark appears to increase with decreasing latitude and increasing rainfall.

4.4 Bark hazard scores

4.4.1 Maximum bark hazard scores

The maximum bark hazard score assigned to each target vegetation class is given in Table 5. For the first 28 classes in this table, allocation was based purely on the proportion of stringybark species listed in Keith (2004); of these, eleven, including five WSF classes, were allocated a score of 5 (Extreme). Scores for the eleven classes for which no stringybark species were listed, were driven by proportions of various non-stringy bark types (last column in Table 5).

Table 5: Maximum bark fuel hazard scores allocated to 39 forest and grassy woodland classes in NSW. Classes are listed in order of decreasing stringybark proportion. Vegetation classes surveyed as a part of the FHS are in **bold**. Colours represent hazard ratings / scores (Red = E (5); Orange = VH (4); Yellow = H (3); Green = M (2)).

Vegetation Subformation	Vegetation Class	Stringybark proportion	Bark fuel hazard score	Score driven by*
WSF shrubby	Northern Escarpment WSF	0.5	5	SB
WSF shrubby	Southern Escarpment WSF	0.4	5	SB
DSF shrubby	Northern Tableland DSF	0.4	5	SB
WSF shrubby	**North Coast WSF**	0.375	5	SB
WSF grassy	**Northern Hinterland WSF**	0.375	5	SB
DSF shrubby	**North Coast DSF**	0.364	5	SB
DSF shrub / grass	Northern Gorge DSF	0.333	5	SB
WSF grassy	Southern Lowland WSF	0.3	5	SB
Grassy woodlands	New England GW	0.3	5	SB
DSF shrubby	**South East DSF**	0.3	5	SB
DSF shrub / grass	Central Gorge DSF	0.3	5	SB
WSF grassy	Northern Tableland WSF	0.289	4	SB
WSF shrubby	South Coast WSF	0.25	4	SB
DSF shrubby	Northern Escarpment DSF	0.25	4	SB
DSF shrubby	**Sydney Coastal DSF**	0.25	4	SB
DSF shrub / grass	Southern Hinterland DSF	0.25	4	SB
DSF shrub / grass	Clarence DSF	0.25	4	SB
DSF shrubby	Sydney Hinterland DSF	0.231	4	SB
DSF shrubby	Sydney Montane DSF	0.222	4	SB
WSF grassy	Montane WSF	0.2	4	SB
DSF shrubby	Coastal Dune DSF	0.2	4	SB
DSF shrub / grass	**Hunter-Macleay DSF**	0.2	4	SB
DSF shrubby	**Southern Tableland DSF**	0.182	4	SB
DSF shrub / grass	**Cumberland DSF**	0.167	4	SB
DSF shrub / grass	New England DSF	0.143	4	SB
DSF shrub / grass	Upper Riverina DSF	0.143	4	SB
Grassy woodlands	**Coastal Valley GW**	0.111	4	SB
Grassy woodlands	Southern Tableland GW	0.111	4	SB
WSF grassy	Southern Tableland WSF	0	4	LR
Grassy woodlands	Tablelands Clay GW	0	4	LR
Grassy woodlands	Subalpine W-lands	0	4	LR
DSF shrubby	South Coast Sands DSF	0	4	LR
Grassy woodlands	Floodplain Transition GW	0	3	SR and SF
Grassy woodlands	Western Slopes GW	0	3	SR and SF
DSF shrub / grass	North-west Slopes DSF	0	3	SR and SF
DSF shrub / grass	Pilliga Outwash DSF	0	3	SR and SF
DSF shrubby	Sydney Sand Flats DSF	0	2	SR and SF
DSF shrubby	Yetman DSF	0	2	SF
DSF shrubby	Western Slopes DSF	0	2	IB

*SB = stringybark; LR = ribbons – long / lots; SR = ribbons – some / short; SF = subfibrous bark; IB = ironbark.

4.4.2 Models from field data

Parameter values for linear models of DSE bark fuel hazard as a function of TSF, for the eight vegetation classes in the FHS, are given in Table 6. Values for all sites in together, and for sites in which more or less than 50% of plots contained stringybark trees, are also included.

Table 6. Values for linear model parameters, and resulting predictions, for DSE bark fuel hazard scores as a function of TSF in eight vegetation classes surveyed as part of the FHS. SE in brackets. P values: ‘, <0.10; *, < 0.05; **, < 0.01; ***, < 0.001; NS, not significant. NM, not modelled, as slope not significant.

Vegetation class	Number of sites	Intercept	Slope	R^2	At 15 yrs post-fire	At 45 yrs post-fire
North Coast / Hinterland WSF	18	2.32 (0.15)***	0.060 (0.012)***	0.60	3.22	5.02
Coastal Valley GW	19	2.98 (0.11)***	0.008 (0.006) NS	0.10	NM	NM
Hunter-Macleay DSF	18	2.93 (0.23)***	0.029 (0.015)’	0.19	3.37	4.24
Cumberland DSF	16	1.88 (0.16)***	0.054 (0.010)***	0.69	2.69	4.31
North Coast DSF	18	3.00 (0.19)***	0.059 (0.018)**	0.40	3.89	5.66
Sydney Coastal DSF	32	2.87 (0.14)***	0.006 (0.010) NS	0.01	NM	NM
South East DSF	18	2.80 (0.22)***	0.040 (0.012)**	0.41	3.40	4.60
Southern Tablelands DSF	18	2.91 (0.21)***	0.034 (0.009)**	0.47	3.42	4.44
All sites	157	2.77 (0.07)***	0.030 (0.004)***	0.24	3.22	4.12
Sites with stringy bark in > 50% of plots	92	2.93 (0.08)***	0.038 (0.005)***	0.41	3.50	4.64
Sites with stringy bark in < 50% of plots	65	2.55 (0.09)***	0.018 (0.005)**	0.15	2.82	3.36

All linear models returned highly significant values for the intercept, which represents bark fuel hazard immediately after a fire. For most vegetation classes, intercepts fell between 2.8 and 3.0 (bark hazard of High); the model for sites in which > 50% of plots contained stringybark trees was also in this range. Two classes, the wet sclerophyll forest and Cumberland DSF, returned intercepts in the Moderate hazard range (2.3 and 1.9 respectively). For both these vegetation classes, this result reflects higher levels of charring (on subfibrous barked trees) immediately post-fire than was found in other classes (Appendix 12). For Cumberland DSF the almost complete absence of stringybark trees may also have contributed.

Slope values reached significance, at P < 0.10 level, for six of the eight vegetation classes, with values ranging from 0.029 to 0.059, equating to 17 to 34 years for bark hazard to increase by one level. Slope was higher in sites where more than half the plots contained stringybark trees (0.038) than in sites in which < 50% contained stringies (0.018), implying a slower rate of development in this latter group.

For five of the six vegetation classes with a significant value for slope, predicted bark hazard levels at 15 years post-fire still did not exceed High; the exception was in North Coast DSF where bark hazard was predicted, by this TSF, to have reached Very High. Across the dataset, in sites where greater than 50% of plots contained stringies the predicted hazard score at 15 years post-fire was 3.50, right on the boundary between High and Very High, while in the remaining sites the predicted bark hazard was still in the lower half of the High range (2.82). By 45 years post-fire, bark hazard in North Coast DSF, South East DSF and the wet sclerophyll forest was predicted have reached Extreme; this also applied for sites across the data set with stringies in over half their plots. For Southern Tablelands, Cumberland and Hunter-Macleay DSF, the predicted bark hazard rating at this post-fire age was in the top half of the Very High range. For sites where less than half the plots contained stringies, the predicted score at 45 years post-fire was 3.36, in the top half of the High range.

Attempts to fit the negative exponential model to DSE bark hazard data for individual vegetation classes in the FHS data were generally unsuccessful, with models unable to be fitted, or *k* values (which indicate the rate at which the curve rises) failing to reach significance, in five of the eight vegetation classes. Where *k* was significant, model fit was poor.

4.4.3 Comparison of bark fuel hazard ratings from Keith (2004) and FHS

Table 7 compares the estimated maximum bark fuel hazard ratings from Table 5 with bark fuel hazard ratings and scores which draw on field data for the eight FHS vegetation classes. For five of the eight vegetation classes, maximum ratings derived using species lists from Keith (2004) were identical to those derived from the FHS species lists, while for three classes these ratings differed by one level, with no trend towards higher scores being linked with either data source. For the six FHS classes with significant linear models, predicted bark fuel hazard scores at 45 years post-fire matched maximum ratings derived from the Keith data exactly.

In none of the vegetation classes surveyed for the FHS did the mean hazard score for bark in the oldest age class (nor in either of the two younger age classes) exceed 4 (VH; Figure 5). This was the case even in the three vegetation classes where stringybark trees were present in over 80% of plots. In the two vegetation classes for which linear models did not provide a good fit, Sydney Coastal DSF and Coastal Valley Grassy Woodland, mean bark fuel hazard scores in sites unburnt for at least 9 years were in the upper half of the High range, slightly lower than the maximum determined using the species lists in Keith (2004). Note, however, that particularly in Sydney Coastal DSF, many of the sites in this category had burned approximately 15 years prior to sampling, so time-since-fire was low relative to the 45 years used in Table 7.

Table 7: Comparison of bark fuel hazard scores using different data sources (Keith (2004) data or FHS data) and calculation methodologies (bark type proportions versus predicted values at 45 years post-fire from linear modelling using data from FHS survey sites). Classes are listed in order of decreasing stringybark proportion. Colours represent hazard ratings / scores (Red = E (5); Orange = VH (4). NM, not modelled as slope not significant.

	Bark fuel hazard score		
Vegetation Class	**Keith data – bark type proportion**	**FHS data – bark type proportion**	**FHS data – predicted bark hazard score at 45 years post-fire**
North Coast DSF	5	5	5.66
North Coast / Hinterland WSF	5	4	5.02
South East DSF	5	4	4.60
Sydney Coastal DSF	4	5	NM
Hunter-Macleay DSF	4	4	4.24
Southern Tableland DSF	4	4	4.44
Cumberland DSF	4	4	4.31
Coastal Valley GW	4	4	NM

4.4.4 Minimum bark hazard scores

As noted above, linear modelling clearly defined minimum values for bark fuel hazard, both across the dataset as a whole and for each FHS vegetation class. In almost every instance, this minimum was in the lower half of the range for High bark fuel hazard (Table 5). The two vegetation classes in the FHS where modelled minima fell into the Moderate range both had particularly high levels of charring. The tendency for bark fuel hazard scores to cluster around 3 (H) in the early post-fire years is also apparent in Figure 5; only in Cumberland DSF, with its low abundance of stringbark trees and high levels of post-fire charring (on paperbarks, a subfibrous barked tree), do scores in the early post-fire years average closer to Moderate.

Examination of the bark hazard tables in Hines *et al*. (2010) throws light on why scores below High are rare, even in the early post-fire years. In sites with stringybark trees, for a hazard score of Moderate the “entire trunk [must be] almost completely black or charred”; char levels from 50-90% attract a hazard rating of High. To allocate a score of Moderate using the ribbon bark table, trees must have “No long ribbons of bark present; trunk and branches of trees almost entirely smooth.” Only on the table for other bark types does Moderate pertain to a situation where a “Limited amount of flammable bark” is present; this rating would only be invoked in situations where stringybark trees were limited to < 10% of the stand, and ribbon bark was absent. A rating of Low is even more difficult to obtain. This rating level is not possible when using the stringybark or ribbon bark tables; and is only allocated for other bark types when there is “No bark present that could contribute to fire behaviour; trunk and branches of tree entirely smooth or free from loose bark.”

On considering both the empirical evidence from the FHS, and the scales in the DSE revised fuel hazard guide, we decided to set the minimum bark fuel hazard for all vegetation classes where maximum scores are driven by stringy bark or propensity to produce long ribbons (Table 5), at High

(3). While this rating may be slightly on the high side for the early post-fire years where fires of reasonably high intensity have left high levels of charring, we thought it best to err on the conservative side, as data from the FHS demonstrates that charring immediately post-fire is often well short of 100% (see Appendix 12). Note also that a tree which produces ribbons can do so as early as one year after a fire; in fact a sub-canopy fire will leave most ribbons intact.

For remaining classes which contain subfibrous bark, we have set minimum bark hazard levels at Moderate (2). In Western Slopes DSF, whose Eucalypt complement consists entirely of ironbarks and gums, we have allowed a minimum of Low (1). See Table 9.

Bark hazard scores in any one vegetation class thus range over either three, or two categories, a relatively flat scale.

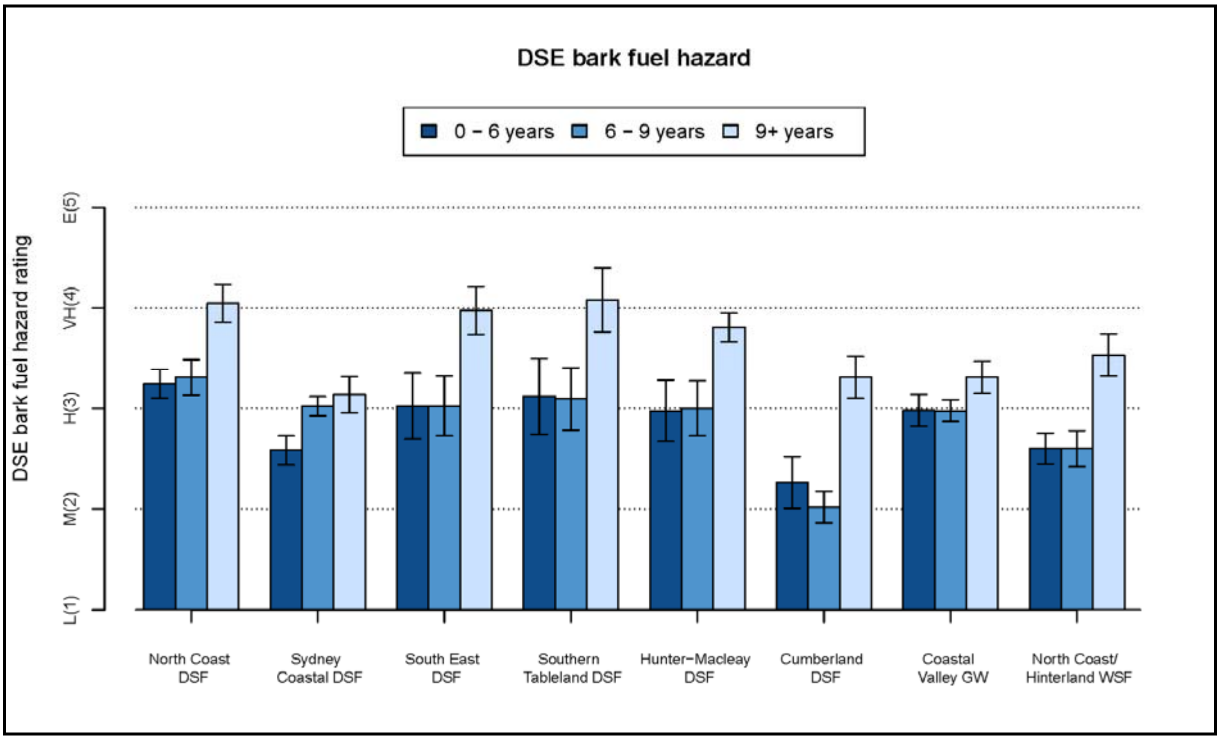

Figure 5: DSE bark fuel hazard scores in vegetation classes studied in the FHS, showing means (± SE) in three TSF classes.

4.4.5 Time since fire trajectory for hazard scores

At what post-fire age(s) should hazard levels be stepped up from minimum to maximum? The FHS data, organised by TSF category (0 – 6 years; 6 – 9 years; and 9+ years), showed a clear rise in DSE bark hazard score between the latter two TSF categories, in seven of the eight surveyed vegetation classes (Figure 5); generally this rise was from a mean of High in the first two groups, to Very High in the longer unburnt category. In the class which did not show this trend, Sydney Coastal DSF, stringybark trees occurred in less than half the plots surveyed (46%). In Coastal Valley Grassy Woodland where the trend is clear but muted (the mean of all categories is still High), this figure was 11%. The lack of stringybarks in Cumberland DSF has already been noted (they occur in only 7% of plots); here the rise, while very clear, was from Moderate to High. Thus for classes where bark hazard varies over three levels, there is a clear argument for having the first step up at a time-since-fire above, but not too far above, 9 years post-fire. Note that the majority (>85%) of sites in the 9+ year category had been fire-free for 14 years or more.

Other evidence points to the likelihood that bark hazard continues to develop slowly for decades. The poor showing of the negative exponential model implies that the pattern of fuel development exemplified by litter load, ie rapid build-up in the early post-fire years, followed by slow development after the first decade or so, does not apply to bark fuel hazard. Rather, a linear model of continuous even-paced development is applicable. The very low slope values for the linear models in Table 6 suggest fuel hazard builds up over many decades. The slope of 0.038 for sites with > 50% stringybark species equates to 26.5 years for bark hazard to move a single level; for sites with < 50% stringybarks, this figure blows out to 56 years. Again taking a conservative approach, we have set a time-since-fire of 25 years as the point at which to scale up bark hazard in classes where the minimum and maximum hazard levels are one class apart. For classes with two steps, this has been set as the point where the maximum is dropped one level. For these classes, following a linear trajectory, we have set the first step up at 12 years (i.e. for classes with a maximum bark fuel hazard of E, at a TSF of 12 to 25 years the hazard level is VH, and at 0 to 12 years post-fire it is scaled down to H).

That stepping up to maximum levels at 25 years is appropriate was confirmed when the linear models in Table 6 were used to calculate the number of years each of the six FHS vegetation classes with a viable linear model would take to reach the lower boundary of the maximum hazard level set for them in Table 5. These figures, in Table 8, range from 17.4 to 42.5 years, with a mean of 28.5 years.

Table 8. Predicted years post-fire for estimated maximum values (from Table 5) to be reached in six vegetation classes surveyed as part of the FHS. Max scores in column 5 are the lower bound of the range for the hazard ratings in column 4.

Vegetation class	Minimum	Slope	Max hazard rating (Table 5)	Max score	Yrs to max
North Coast / Hinterland WSF	2.32	0.060	E	4.5	36.3
Hunter-Macleay DSF	2.93	0.029	VH	3.5	19.7
Cumberland DSF	1.88	0.054	VH	3.5	30.0
North Coast DSF	3.00	0.059	E	4.5	25.4
South East DSF	2.80	0.040	E	4.5	42.5
Southern Tablelands DSF	2.91	0.034	VH	3.5	17.4
Mean					28.5

Table 9 gives recommended hazard ratings and scores for the 39 vegetation classes considered in this report, by time since fire. For ease of reference this table has been repeated in Appendix10, ordered by subformation and class.

Table 9: Estimated bark hazard scores and ratings for 39 vegetation classes, considering development with time since fire. Vegetation classes surveyed as a part of the FHS in **bold**. Colours represent hazard ratings / scores (Red = E (5); Orange = VH (4); Yellow = H (3); Green = M (2); Blue = L (1)). For ease of reference this table is repeated in Appendix 10, ordered by subformation and class.

Vegetation Subformation	Vegetation Class	Bark Haz Score MAX (TSF>25yrs)	Bark Haz Score MED (TSF 12-25yrs)	Bark Haz Score MIN (TSF 0-12yrs)
WSF shrubby	Northern Escarpment WSF	5	4	3
WSF shrubby	Southern Escarpment WSF	5	4	3
DSF shrubby	Northern Tableland DSF	5	4	3
WSF shrubby	**North Coast WSF**	5	4	3
WSF grassy	**Northern Hinterland WSF**	5	4	3
DSF shrubby	**North Coast DSF**	5	4	3
DSF shrub / grass	Northern Gorge DSF	5	4	3
WSF grassy	Southern Lowland WSF	5	4	3
Grassy woodlands	New England GW	5	4	3
DSF shrubby	**South East DSF**	5	4	3
DSF shrub / grass	Central Gorge DSF	5	4	3
WSF grassy	Northern Tableland WSF	4	3	3
WSF shrubby	South Coast WSF	4	3	3
DSF shrubby	Northern Escarpment DSF	4	3	3
DSF shrubby	**Sydney Coastal DSF**	4	3	3
DSF shrub / grass	Southern Hinterland DSF	4	3	3
DSF shrub / grass	Clarence DSF	4	3	3
DSF shrubby	Sydney Hinterland DSF	4	3	3
DSF shrubby	Sydney Montane DSF	4	3	3
WSF grassy	Montane WSF	4	3	3
DSF shrubby	Coastal Dune DSF	4	3	3
DSF shrub / grass	**Hunter-Macleay DSF**	4	3	3
DSF shrubby	**Southern Tableland DSF**	4	3	3
DSF shrub / grass	**Cumberland DSF**	4	3	3
DSF shrub / grass	New England DSF	4	3	3
DSF shrub / grass	Upper Riverina DSF	4	3	3
Grassy woodlands	**Coastal Valley GW**	4	3	3
Grassy woodlands	Southern Tableland GW	4	3	3
WSF grassy	Southern Tableland WSF	4	3	3
Grassy woodlands	Tablelands Clay GW	4	3	3
Grassy woodlands	Subalpine W-lands	4	3	3
DSF shrubby	South Coast Sands DSF	4	3	3
Grassy woodlands	Floodplain Transition GW	3	2	2
Grassy woodlands	Western Slopes GW	3	2	2
DSF shrub / grass	North-west Slopes DSF	3	2	2
DSF shrub / grass	Pilliga Outwash DSF	3	2	2
DSF shrubby	Sydney Sand Flats DSF	2	2	2
DSF shrubby	Yetman DSF	2	2	2
DSF shrubby	Western Slopes DSF	2	1	1

4.5 Bark Fuel Loads

4.5.1 Maximum bark fuel loads

As with bark hazard, maximum bark fuel loads are likely to occur in long-unburnt forests of mature trees. The estimated maximum overall bark fuel load for each vegetation class, calculated using the methods in Section 3.5.2, is given in Table 14. Fuel loads ranged from 0.6 t/ha (Sydney Sand Flats DSF) to 4.5 t/ha (Northern Escarpment WSF), with estimates for the large majority of classes (28 of 39) falling between 1.5 and 3.5 t/ha. Figure 6 shows the range of fuel load estimates across classes in each vegetation subformation, together with the contribution of the bark types used in deriving these figures (because smooth barked species were assumed to make no contribution to fuel load, only five of the six categories in Section 3.5.1 appear in this figure). Wet sclerophyll forests tend to carry relatively heavy bark fuel loads; of the five classes with an estimate above 3.5 t/ha, four are in this formation. By contrast, estimates for all but one class in the grassy woodland formation fall below 2.2 t/ha. Estimated bark loads in dry sclerophyll forests cover a wide range, particularly in the shrubby subformation. Of the six classes with estimates below 1.5 t/ha, four are dry sclerophyll forests and two are grassy woodlands. For most but not all classes, stringy bark is the major contributor to fuel load estimates.

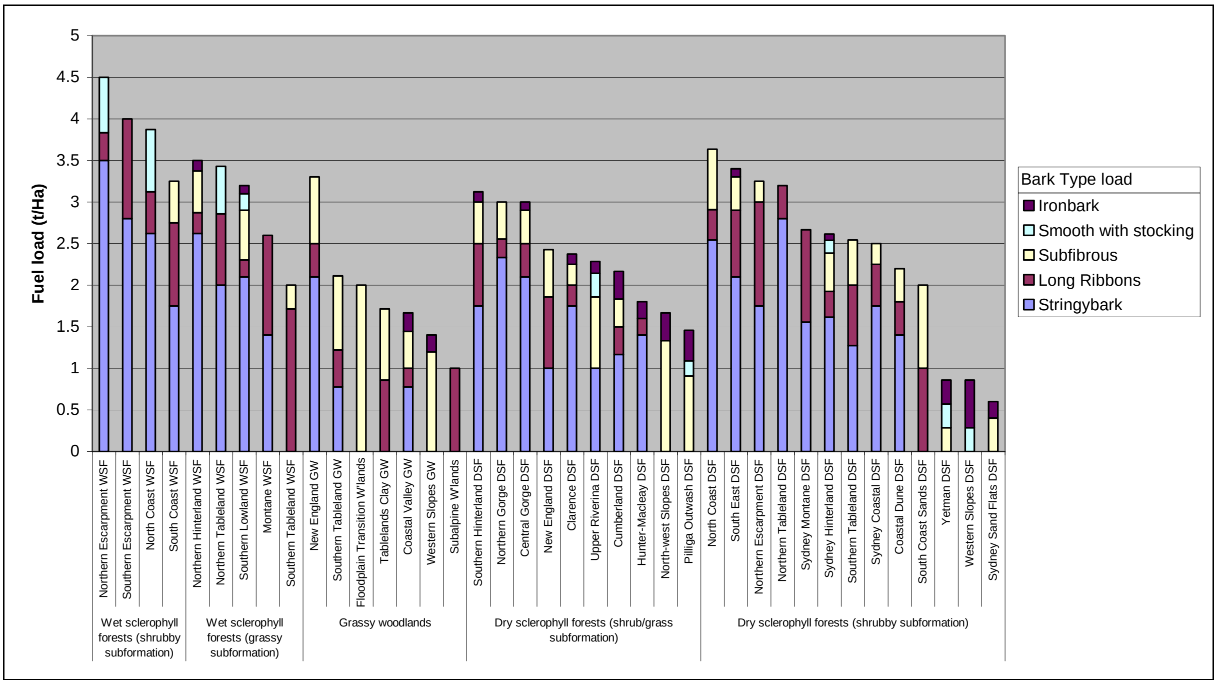

Figure 6: Estimated maximum bark fuel loads for NSW forest and grassy woodland vegetation classes, showing the contribution of each of five bark types (smooth bark type omitted as it is assumed not to contribute to bark fuel load).

4.5.2 Models from field data

Parameter values for linear models of stringy bark char as a function of TSF, for six vegetation classes in the FHS, are given in Table 10 (models for char on stringybarks were not fitted for Cumberland DSF or Coastal Valley GW, as this bark type did not occur in a sufficient number of sites). For subfibrous bark, linear models were fitted for all vegetation classes, although for two classes, South East DSF and Hunter-Macleay DSF, slope was not significant (Table 11).

Table 10: Values for ***linear*** model parameters, and resulting predictions, for percent char on ***stringybark*** tree trunks to 5m, as a function of TSF in six vegetation classes surveyed as part of the FHS. SE in brackets. P values: *, < 0.05; **, < 0.01; ***, < 0.001.

Vegetation class	Intercept	Slope	R^2	Yrs to no char
North Coast / Hinterland WSF	69 (12)***	-2.1 (0.9)*	0.31	32
Hunter-Macleay DSF	42 (7)***	-1.4 (0.4)**	0.52	29
North Coast DSF	58 (7)***	-3.1 (0.6)***	0.62	18
Sydney Coastal DSF	60 (8)***	-2.4 (0.6)**	0.42	25
South East DSF	54 (8)***	-1.5 (0.4)**	0.46	37
Southern Tablelands DSF	50 (10)***	-0.9 (0.4)*	0.25	53
Mean	55			33

Table 11: Values for ***linear*** model parameters, and resulting predictions, for percent char on trunks of trees with ***subfibrous*** bark, to 5m, as a function of TSF in eight vegetation classes surveyed as part of the FHS. SE in brackets. P values: *, < 0.05; **, < 0.01; ***, < 0.001; NS, not significant. NM, not modelled, as slope not significant.

Vegetation class	Intercept	Slope	R^2	Yrs to no char
North Coast / Hinterland WSF	82 (7)***	-2.7 (0.6)***	0.57	31
Coastal Valley GW	15 (3)***	-0.42 (0.2)*	0.28	35
Hunter-Macleay DSF	31 (10)**	-1.1 (0.6) ^{NS}	0.18	NM
Cumberland DSF	87 (6)***	-2.75 (0.3)***	0.83	32
North Coast DSF	72 (7)***	-3.6 (0.6)***	0.66	20
Sydney Coastal DSF	53 (5)***	-1.8 (0.3)***	0.48	29
South East DSF	39 (9)***	-0.7 (0.5)^{NS}	0.10	NM
Southern Tablelands DSF	26 (6)***	-0.5 (0.2)*	0.26	49
Mean	51			33

Intercepts, which represent estimated mean char levels immediately after a fire, ranged from 42 to 69% for stringybarks, with values in four of the six classes falling between 50 and 60%. Intercepts for subfibrous bark covered a wider range, from 15 to 87%. Modelled post-fire char was highest in Cumberland DSF (87% on trees with subfibrous bark, mostly *Melaleuca decora*), and the wet sclerophyll forest (82% for subfibrous barked trees, 69% for stringybarks). Intercept means across vegetation classes were 55% for stringybarks, and 51% for fibrous barked trees. Significant slope values ranged from - 0.4 to -3.6 (across both bark types). For both bark types the steepest slope, representing fastest loss of char, was recorded for the most northerly vegetation class, North Coast

DSF; by contrast values for the high altitude Southern Tablelands DSF were particularly low. This discrepancy is reflected in predicted number of years to reach zero char, using these linear models: for both bark types this figure is lowest in North Coast DSF (18 and 20 years for char on stringy and subfibrous-barked trees, respectively), and highest in Southern Tablelands DSF (53 and 49 years). Across vegetation classes, predicted mean time to no char was 33 years, for both bark types.

Attempts to fit negative exponential (exponential decay) models to bark char data (with minimum values pinned to zero), for the six vegetation classes with sufficient stringybark trees, were successful in four cases (Table 12); for subfibrous bark, six vegetation classes returned negative exponential models with significant values for both *Max* and *k* (Table 13). Comparison of R^2 values (Tables 10-13) and consideration of the extent to which models can be fitted, suggests that each model type (linear and negative exponential) had a similar degree of success in describing the post-fire trajectory of bark char.

Table 12: Values for ***exponential*** decay model parameters, and resulting predictions, for percent char on ***stringybark*** tree trunks to 5m, as a function of TSF in four vegetation classes surveyed as part of the FHS. SE in brackets. P values: ', < 0.10; *, < 0.05; **, < 0.01; ***, < 0.001.

Vegetation class	Max	k	R^2	Yrs to 5% char
Hunter-Macleay DSF	54 (12)***	0.09 (0.03)*	0.57	33
North Coast DSF	69 (12)***	0.11 (0.03)***	0.59	27
Sydney Coastal DSF	82 (13)***	0.11 (0.03)**	0.53	27
South East DSF	64 (14)***	0.07 (0.04)'	0.48	43
Mean	67	0.10		33

Table 13: Values for ***exponential*** decay model parameters, and resulting predictions, for percent char on trunks of trees with ***subfibrous*** bark to 5m, as a function of TSF in six vegetation classes surveyed as part of the FHS. SE in brackets. P values: *, < 0.05; **, < 0.01; ***, < 0.001.

Vegetation class	Max	k	R^2	Yrs to 5% char
North Coast / Hinterland WSF	91 (12)***	0.06 (0.02)**	0.55	50
Coastal Valley GW	23 (5)***	0.16 (0.07)*	0.45	19
Cumberland DSF	106 (12)***	0.07 (0.02)**	0.81	43
North Coast DSF	85 (11)***	0.10 (0.02)***	0.66	30
Sydney Coastal DSF	71 (8)***	0.09 (0.02)***	0.58	33
Southern Tablelands DSF	69 (13)***	0.24 (0.06)**	0.61	13
Mean	74	0.12		31

Maximum char levels predicted by the negative exponential models were somewhat higher than those defined by the linear models; means for stringy and subfibrous bark respectively, for the models in Tables 12 and 13, were 67 and 74%. *k* values for stringy bark char all fell within a limited range, between 0.07 and 0.11. Values for subfibrous char varied widely, from 0.06 in the wet sclerophyll forest to 0.24 in Southern Tablelands DSF. No climate signal is apparent in these values. Mean years to low char levels (we used 5% char, as predictions from this model type never reach zero) were very similar to those derived from the linear models, 33 and 31 years for stringy and subfibrous bark respectively.

4.5.3 Minimum bark fuel loads

Minimum bark fuel loads are assumed to occur in forests that have just experienced a fire. Models from the previous section, which consistently show that trees tend to retain a proportion of their bark uncharred even immediately after a fire, confirm the decision not to reduce our figure for post-fire stringybark loads below 2 t/ha.

Estimated minimum bark fuel load for each vegetation class, calculated using the methods in Section 3.5.4, is given in Table 14. Minimum bark fuel loads ranged from 0.14 t/ha (Western Slopes DSF) to 1.5 t/ha (Northern Escarpment WSF). Figure 7 shows the range of fuel load estimates across classes in each vegetation subformation, as a composite of the contributing bark types used in deriving these figures (because smooth and iron barked species were assumed to make no contribution to fuel load in a recently burnt forest or woodland, only four of the six categories in Section 3.5.1 appear in this figure).

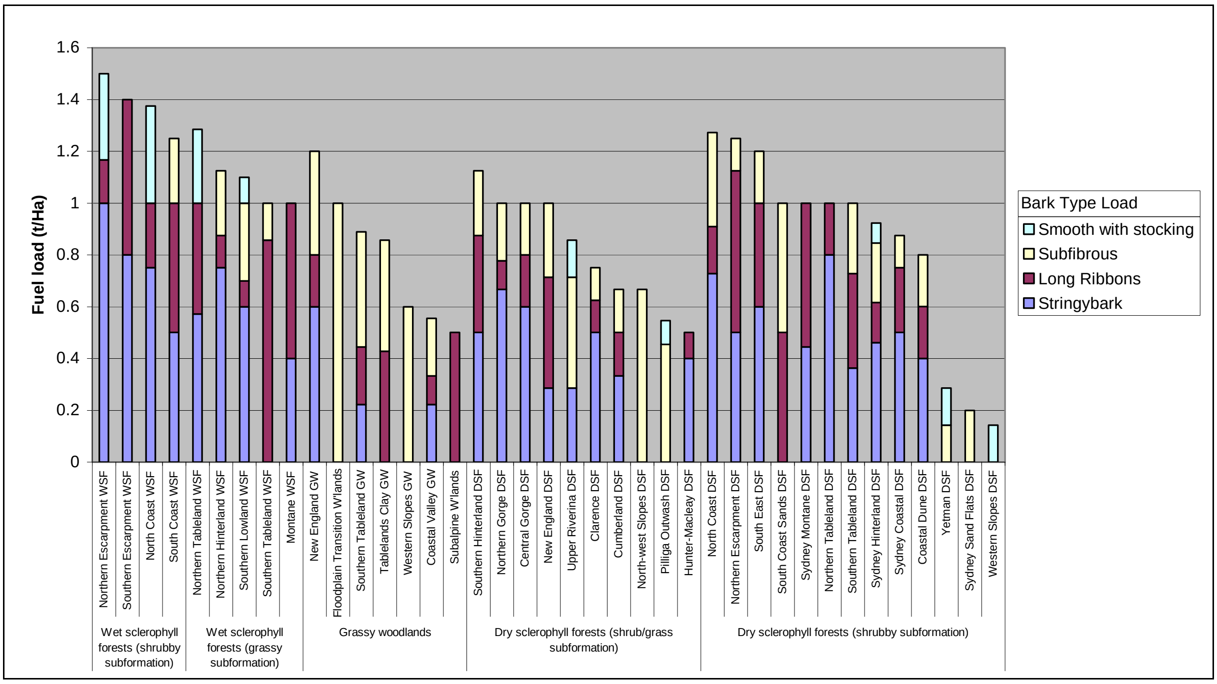

Figure 7: Estimated minimum bark fuel loads for NSW forest and grassy woodland vegetation classes, showing the contribution of each of four bark types (smooth and ironbark type omitted as they are assumed not to contribute to bark fuel load in recently burnt forests).

Table 14: Estimated minimum and maximum bark fuel loads (t/ha) for 39 vegetation classes, calculated using bark type proportions and equivalent bark fuel loads.

Vegetation Subformation	Vegetation Class	Minimum bark fuel load (t/ha)	Maximum bark fuel load (t/ha)
Wet sclerophyll forests (shrubby subformation)	North Coast WSF	1.38	3.88
	South Coast WSF	1.25	3.25
	Northern Escarpment WSF	1.50	4.50
	Southern Escarpment WSF	1.40	4.00
Wet sclerophyll forests (grassy subformation)	Northern Hinterland WSF	1.13	3.50
	Southern Lowland WSF	1.10	3.20
	Northern Tableland WSF	1.29	3.43
	Southern Tableland WSF	1.00	2.00
	Montane WSF	1.00	2.60
Grassy woodlands	Coastal Valley GW	0.56	1.67
	Tablelands Clay GW	0.86	1.71
	New England GW	1.20	3.30
	Southern Tableland GW	0.89	2.11
	Subalpine W'lands	0.50	1.00
	Western Slopes GW	0.60	1.40
	Floodplain Transition W'lands	1.00	2.00
Dry sclerophyll forests (shrub/grass subformation)	Clarence DSF	0.75	2.38
	Hunter-Macleay DSF	0.50	1.80
	Cumberland DSF	0.67	2.17
	Southern Hinterland DSF	1.13	3.13
	Northern Gorge DSF	1.00	3.00
	Central Gorge DSF	1.00	3.00
	New England DSF	1.00	2.43
	North-west Slopes DSF	0.67	1.67
	Upper Riverina DSF	0.86	2.29
	Pilliga Outwash DSF	0.55	1.45
Dry sclerophyll forests (shrubby subformation)	Coastal Dune DSF	0.80	2.20
	North Coast DSF	1.27	3.64
	Sydney Coastal DSF	0.88	2.50
	Sydney Hinterland DSF	0.92	2.62
	Sydney Sand Flats DSF	0.20	0.60
	South Coast Sands DSF	1.00	2.00
	South East DSF	1.20	3.40
	Northern Escarpment DSF	1.25	3.25
	Sydney Montane DSF	1.00	2.67
	Northern Tableland DSF	1.00	3.20
	Southern Tableland DSF	1.00	2.55
	Western Slopes DSF	0.14	0.86
	Yetman DSF	0.29	0.86

4.5.4 Time since fire trajectory for fuel load

The fit of models describing the decrease in bark char with TSF, for FHS vegetation classes (Section 4.5.2), suggests that either a linear or a negative exponential model would be appropriate to depict the trajectory between minimum and maximum levels of bark fuel, particularly where stringy and / or subfibrous bark types predominate – which they do in most vegetation classes, particularly those with high predicted maximum bark fuel loads (Figure 6). As noted previously, ribbon bark accumulation is unlikely to follow either model; data from the FHS shows little evidence of significant differences between TSF categories in the amount of ribbon bark present (Figure 8).

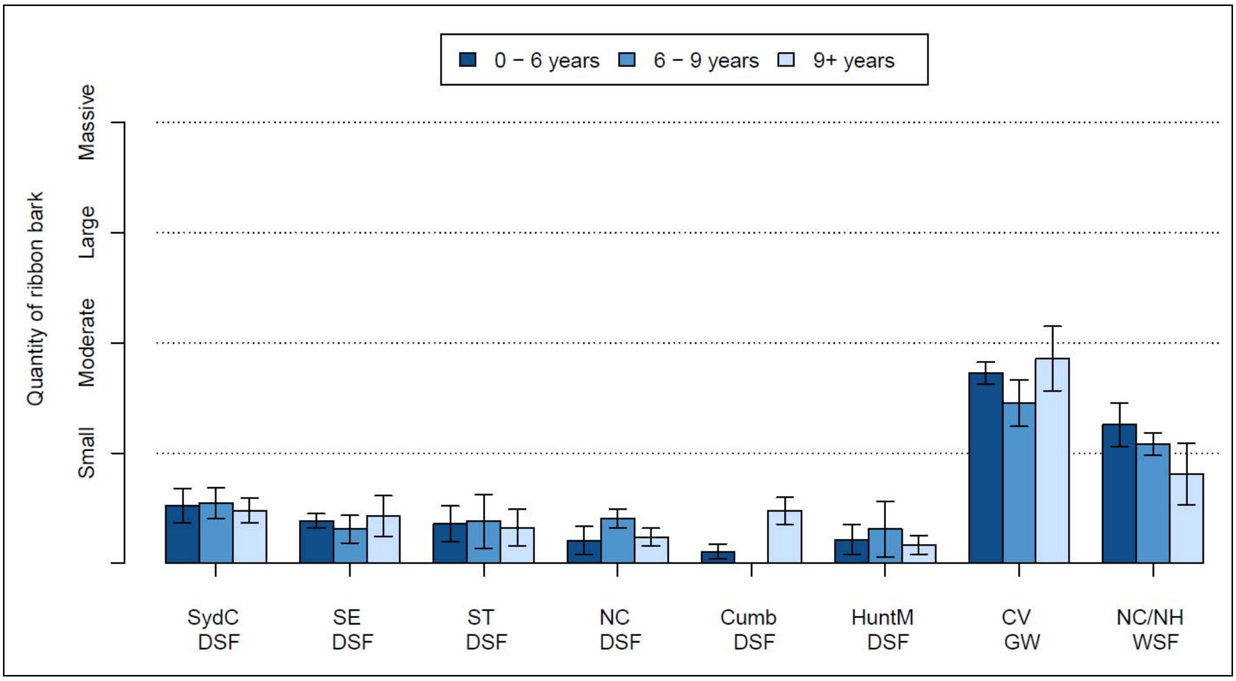

Figure 8: Quantity of ribbon bark in vegetation classes studied in the FHS, showing mean (± SE) for three time-since-fire categories.

The Phoenix fire behaviour simulator uses a negative exponential model to describe bark development with TSF. For simplicity, we suggest using the mean *k* value for decline in stringy bark char, 0.10, to portray the trajectory of bark fuel load from minimum to maximum levels, across all forest and grassy woodland vegetation classes. This value equates to 30 years to 5% char, capturing a primary message from the FHS char data: that char, and thus presumably fuel load on stringybark trees, changes slowly (Figure 9). By comparison, *k* values for litter accumulation range from a low of around 0.15 in some dry sclerophyll forests, to around 0.45 in some shrubby wet sclerophyll forests. Even a *k* of 0.10 may be higher than the reality for bark fuel load, which almost certainly continues to develop beyond the point where char levels reach zero.

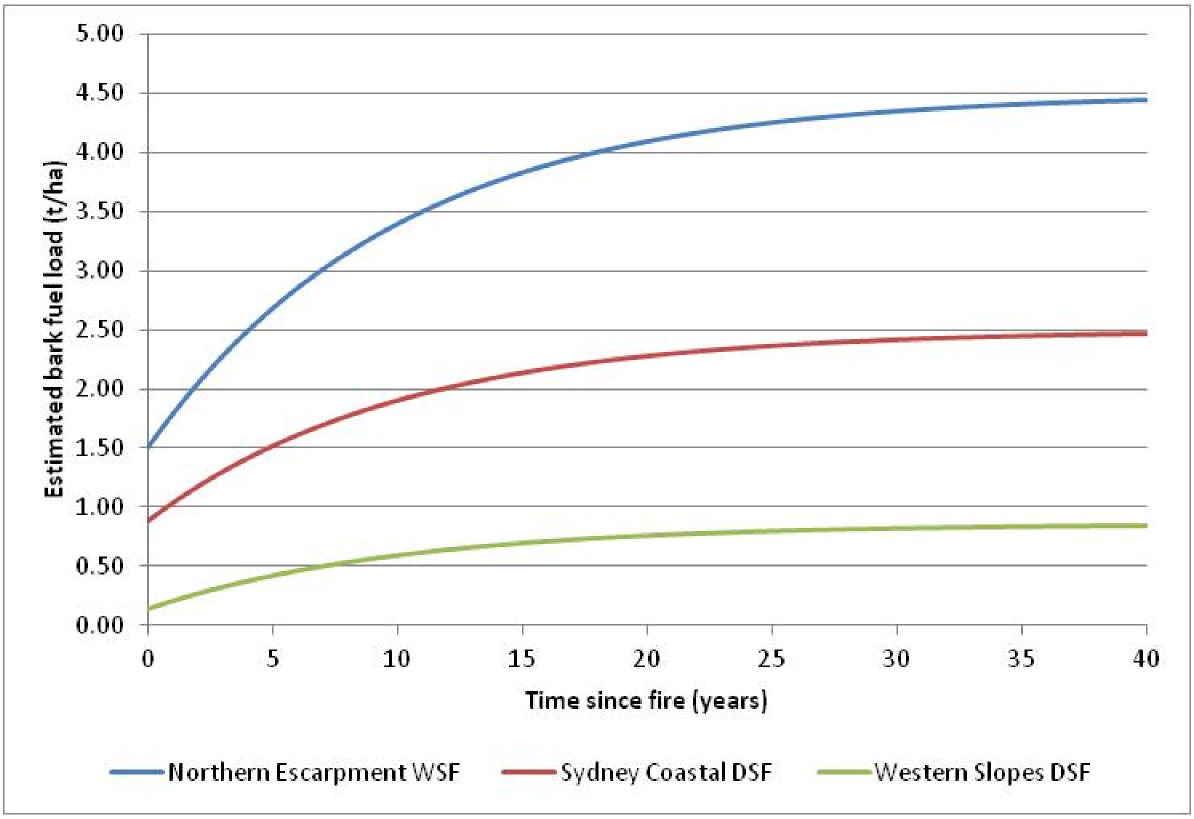

Figure 9: Development of bark fuel load over 40 years after a fire in three sclerophyll forest classes, using estimated values for minima, maxima and *k*.

5 Discussion

This report provides land and fire managers in NSW with estimates of bark fuel hazard and load in eucalypt-dominated forests and grassy woodlands. These estimates are based on an analysis of bark types exhibited by Eucalypt species listed in Keith (2004). It draws on findings from a study of fuel hazard and bark char in eight vegetation classes in NSW, figures from limited research into bark fuel load from other states, and several assumptions. As outlined below, we have tended to err on the side of over-estimating, rather than under-estimating, fuel hazard and load.

Complexities in considering bark as a fuel in NSW

NSW forest and grassy woodland classes are rarely dominated by a single tree species, and this is often the case even at a stand, site and plot level. Co-occurring species often differ in bark type, making classification of vegetation communities and classes by bark type (e.g. “a stringybark forest”) unrealistic. Within a class, the mix of bark types may vary between communities and sites.

Tree age and stage of development will also influence the quantity of available bark fuel, through changes in stand density, height and tree circumference. Older trees, with larger boles, not only have a greater surface area of bark but also greater bark thickness than younger trees of the same species (Vine, 1968). A forest of older trees is therefore going to have more bark per hectare than a forest of younger trees. Younger trees, however, may slough off char more rapidly, as their trunks expand. This is relevant in NSW as many forests are in a regrowth phase. Differences in basal area between forest and woodland types will also influence the amount of available bark. Thus in theoretical stands with identical bark types, a well-stocked wet sclerophyll forest will have a higher bark fuel load than a sparsely-treed woodland.

The role of fire intensity in bark consumption is a complicating factor. Where consumption of surface, near-surface, and to a lesser extent elevated fine fuel after the passage of a fire can be assumed to be close to total, this is often not the case for bark. Fire intensity determines the height and depth of bark burnt. The intensity of the previous fire (and perhaps even of fires before that) thus assumes greater prominence in determining hazard and load, and ideally would be considered along with time-since-fire when modelling the post-fire availability of bark fuel. There is almost certainly an interaction here with species present, with some taxa (eg paperbarks) likely to sustain high levels of char in almost any fire, while others, such as *Eucalyptus moluccana*, char very little (pers. obs. 2009-2011).

Method and its limitations

The analysis of bark types, and the estimates of bark hazard and load presented in this report, are based on a number of assumptions.

The basic assumption of the methods we have used is that the proportion of species exhibiting different bark types in indicative species lists presented in class profiles by Keith (2004), reflect the proportion of bark types across stands within each class. These indicative species lists have limitations: these taxa “were selected from the source (regional or local) studies as characteristic, frequently occurring, visually prominent or otherwise noteworthy. These lists are only an indicative guide for each vegetation class: no species occurs everywhere within a given vegetation class … and some sites within a given class may have only a minority of species listed" (Keith 2004:24). Nevertheless, the similarity in the distribution of bark types between the species listed in Keith (2004) and the species recorded in the field during the FHS, for eight vegetation classes, gives confidence that the Keith lists are reflecting the reality of bark types in the field.

An alternate way to determine bark type proportions might be to work directly with quadrat data, using species abundance or frequency. However even if this approach were taken, issues of tree size and bark availability would present methodological challenges that could only be met by the use of assumptions (eg that the size distribution of trees of different bark types is the same; that frequency data reflect bark abundance). There is no *a priori* reason to think that these assumptions would be more realistic than the assumptions involved in using the species listed in Keith (2004); and the work involved in gathering and processing quadrat data would be considerable. Considering the effort and complexity of working with vegetation survey data, the approach we have taken may well be as valid as any other.

Hazard Ratings for Bark Fuel

Maximum bark fuel hazard estimates in this report pertain to mature vegetation unburnt for many years. When compared to mean bark hazard scores recorded in the field in sites unburnt for at least 9 years (Figure 5), the derived maxima (Table 5) were one hazard level higher for the majority of the eight vegetation classes for which comparisons were possible. This may reflect a lack of data points , in the FHS, at the upper end of bark fuel development. Even in the three FHS vegetation classes where stringybark was found in over 80% of plots unburnt for at least 9 years, stringy amount was assessed as moderate, indicating limited development of loose stringy bark in survey sites, probably due to insufficient post-fire age or post-logging effects (trees may still be immature). It could be that maximum bark fuel hazard ratings are rarely achieved in the flammable forests and woodlands of NSW, particularly those in continuous areas of bush where wildfires occur periodically. Thus we have probably erred on the side of over-estimating rather than underestimating, these maxima.

Although maximum bark fuel hazard scores in field sites tended to be lower than those allocated using our decision-rules and the species lists in Keith (2004), the ranking of classes on this variable was similar, giving confidence in the relative positioning of the 39 vegetation classes with respect to bark fuel hazard.

Estimated minimum bark fuel hazard scores may also be conservative, that is, set relatively high. These values were based, to some extent, on intercepts in linear models fitted to field data from the FHS. These intercepts could have been influenced by the fact that many of our recently-burnt sites had been subject to planned burns whose intensity might have been low relative to a wildfire in the same area. However as noted in Section 4.4.4, bark hazard ratings below High are difficult to obtain, due to the nature of hazard scales.

For the majority of vegetation classes addressed in this study, estimated minimum and maximum bark fuel hazard scores were only a single level apart, and the difference between these two estimates never exceeded two levels. This reflects the considerable influence of bark type, as opposed to bark condition, in bark hazard scales.

Suggested post-fire ages for hazard scores to move from minimum to maximum (a single step for most vegetation types, two steps for some) are necessarily approximate. The point at which this occurs will depend not only on time-since-fire, but also on stand age and structure, and on the intensity of the previous fire.

Bark Fuel Load

As bark fuel is essentially the bark available for burning, there is a wide range in the potential load as a result of differences in bark characteristics between species (Gould *et al*., 2007a). Bark fuel load estimates need to take into account the relative mix of different species, and therefore bark types, in a vegetation community. The range of estimated values for bark fuel load reflect the variation in bark type makeup between NSW forest and woodland vegetation classes.

It could be argued, as for fuel hazard, that estimated maximum fuel load values are set conservatively high, for many classes, as they are designed to represent values in mature, long-unburnt vegetation. In reality, in regrowth forests tree immaturity will limit bark load. In addition, the very long fire-free periods needed for maximum bark loads to be reached may rarely occur, given mean fire return intervals in NSW forests and woodlands.

Note too that estimated fuel loads represent **all bark available for consumption**. While a proportion of available bark is likely to burn in the initial stages of flaming combustion, and thus could be considered 'fine fuel', combustion of bark on tree trunks may continue for some time. Particularly for rough-barked trees, including stringybarks, the concept of 'fine fuel < 6 mm' is difficult to apply. Although loose, surface bark may be 'fine' and burn rapidly, inner layers of more closely-packed bark may burn after the passage of the fire front. In applying the estimates in this report, modellers need to take this into account, perhaps by assigning a proportion of estimated fuel load values to each combustion stage.

In setting minimum values for bark fuel load we have assumed a proportion of bark fuel remains immediately post-fire. If maximum levels were to pertain pre-fire, our assumptions equate to a 71% loss for stringy barks, and a 50% loss for other bark types. If, as is likely given the factors discussed above, pre-fire levels are below their maximum potential, assumed percentage losses would be lower. We consider these assumptions reasonable given the results of modelling of post-fire char levels in FHS vegetation classes. In reality, the extent of bark remaining immediately after a fire will depend on fire intensity.

When determining maximum and minimum bark fuel loads, we considered scaling vegetation formations and / or classes according to basal area. Basal area is relevant to considering the amount of available bark as it provides an indication of bark **area** per ha; this will equate, broadly, to tree circumference X bark height, and will rise with BA. The figure of 7 t/ha for available fuel load in a forest of stringybark trees draws on studies in Victoria (Tolhurst *et al.* 1992) and Western Australia (Gould *et al.* 2007); in each case, basal area was around 33 m^2/ha. Basal areas figures sourced from

NSW studies (Table 16) suggest a range in the vegetation formations of interest of between 12 and 40 m^2/ha. Thus the benchmark studies are within, and towards the top of, the NSW range. While there are trends in the pattern of basal areas across vegetation formations in Table 16, no clear rules (eg WSF>DSF>GW) emerge. Partly for this reason, we decided not to include a basal area scaling factor. In addition, calculations indicated that although basal area in Table 16 covers about a 3-fold range, this equates to less than a two-fold range in terms of circumference per ha (13-22 m). The more limited range in circumference also reduced the need to take basal area into account. However note that lack of scaling for basal area means that our bark fuel load estimates may over-predict in vegetation types, and sites, where Eucalypt basal area is low.

Table 16: Basal area (BA) figures reported for a range of vegetation types in NSW

Vegetation Class	Study location	Mean BA (m^2/ha)	Reference	Comments
Sydney Montane DSF	7 km NE of Lithgow	39.3	Williams and Wardle (2007)	
Southern Tableland DSF	Upper catchment of Yass River	34.1	Crockford and Richardson (1998)	
North Coast WSF	Near Coffs Harbour	30.4	Turner and Lambert (1983)	27-year-old plantation on site that previously supported rainforest
Northern Hinterland WSF	27 km north of Taree	28.8	van Loon (1969)	29-year-old Blackbutt regeneration
South East DSF	Yambulla SF	28.5	Turner *et al.* (1992)	
Southern Tableland DSF	South-east Highlands	27.0	McElhinny (2005)	
Coastal Dune DSF	West of Seal Rocks	25.0	Fox *et al.* (1979)	
Sydney Coastal DSF	Blue Mts, NSW	16.8	van Loon (1977)	
Southern Tableland GW	South-east Highlands	16.8	McElhinny (2005)	
South Coast WSF	15 km NE of Batemans Bay	16.4	Pook (1984)	BA figure for eucs; with wattles it was 21.3 m^2/ha
Coastal Valley GW	Western Sydney, NSW	12.9	Watson (2005)	Figure includes all canopy trees over 10 cm diameter

In determining the trajectory between minimum and maximum bark fuel load, we have assumed that bark fuel load development parallels loss of char on trunks of stringy- and subfibrous- barked trees. A similar mean number of years to reach zero (or close to zero) char was predicted for both bark types (stringy and subfibrous bark) when either a linear or an exponential decay model was used (between 31 and 33 years). Similar goodness of fit for each model type suggested that either a linear or a negative exponential function could be used to describe the development trajectory of bark fuel load. Our choice of the negative exponential model reflected the input needs of Phoenix, and was again conservative, as predicted bark fuel loads will be higher in the early post-fire years than they would be if a linear model was used. The chosen figure for k, 0.10, represents the mean value for this parameter across the four FHS vegetation classes for which the exponential model was successfully fitted to data for stringybark char. Although there was some suggestion, from linear modelling, that char may decline more rapidly in warmer climates than in cooler ones, this trend was not apparent when exponential models were fitted, leading to the decision to use a single *k* value across all classes.

The wider range of intercepts for subfibrous relative to stringy bark char, observed whether the linear or exponential model was used, reflects the greater range in bark qualities in the subfibrous bark type category. While some bark types classified as subfibrous char little, or slough their char relatively fast (e.g. boxes and peppermints), others may hold and retain char much more effectively (e.g. bloodwoods).

To summarise, after a fire, bark fuel on stringy and other rough-barked trees develops more slowly than other fuel layers; this can be seen in the results from the Fuel Hazard Study, and has also been noted elsewhere (Chatto *et al*., 2003). While fuel development in the surface and near surface layers generally approached maximum values within one or two decades in the vegetation classes studied as part of the FHS, both linear and exponential modelling showed a mean duration of char retention of over 30 years. Even after char levels have fallen to zero, stringy bark in particular may continue to accumulate and loosen for decades. This is reflected in the linear models of bark fuel hazard score, based on the FHS data, which predict that the vegetation classes studied will take between 17 and 43 years to reach their estimated maximum bark fuel hazard score.

Due to the emphasis on spotting potential, bark hazard ratings assigned to vegetation classes are primarily determined by presence of certain bark types (and therefore species); this is reflected in the narrow range of scores given to vegetation classes across the post-fire sequence (TSF doesn't change the species present). Species presence is also important for estimating fuel load: for example a stringybark tree will carry more flammable bark than an ironbark no matter how much time has passed since the last fire. However, it is mitigated by relative abundance of bark types, the age and size of trees, and the intensity of the past fire/s. A comprehensive model of bark fuel load development would take into account not only all species present within a class plus their abundance and geographical spread, but also tree age, circumference, density, and the intensity of last fire/s. Fuel load figures presented in this report for individual vegetation classes represent estimated mean values. While bark fuel load in particular stands after particular fires will inevitably deviate from these estimates, they provide a logical set of figures where none previously existed.

Abbreviations

BA	basal area
DSF	dry sclerophyll forest
FHS	Fuel Hazard Study (UOW research project)
GW	grassy woodland
PPR	propensity to produce ribbons
TSF	time since fire
UOW	University of Wollongong
WSF	wet sclerophyll forest

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Appendices

Appendix 1: Bark types in forest and grassy woodland vegetation classes based on indicative tree species in Keith (2004). Colours delineate subformations: purple = WSF (shrubby); pink = WSF (grassy); yellow = grassy woodlands; blue = DSF (shrub / grass); green = DSF (shrubby).

	Count of Species								TOTAL	Proportion of species listed							
	Bark type					Propensity to produce ribbons			Species Listed	Bark type					Propensity to produce ribbons		
Vegetation Class	Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Long / lots	Short / some	No		Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Long / lots	Short / some	No
North Coast WSF	3	1	4	0	0	2	3	3	**8**	0.375	0.125	0.500	0.000	0.000	0.250	0.375	0.375
South Coast WSF	1	2	0	0	1	2	0	2	**4**	0.250	0.500	0.000	0.000	0.250	0.500	0.000	0.500
Northern Escarpment WSF	3	1	2	0	0	1	4	1	**6**	0.500	0.167	0.333	0.000	0.000	0.167	0.667	0.167
Southern Escarpment WSF	2	0	2	0	1	4	1	0	**5**	0.400	0.000	0.400	0.000	0.200	0.800	0.200	0.000
Northern Hinterland WSF	3	3	0	1	1	1	0	7	**8**	0.375	0.375	0.000	0.125	0.125	0.125	0.000	0.875
Southern Lowland WSF	3	4	1	1	1	1	3	6	**10**	0.300	0.400	0.100	0.100	0.100	0.100	0.300	0.600
Northern Tableland WSF	2	1	3	0	1	3	3	1	**7**	0.286	0.143	0.429	0.000	0.143	0.429	0.429	0.143
Southern Tableland WSF	0	4	3	0	0	6	1	0	**7**	0.000	0.571	0.429	0.000	0.000	0.857	0.143	0.000
Montane WSF	1	1	2	0	1	4	1	0	**5**	0.200	0.200	0.400	0.000	0.200	0.800	0.200	0.000
Coastal Valley GW	1	3	0	2	3	1	0	8	**9**	0.111	0.333	0.000	0.222	0.333	0.111	0.000	0.889
Tablelands Clay GW	0	4	2	0	1	3	3	1	**7**	0.000	0.571	0.286	0.000	0.143	0.429	0.429	0.143
New England GW	3	5	1	0	1	2	4	4	**10**	0.300	0.500	0.100	0.000	0.100	0.200	0.400	0.400
Southern Tableland GW	1	5	1	0	2	2	5	2	**9**	0.111	0.556	0.111	0.000	0.222	0.222	0.556	0.222
Subalpine W-lands	0	1	2	0	3	3	3	0	**6**	0.000	0.167	0.333	0.000	0.500	0.500	0.500	0.000
Western Slopes GW	0	3	0	1	1	0	3	2	**5**	0.000	0.600	0.000	0.200	0.200	0.000	0.600	0.400
Floodplain Transition W-lands	0	5	0	0	0	0	5	0	**5**	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000

Vegetation Class	Count of Species: Bark type: Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Propensity to produce ribbons: Long / lots	Short / some	No	TOTAL Species Listed	Proportion of species listed: Bark type: Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Propensity to produce ribbons: Long / lots	Short / some	No
Clarence DSF	2	2	0	1	3	1	0	7	**8**	0.250	0.250	0.000	0.125	0.375	0.125	0.000	0.875
Hunter-Macleay DSF	2	1	0	2	5	1	0	9	**10**	0.200	0.100	0.000	0.200	0.500	0.100	0.000	0.900
Cumberland DSF	1	2	0	2	1	1	1	4	**6**	0.167	0.333	0.000	0.333	0.167	0.167	0.167	0.667
Southern Hinterland DSF	2	3	1	1	1	3	2	3	**8**	0.250	0.375	0.125	0.125	0.125	0.375	0.250	0.375
Northern Gorge DSF	3	3	0	0	3	1	0	8	**9**	0.333	0.333	0.000	0.000	0.333	0.111	0.000	0.889
Central Gorge DSF	3	4	0	1	2	2	2	6	**10**	0.300	0.400	0.000	0.100	0.200	0.200	0.200	0.600
New England DSF	1	3	2	0	1	3	3	1	**7**	0.143	0.429	0.286	0.000	0.143	0.429	0.429	0.143
North-west Slopes DSF	0	2	0	1	0	0	2	1	**3**	0.000	0.667	0.000	0.333	0.000	0.000	0.667	0.333
Upper Riverina DSF	1	3	1	1	1	0	3	4	**7**	0.143	0.429	0.143	0.143	0.143	0.000	0.429	0.571
Pilliga Outwash DSF	0	5	1	4	1	0	5	6	**11**	0.000	0.455	0.091	0.364	0.091	0.000	0.455	0.545
Coastal Dune DSF	1	2	0	0	2	1	2	2	**5**	0.200	0.400	0.000	0.000	0.400	0.200	0.400	0.400
North Coast DSF	4	6	0	0	1	2	2	7	**11**	0.364	0.545	0.000	0.000	0.091	0.182	0.182	0.636
Sydney Coastal DSF	2	3	0	0	3	2	2	4	**8**	0.250	0.375	0.000	0.000	0.375	0.250	0.250	0.500
Sydney Hinterland DSF	3	5	1	1	3	2	2	9	**13**	0.231	0.385	0.077	0.077	0.231	0.154	0.154	0.692
Sydney Sand Flats DSF	0	1	0	1	3	0	1	4	**5**	0.000	0.200	0.000	0.200	0.600	0.000	0.200	0.800
South Coast Sands DSF	0	2	0	0	0	1	1	0	**2**	0.000	1.000	0.000	0.000	0.000	0.500	0.500	0.000
South East DSF	3	6	0	1	0	4	1	5	**10**	0.300	0.600	0.000	0.100	0.000	0.400	0.100	0.500
Northern Escarpment DSF	2	3	2	0	1	5	1	2	**8**	0.250	0.375	0.250	0.000	0.125	0.625	0.125	0.250
Sydney Montane DSF	2	4	1	0	2	5	3	1	**9**	0.222	0.444	0.111	0.000	0.222	0.556	0.333	0.111
Northern Tableland DSF	2	1	0	0	2	1	0	4	**5**	0.400	0.200	0.000	0.000	0.400	0.200	0.000	0.800
Southern Tableland DSF	2	6	1	0	2	4	6	1	**11**	0.182	0.545	0.091	0.000	0.182	0.364	0.545	0.091
Western Slopes DSF	0	0	1	4	2	0	0	7	**7**	0.000	0.000	0.143	0.571	0.286	0.000	0.000	1.000
Yetman DSF	0	1	1	2	3	0	0	7	**7**	0.000	0.143	0.143	0.286	0.429	0.000	0.000	1.000

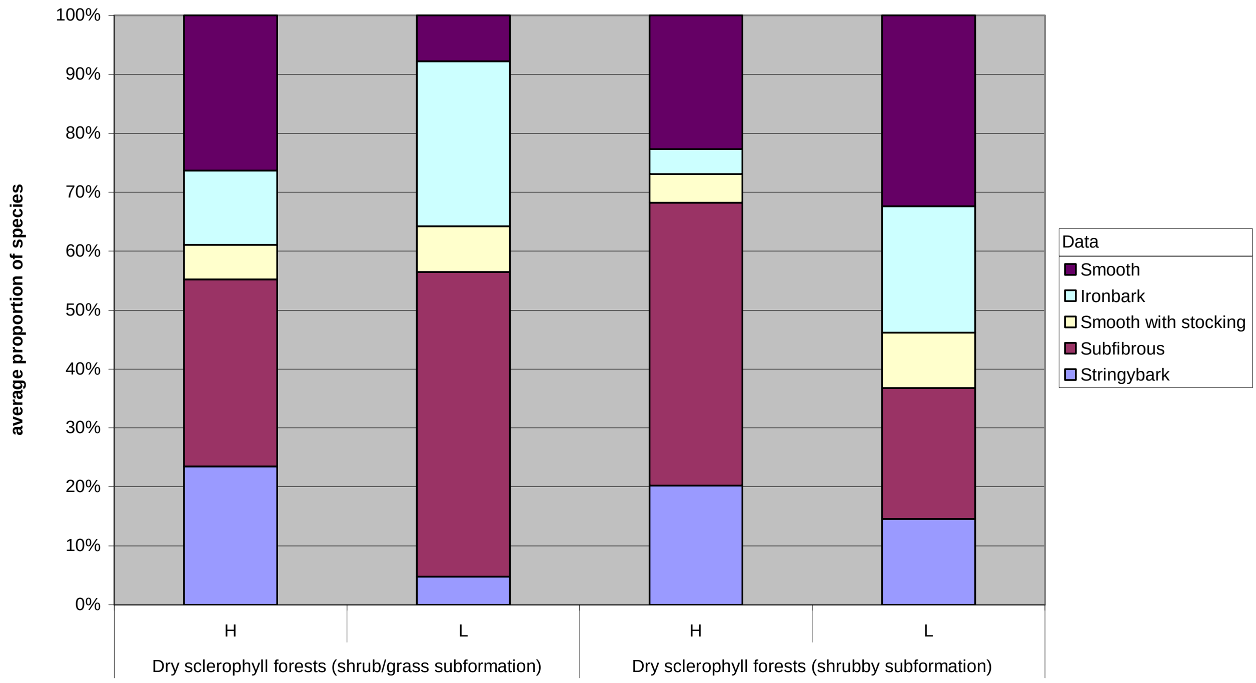
Appendix 2: Bark types in forest and grassy woodland vegetation classes surveyed as part of the FHS. Equivalent figures using indicative tree species in Keith (2004) included for comparison.

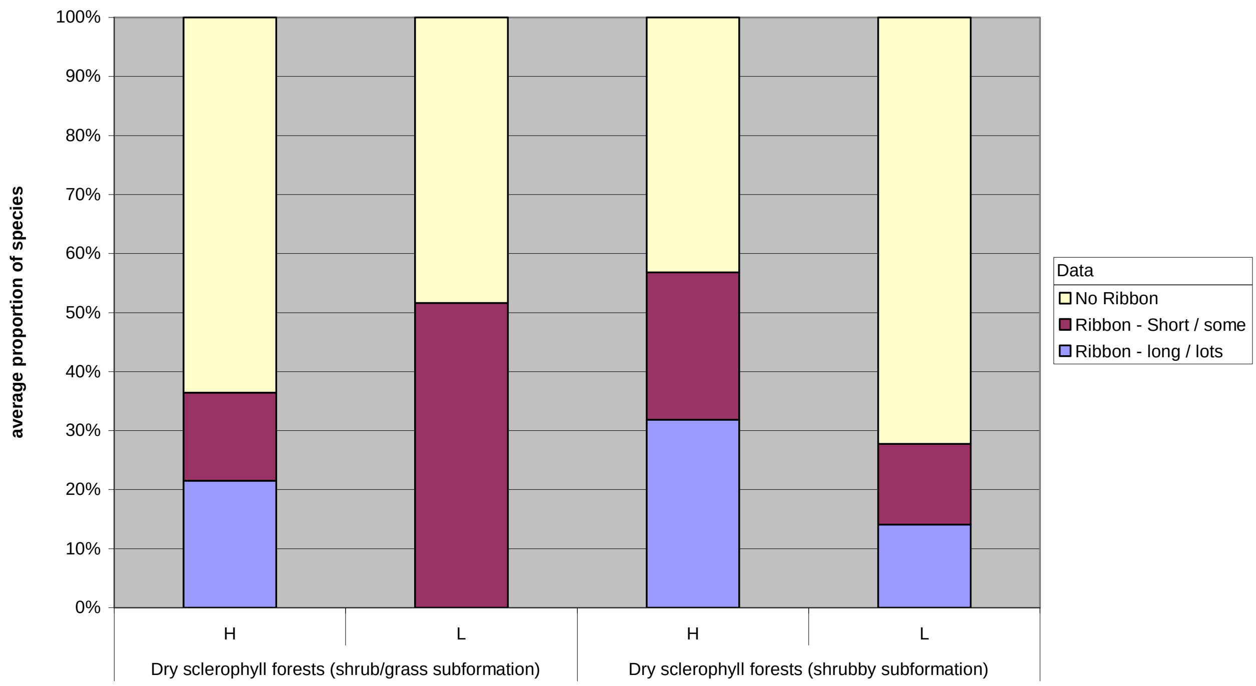
		Count of Species								TOTAL	Proportion of Species listed							
		Bark type					Propensity to produce ribbons			Species	Bark type					Propensity to produce ribbons		
Vegetation Class	Data Source	Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Long / lots	Short / some	No ribbons	Listed	Stringybark	Subfibrous	Smooth w/ stocking	Ironbark	Smooth	Long / lots	Short / some	No ribbons
North Coast / Hinterland WSF	FHS	5	5	2	2	4	2	2	14	**18**	0.278	0.278	0.111	0.111	0.222	0.111	0.111	0.778
	Keith (2004)	4	3	4	1	1	2	3	8	**13**	0.308	0.231	0.308	0.077	0.077	0.154	0.231	0.615
Coastal Valley GW	FHS	1	4	0	1	2	1	0	7	**8**	0.125	0.500	0.000	0.125	0.250	0.125	0.000	0.875
	Keith (2004)	1	3	0	2	3	1	0	8	**9**	0.111	0.333	0.000	0.222	0.333	0.111	0.000	0.889
Hunter-Macleay DSF	FHS	5	3	0	4	5	1	0	16	**17**	0.294	0.176	0.000	0.235	0.294	0.059	0.000	0.941
	Keith (2004)	2	1	0	2	5	1	0	9	**10**	0.200	0.100	0.000	0.200	0.500	0.100	0.000	0.900
Cumberland DSF	FHS	1	3	0	2	4	1	1	8	**10**	0.100	0.300	0.000	0.200	0.400	0.100	0.100	0.800
	Keith (2004)	1	2	0	2	1	1	1	4	**6**	0.167	0.333	0.000	0.333	0.167	0.167	0.167	0.667
North Coast DSF	FHS	7	6	0	0	2	2	2	11	**15**	0.467	0.400	0.000	0.000	0.133	0.133	0.133	0.733
	Keith (2004)	4	6	0	0	1	2	2	7	**11**	0.364	0.545	0.000	0.000	0.091	0.182	0.182	0.636
Sydney Coastal DSF	FHS	8	5	0	0	5	3	3	12	**18**	0.444	0.278	0.000	0.000	0.278	0.167	0.167	0.667
	Keith (2004)	2	3	0	0	3	2	2	4	**8**	0.250	0.375	0.000	0.000	0.375	0.250	0.250	0.500
South East DSF	FHS	4	9	0	1	2	7	2	7	**16**	0.250	0.563	0.000	0.063	0.125	0.438	0.125	0.438
	Keith (2004)	3	6	0	1	0	4	1	5	**10**	0.300	0.600	0.000	0.100	0.000	0.400	0.100	0.500
Southern Tableland DSF	FHS	1	7	2	0	2	4	6	2	**12**	0.083	0.583	0.167	0.000	0.167	0.333	0.500	0.167
	Keith (2004)	2	6	1	0	2	4	6	1	**11**	0.182	0.545	0.091	0.000	0.182	0.364	0.545	0.091

Appendix 3: Target vegetation classes and environmental gradient categories, based on Keith (2004).

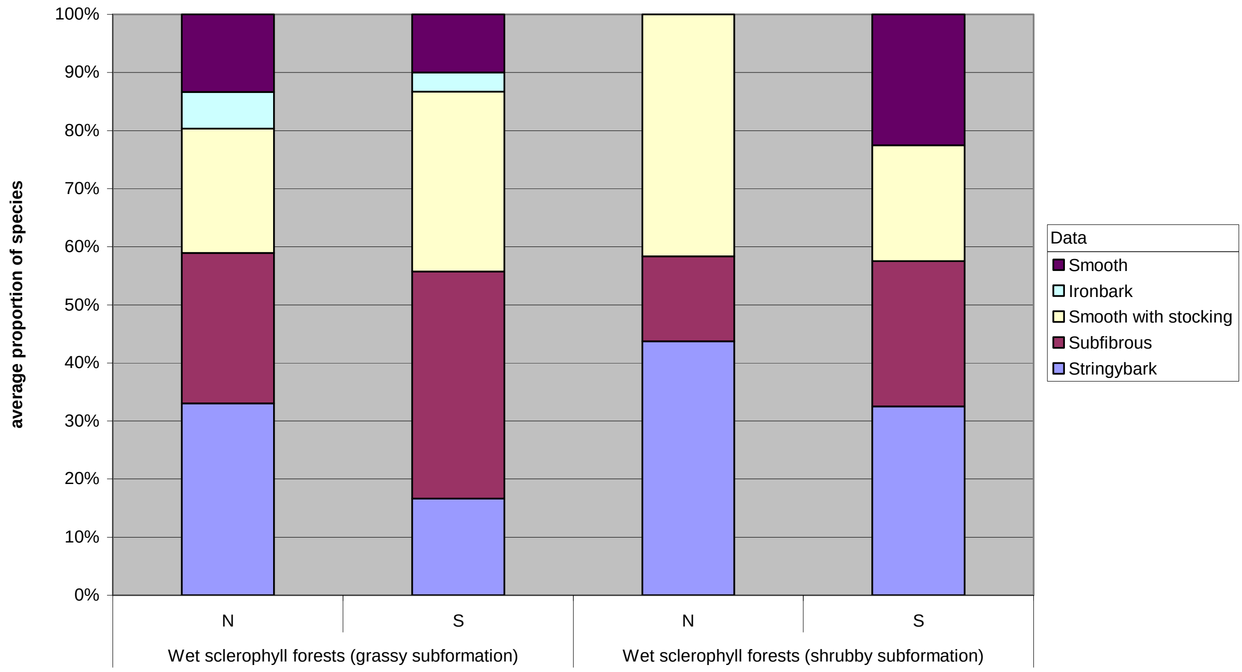
Vegetation Subformation	Vegetation Class	**Rainfall:** H (>800mm); L (<800mm)	**Latitude, relative to NSW State:** North (N); Central (C); South (S)	**Elevation & East-West:** coast (C); tablelands & escarpment >600m (H); western slopes and plains (W)
Wet sclerophyll forests (shrubby subformation)	North Coast WSF	H	N	C
	South Coast WSF	H	S	C
	Northern Escarpment WSF	H	N	H
	Southern Escarpment WSF	H	S	H
Wet sclerophyll forests (grassy subformation)	Northern Hinterland WSF	H	N	C
	Southern Lowland WSF	H	S	C
	Northern Tableland WSF	H	N	H
	Southern Tableland WSF	H	S	H
	Montane WSF	H	S	H
Grassy woodlands	Coastal Valley GW	H	C	C
	Tablelands Clay GW	L	C	H
	New England GW	L	N	H
	Southern Tableland GW	L	S	H
	Subalpine W'lands	L	C	H
	Western Slopes GW	L	C	W
	Floodplain Transition W'lands	L	C	W
Dry sclerophyll forests (shrub/grass subformation)	Clarence DSF	H	N	C
	Hunter-Macleay DSF	H	N	C
	Cumberland DSF	H	C	C
	Southern Hinterland DSF	H	S	C
	Northern Gorge DSF	H	N	H
	Central Gorge DSF	H	C	H
	New England DSF	H	N	H
	North-west Slopes DSF	L	N	W
	Upper Riverina DSF	L	S	W
	Pilliga Outwash DSF	L	N	W
Dry sclerophyll forests (shrubby subformation)	Coastal Dune DSF	H	C	C
	North Coast DSF	H	N	C
	Sydney Coastal DSF	H	C	C
	Sydney Hinterland DSF	H	C	C
	Sydney Sand Flats DSF	H	C	C
	South Coast Sands DSF	H	S	C
	South East DSF	H	S	H
	Southern Wattle DSF	L	S	H
	Northern Escarpment DSF	H	N	H
	Sydney Montane DSF	H	C	H
	Northern Tableland DSF	L	N	H
	Southern Tableland DSF	L	S	H
	Western Slopes DSF	L	C	W
	Yetman DSF	L	N	W

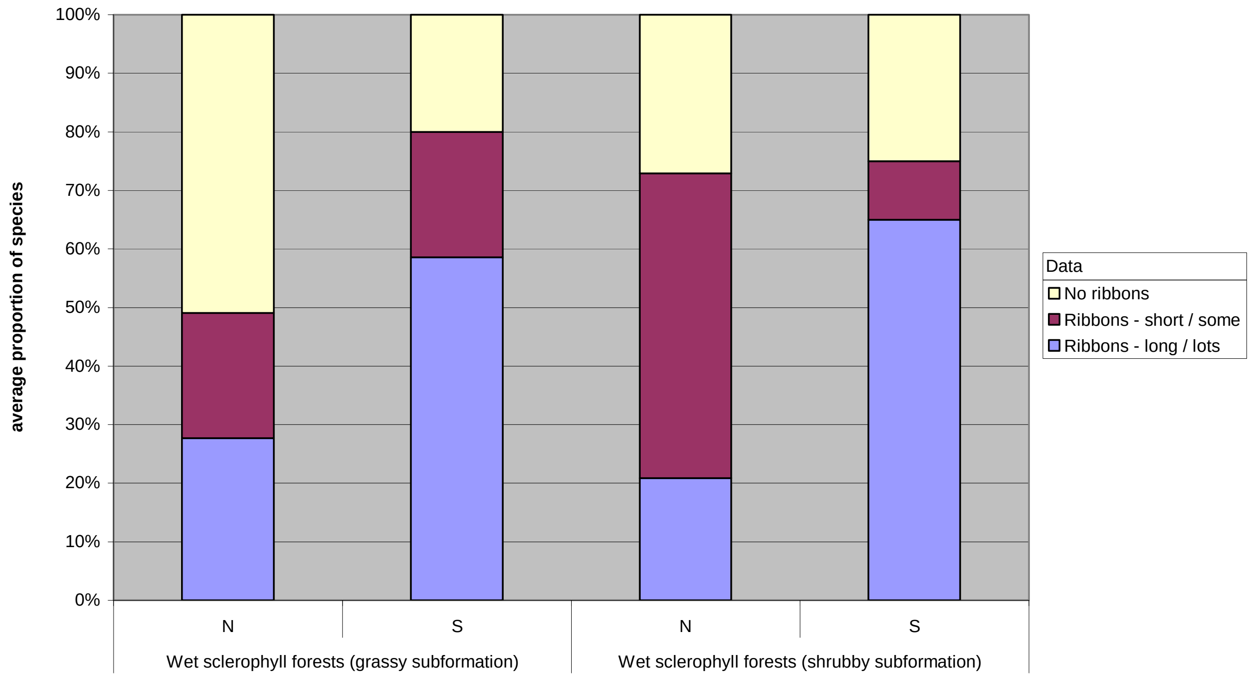
Appendix 4: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories, in ***DSF vegetation classes*** found predominantly in low **(L)** or high **(H)** rainfall regions of NSW.



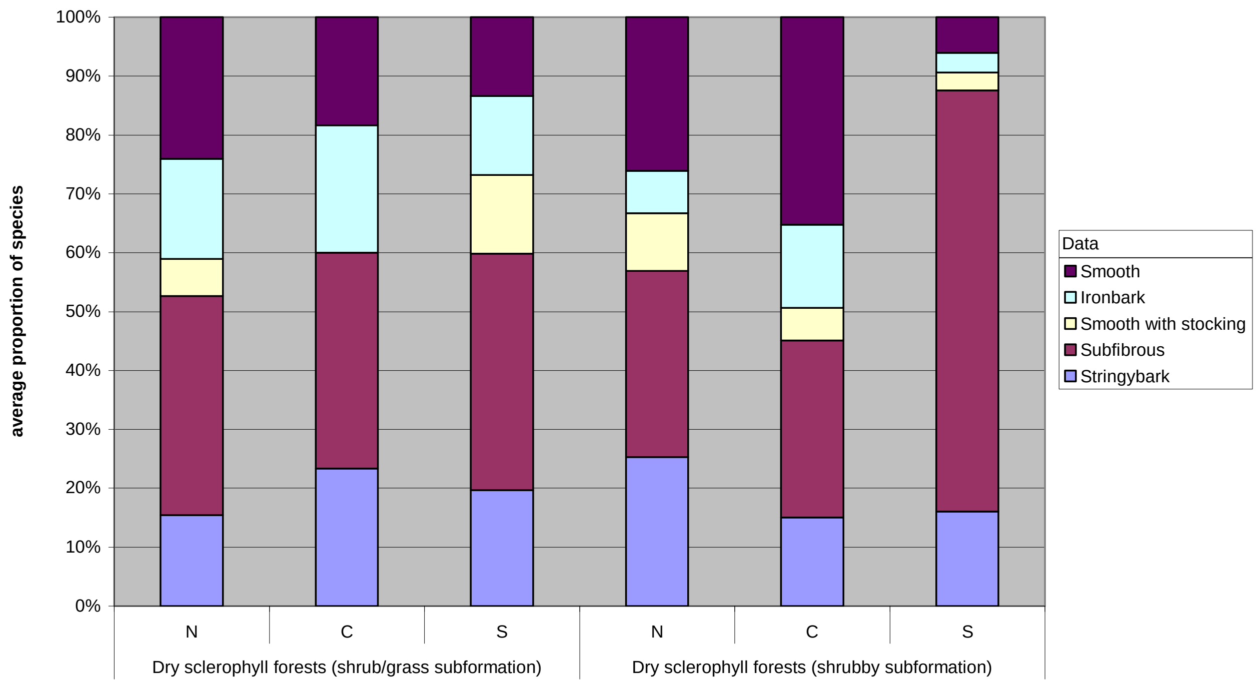


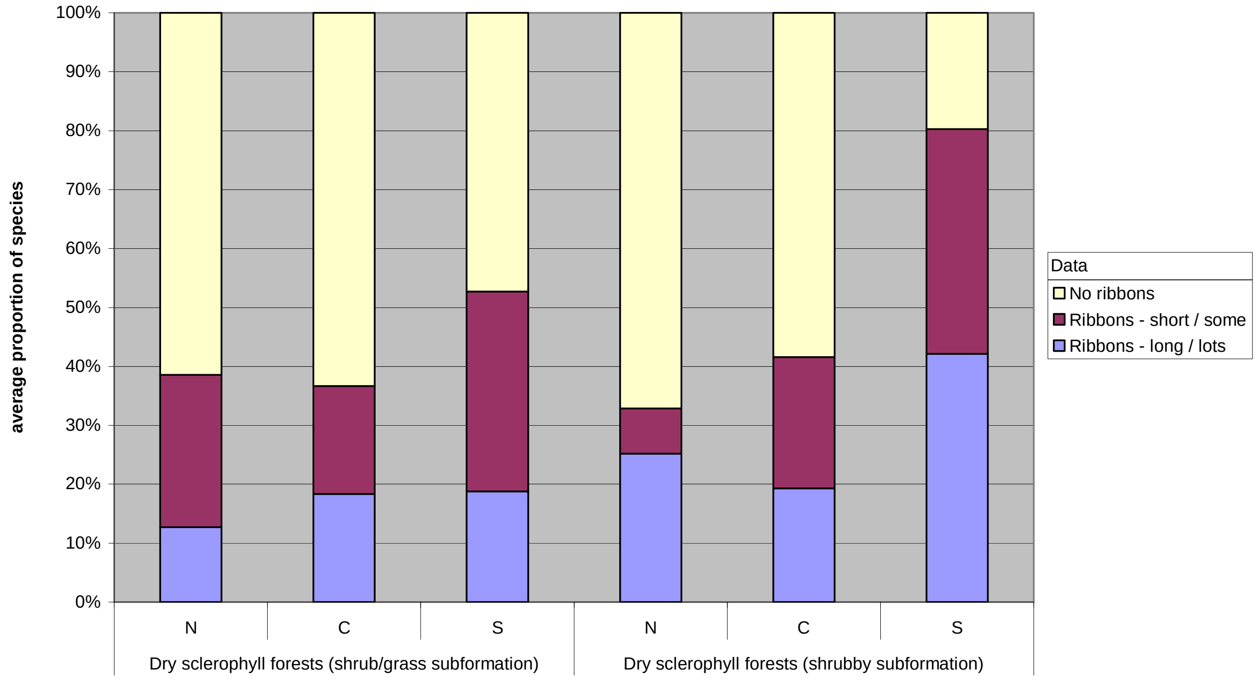
Appendix 5: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories in ***WSF vegetation classes*** found predominantly in the North **(N)**, or the South **(S)** of NSW.



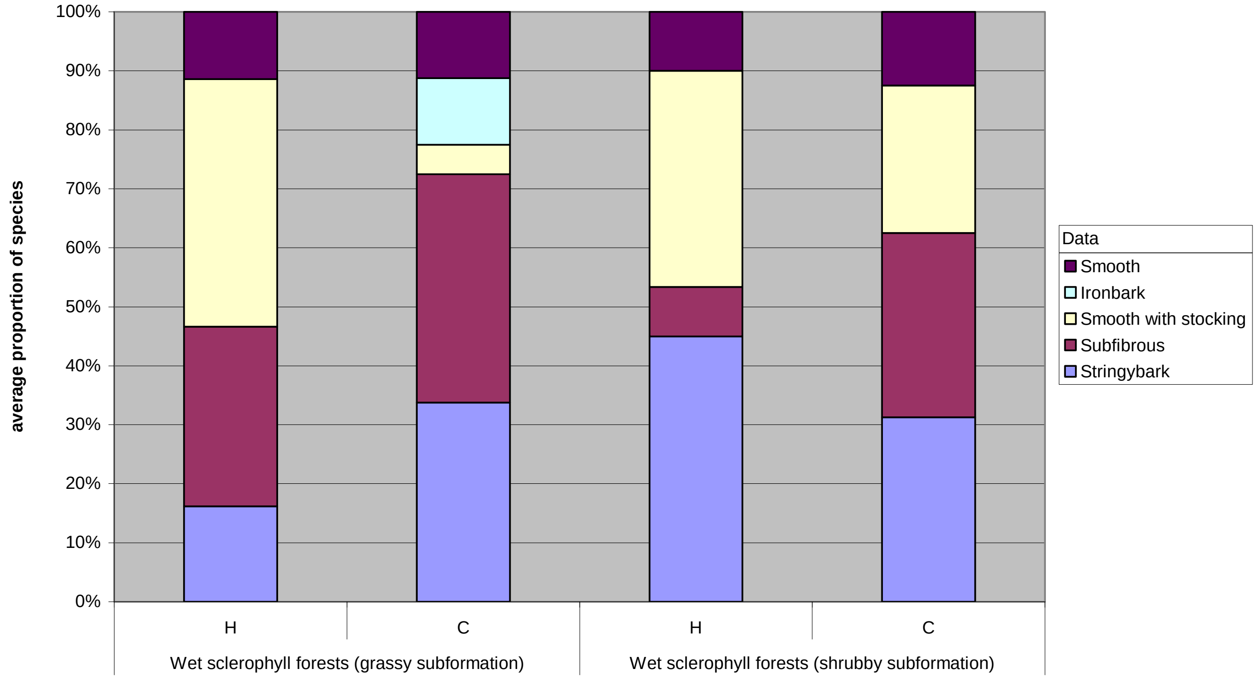


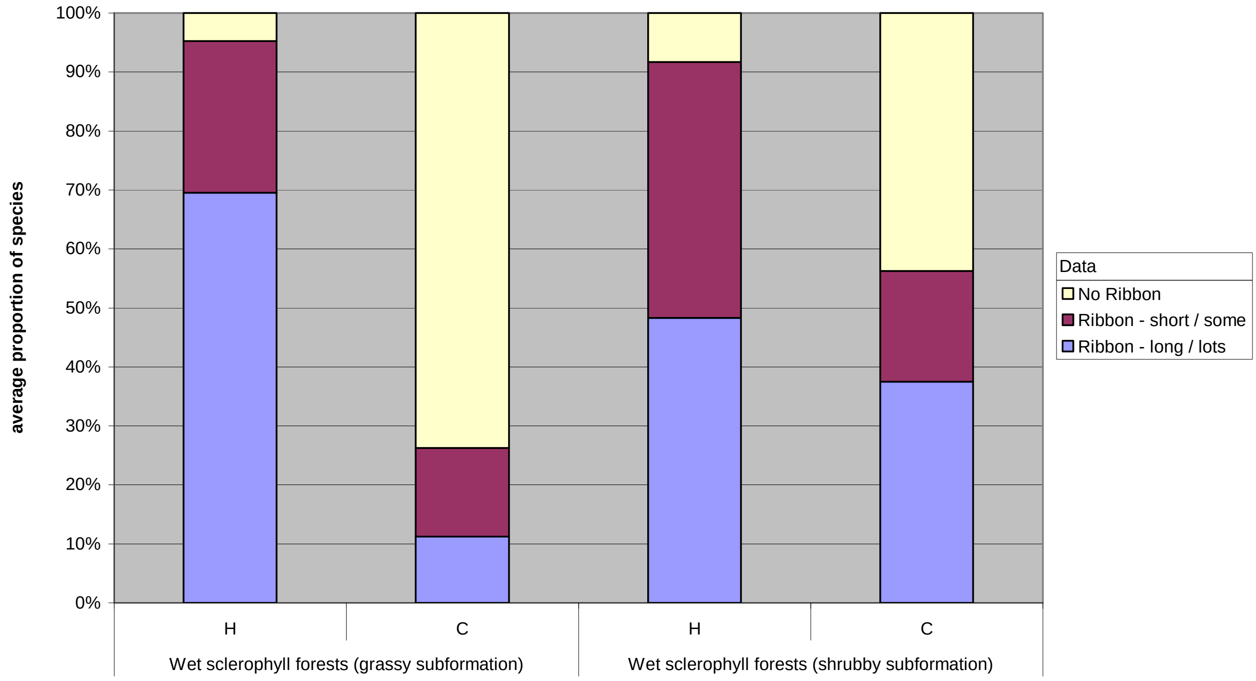
Appendix 6: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories in ***DSF vegetation classes*** found predominantly in northern NSW **(N)**; those found predominantly in southern NSW **(S)**; and those found centrally or across the entire latitudinal range of NSW **(C)**.



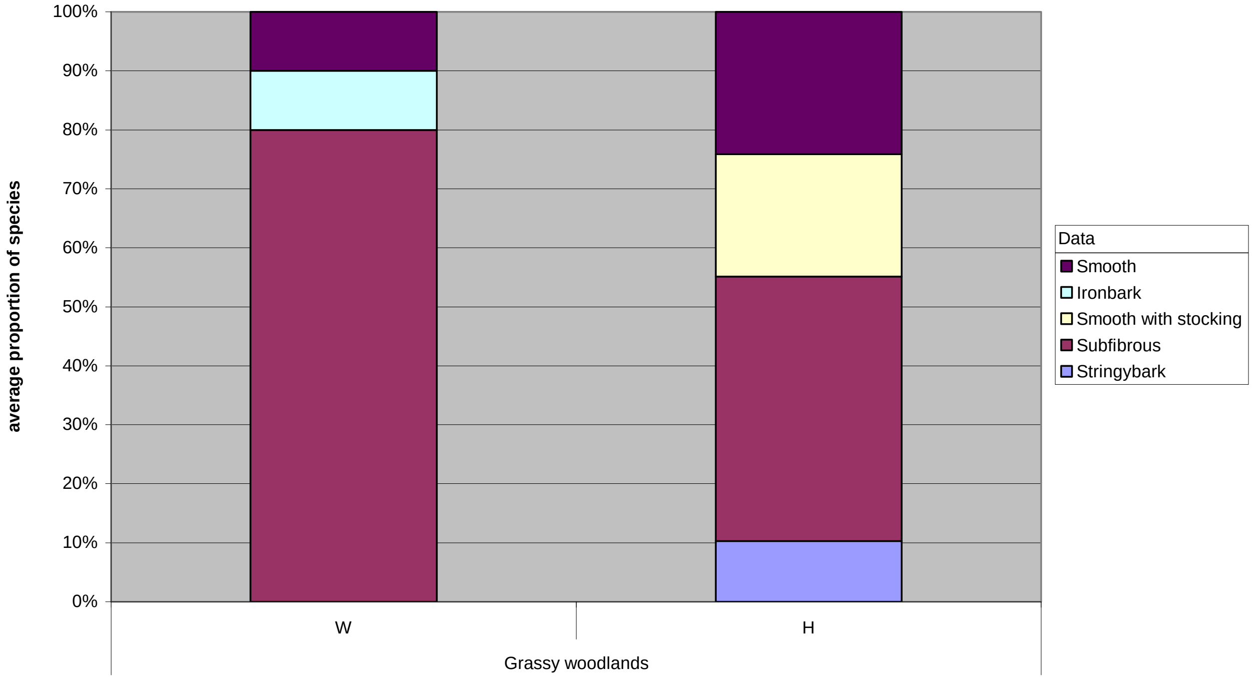


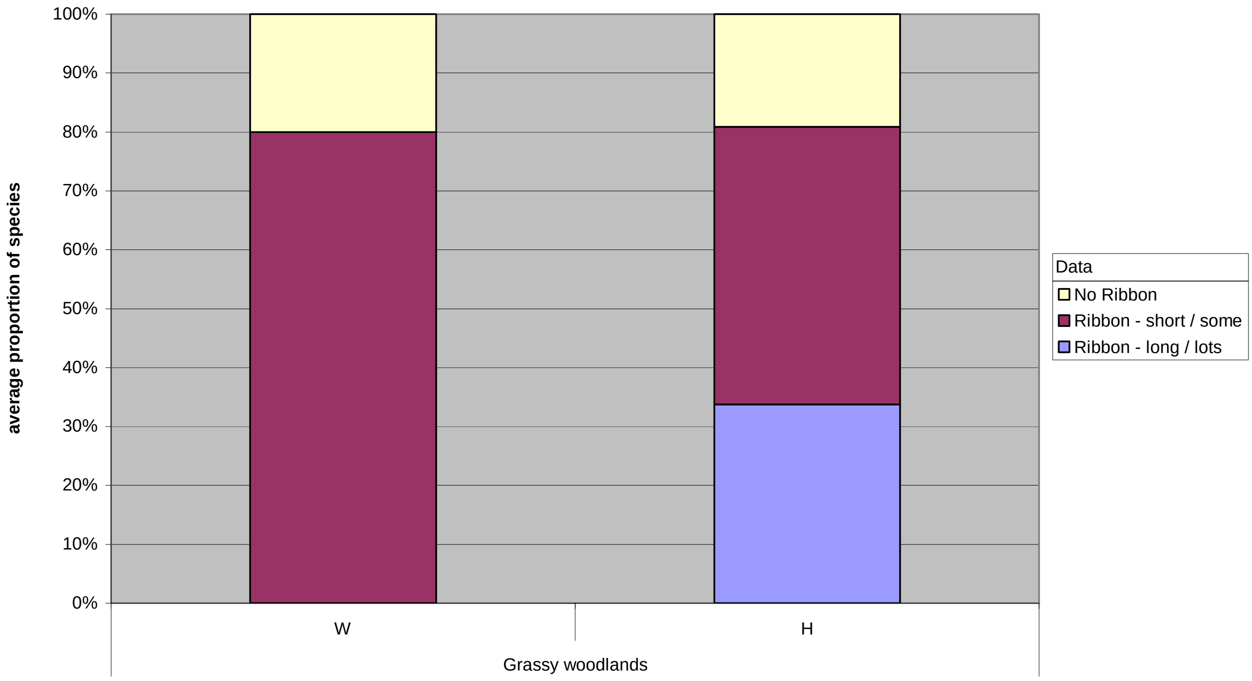
Appendix 7: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories in ***WSF vegetation classes*** found predominantly in escarpment and tableland **(H)** or coastal **(C)** regions of NSW.



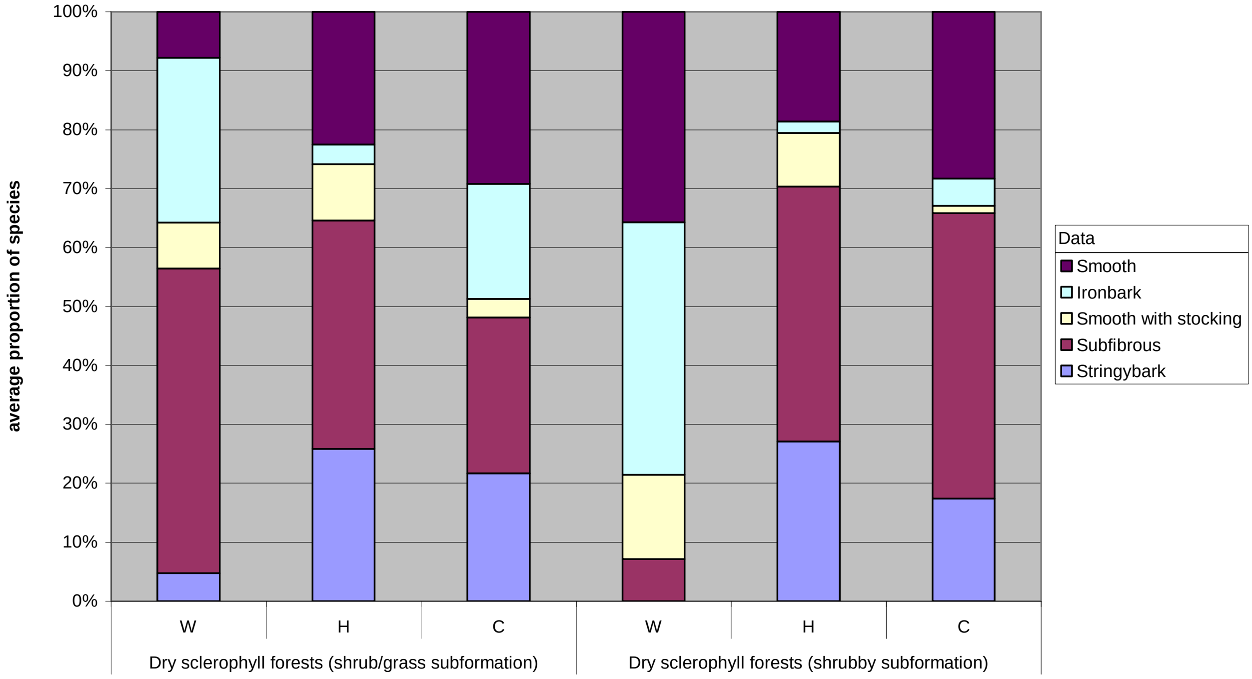


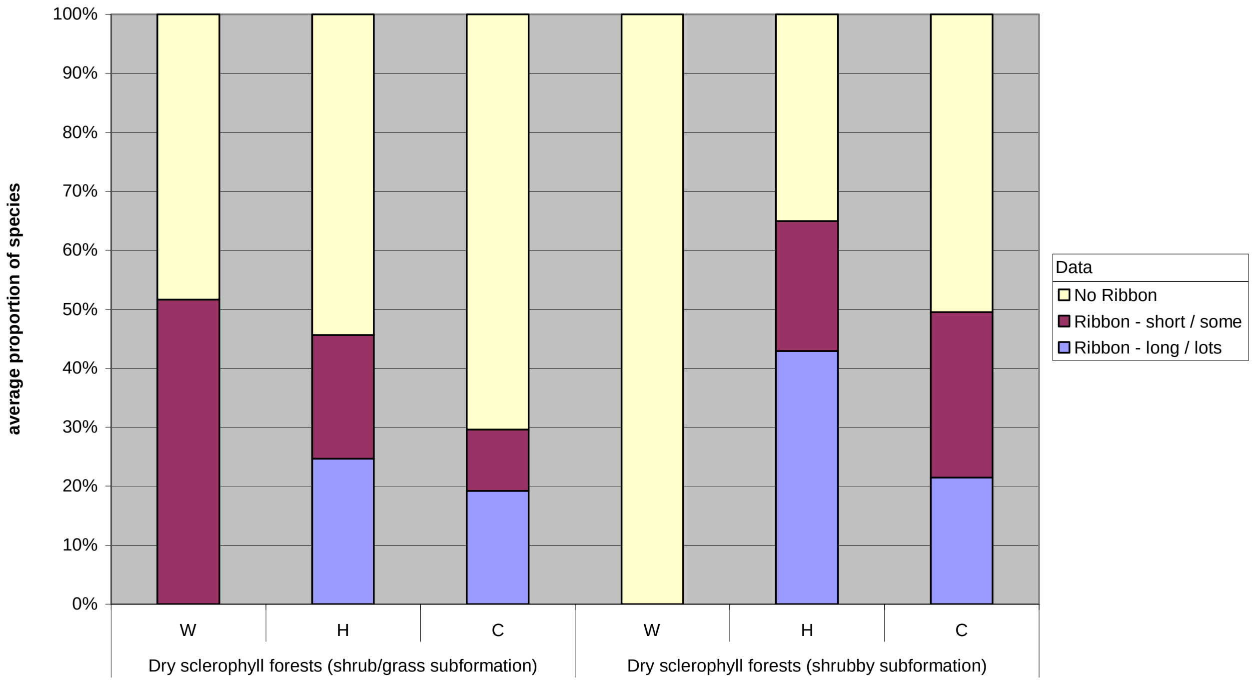
Appendix 8: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories in ***grassy woodland*** vegetation classes found predominantly in escarpment or tableland **(H)** or western slopes and plains **(W)** regions of NSW.





Appendix 9: Mean proportion of listed species (Keith 2004) in bark type (top) and propensity to produce ribbons (bottom) categories in ***DSF vegetation classes*** found predominantly in the western slopes and plains **(W)**; escarpment and tablelands **(H)**; or coastal **(C)** regions of NSW.





Appendix 10: Estimated bark hazard scores and ratings for 39 vegetation classes, considering development with time since fire. Vegetation classes surveyed as a part of the FHS in **bold**. Colours represent hazard ratings / scores (Red = E (5); Orange = VH (4); Yellow = H (3); Green = M (2); Blue = L (1)).

Vegetation Subformation	Vegetation Class	Bark Haz Score MAX (TSF>25yrs)	Bark Haz Score MED (TSF 12-25yrs)	Bark Haz Score MIN (TSF 0-12yrs)
Wet Sclerophyll Forests (shrubby Subformation)	**North Coast WSF**	5	4	3
	South Coast WSF	4	3	3
	Northern Escarpment WSF	5	4	3
	Southern Escarpment WSF	5	4	3
Wet Sclerophyll Forests (grassy Subformation)	**Northern Hinterland WSF**	5	4	3
	Southern Lowland WSF	5	4	3
	Northern Tableland WSF	4	3	3
	Southern Tableland WSF	4	3	3
	Montane WSF	4	3	3
Grassy Woodlands	**Coastal Valley GW**	4	3	3
	Tablelands Clay GW	4	3	3
	New England GW	5	4	3
	Southern Tableland GW	4	3	3
	Subalpine W-lands	4	3	3
	Western Slopes GW	3	2	2
	Floodplain Transition GW	3	2	2
Dry Sclerophyll Forests (shrub / grass Subformation)	Clarence DSF	4	3	3
	Hunter-Macleay DSF	4	3	3
	Cumberland DSF	4	3	3
	Southern Hinterland DSF	4	3	3
	Northern Gorge DSF	5	4	3
	Central Gorge DSF	5	4	3
	New England DSF	4	3	3
	North-west Slopes DSF	3	2	2
	Upper Riverina DSF	4	3	3
	Pilliga Outwash DSF	3	2	2
Dry Sclerophyll Forests (shrubby Subformation)	Coastal Dune DSF	4	3	3
	North Coast DSF	5	4	3
	Sydney Coastal DSF	4	3	3
	Sydney Hinterland DSF	4	3	3
	Sydney Sand Flats DSF	2	2	2
	South Coast Sands DSF	4	3	3
	South East DSF	5	4	3
	Northern Escarpment DSF	4	3	3
	Sydney Montane DSF	4	3	3
	Northern Tableland DSF	5	4	3
	Southern Tableland DSF	4	3	3
	Western Slopes DSF	2	1	1
	Yetman DSF	2	2	2

Appendix 11: Bark types, following merging of bark type and PPR categories described in Section 3.5.1, in forest and grassy woodland vegetation classes based on indicative tree species in Keith (2004). Colours delineate subformations: purple = WSF (shrubby); pink = WSF (grassy); yellow = grassy woodlands; blue = DSF (shrub / grass); green = DSF (shrubby).

	Count of Species						TOTAL	Proportion of Species listed					
Vegetation Class	stringybark	long ribbons	subfibrous	smooth w/ stocking	ironbark	smooth	Species Listed	stringybark	long ribbons	subfibrous	smooth w/ stocking	ironbark	smooth
North Coast WSF	3	2	0	3	0	0	**8**	0.375	0.250	0.000	0.375	0.000	0.000
South Coast WSF	1	2	1	0	0	0	**4**	0.250	0.500	0.250	0.000	0.000	0.000
Northern Escarpment WSF	3	1	0	2	0	0	**6**	0.500	0.167	0.000	0.333	0.000	0.000
Southern Escarpment WSF	2	3	0	0	0	0	**5**	0.400	0.600	0.000	0.000	0.000	0.000
Northern Hinterland WSF	3	1	2	0	1	1	**8**	0.375	0.125	0.250	0.000	0.125	0.125
Southern Lowland WSF	3	1	3	1	1	1	**10**	0.300	0.100	0.300	0.100	0.100	0.100
Northern Tableland WSF	2	3	0	2	0	0	**7**	0.286	0.429	0.000	0.286	0.000	0.000
Southern Tableland WSF	0	6	1	0	0	0	**7**	0.000	0.857	0.143	0.000	0.000	0.000
Montane WSF	1	3	0	0	0	1	**5**	0.200	0.600	0.000	0.000	0.000	0.200
Coastal Valley GW	1	1	2	0	2	3	**9**	0.111	0.111	0.222	0.000	0.222	0.333
Tablelands Clay GW	0	3	3	0	0	1	**7**	0.000	0.429	0.429	0.000	0.000	0.143
New England GW	3	2	4	0	0	1	**10**	0.300	0.200	0.400	0.000	0.000	0.100
Southern Tableland GW	1	2	4	0	0	2	**9**	0.111	0.222	0.444	0.000	0.000	0.222
Subalpine W'lands	0	3	0	0	0	3	**6**	0.000	0.500	0.000	0.000	0.000	0.500
Western Slopes GW	0	0	3	0	1	1	**5**	0.000	0.000	0.600	0.000	0.200	0.200
Floodplain Transition W'lands	0	0	5	0	0	0	**5**	0.000	0.000	1.000	0.000	0.000	0.000
Clarence DSF	2	1	1	0	1	3	**8**	0.250	0.125	0.125	0.000	0.125	0.375
Hunter-Macleay DSF	2	1	0	0	2	5	**10**	0.200	0.100	0.000	0.000	0.200	0.500
Cumberland DSF	1	1	1	0	2	1	**6**	0.167	0.167	0.167	0.000	0.333	0.167
Southern Hinterland DSF	2	3	2	0	1	0	**8**	0.250	0.375	0.250	0.000	0.125	0.000
Northern Gorge DSF	3	1	2	0	0	3	**9**	0.333	0.111	0.222	0.000	0.000	0.333

Vegetation Class	Count of Species						TOTAL	Proportion of Species listed					
	stringybark	long ribbons	subfibrous	smooth w/ stocking	ironbark	smooth	Species Listed	stringybark	long ribbons	subfibrous	smooth w/ stocking	ironbark	smooth
Central Gorge DSF	3	2	2	0	1	2	**10**	0.300	0.200	0.200	0.000	0.100	0.200
New England DSF	1	3	2	0	0	1	**7**	0.143	0.429	0.286	0.000	0.000	0.143
North-west Slopes DSF	0	0	2	0	1	0	**3**	0.000	0.000	0.667	0.000	0.333	0.000
Upper Riverina DSF	1	0	3	1	1	1	**7**	0.143	0.000	0.429	0.143	0.143	0.143
Pilliga Outwash DSF	0	0	5	1	4	1	**11**	0.000	0.000	0.455	0.091	0.364	0.091
Coastal Dune DSF	1	1	1	0	0	2	**5**	0.200	0.200	0.200	0.000	0.000	0.400
North Coast DSF	4	2	4	0	0	1	**11**	0.364	0.182	0.364	0.000	0.000	0.091
Sydney Coastal DSF	2	2	1	0	0	3	**8**	0.250	0.250	0.125	0.000	0.000	0.375
Sydney Hinterland DSF	3	2	3	1	1	3	**13**	0.231	0.154	0.231	0.077	0.077	0.231
Sydney Sand Flats DSF	0	0	1	0	1	3	**5**	0.000	0.000	0.200	0.000	0.200	0.600
South Coast Sands DSF	0	1	1	0	0	0	**2**	0.000	0.500	0.500	0.000	0.000	0.000
South East DSF	3	4	2	0	1	0	**10**	0.300	0.400	0.200	0.000	0.100	0.000
Northern Escarpment DSF	2	5	1	0	0	0	**8**	0.250	0.625	0.125	0.000	0.000	0.000
Sydney Montane DSF	2	5	0	0	0	2	**9**	0.222	0.556	0.000	0.000	0.000	0.222
Northern Tableland DSF	2	1	0	0	0	2	**5**	0.400	0.200	0.000	0.000	0.000	0.400
Southern Tableland DSF	2	4	3	0	0	2	**11**	0.182	0.364	0.273	0.000	0.000	0.182
Western Slopes DSF	0	0	0	1	4	2	**7**	0.000	0.000	0.000	0.143	0.571	0.286
Yetman DSF	0	0	1	1	2	3	**7**	0.000	0.000	0.143	0.143	0.286	0.429

Appendix 12: Summary of bark-related data from the University of Wollongong Fuel Hazard Study. For all variables values are averages of site means. "Presence" variables: % plots containing that bark type. "Amount" variables: scale 0 – 3. "Char" variables: % bark char to 5m, in plots and sites containing that bark type.

Vegetation Class	TSF category	Mean TSF (yrs)	Stringybark present	Stringybark amount	Stringybark char	Subfibrous present	Subfibrous amount	Subfibrous char	Ribbon present	Ribbon amount	Bark fuel haz score	No. sites	No. plots
North Coast / Hinterland	0 - 6	2.72	28.57	0.34	46.67	100.00	1.17	73.14	100.00	1.26	2.60	5	35
WSF	6 - 9	7.51	64.49	0.88	71.50	93.54	1.16	66.65	95.92	1.08	2.60	7	46
	9 +	18.45	68.57	1.50	19.35	85.71	1.69	27.87	61.90	0.81	3.53	6	38
North Coast / Hinterland WSF Ave		**9.83**	**55.87**	**0.94**	**45.67**	**92.72**	**1.34**	**55.53**	**85.71**	**1.04**	**2.91**	**18**	**119**
Coastal Valley GW	0 - 6	1.83	16.33	0.27	11.25	95.92	1.61	16.29	100.00	1.73	2.98	7	47
	6 - 9	7.75	11.90	0.14	61.11	90.48	1.52	10.10	97.62	1.45	2.98	6	42
	9 +	30.20	2.38	0.05	0.00	92.86	1.55	0.67	97.62	1.86	3.31	6	42
Coastal Valley GW Average		**12.66**	**10.53**	**0.16**	**34.31**	**93.23**	**1.56**	**9.40**	**98.50**	**1.68**	**3.08**	**19**	**131**
Hunter Macleay DSF	0 - 6	3.18	38.10	0.74	35.52	47.62	0.67	30.56	19.05	0.21	2.98	6	42
	6 - 9	7.75	64.29	0.95	42.74	40.48	0.62	23.33	21.43	0.31	3.00	6	42
	9 +	23.87	78.57	1.86	1.24	45.24	0.86	0.00	19.05	0.17	3.81	6	40
Hunter-Macleay DSF Average		**11.60**	**60.32**	**1.18**	**22.89**	**44.44**	**0.71**	**18.75**	**19.84**	**0.23**	**3.26**	**18**	**124**
Cumberland DSF	0 - 6	3.20	0.00	0.00		100.00	1.30	70.71	10.71	0.11	2.26	4	26
	6 - 9	7.00	9.52	0.10	67.50	68.57	0.78	79.29	0.00	0.00	2.02	6	40
	9 +	24.75	9.52	0.21	0.00	97.62	2.45	14.13	40.48	0.48	3.31	6	42
Cumberland DSF Average		**12.71**	**7.14**	**0.12**	**33.75**	**87.32**	**1.54**	**50.94**	**17.86**	**0.21**	**2.56**	**16**	**108**
North Coast DSF	0 - 6	3.08	92.86	1.36	46.63	100.00	1.17	61.00	20.48	0.20	3.24	6	40
	6 - 9	8.10	85.71	1.43	38.17	100.00	1.67	46.19	52.38	0.40	3.31	6	42
	9 +	15.68	83.33	1.93	3.68	100.00	2.26	11.43	30.95	0.24	4.05	6	42
North Coast DSF Average		**8.96**	**87.30**	**1.57**	**29.49**	**100.00**	**1.70**	**39.54**	**34.60**	**0.28**	**3.53**	**18**	**124**
Sydney Coastal DSF	0 - 6	2.72	41.20	0.43	62.73	93.33	1.25	55.71	48.36	0.52	2.58	9	55
	6 - 9	7.33	61.67	0.91	38.65	98.81	1.43	36.81	50.48	0.55	3.02	12	70
	9 +	21.34	33.51	0.74	11.75	90.13	1.94	12.31	36.10	0.48	3.14	11	67
Sydney Coastal DSF Average		**10.85**	**46.23**	**0.72**	**37.88**	**94.29**	**1.55**	**33.70**	**44.94**	**0.52**	**2.94**	**32**	**192**
South East DSF	0 - 6	3.25	78.57	1.29	56.99	88.57	1.46	41.25	55.24	0.39	3.02	6	40
	6 - 9	7.25	59.52	1.07	29.87	100.00	1.67	29.05	35.71	0.31	3.02	6	42
	9 +	30.13	88.10	2.33	10.91	83.33	1.69	19.40	45.24	0.43	3.98	6	42
South East DSF Average		**13.54**	**75.40**	**1.57**	**32.93**	**90.63**	**1.60**	**29.90**	**45.40**	**0.37**	**3.34**	**18**	**124**
Southern Tablelands DSF	0 - 6	3.40	95.24	1.74	49.62	87.14	1.28	31.17	56.19	0.36	3.12	6	40
	6 - 9	7.47	90.48	1.60	38.79	83.33	1.55	16.38	50.00	0.38	3.10	6	42
	9 +	35.33	97.62	2.50	17.62	54.76	1.27	4.40	35.71	0.32	4.08	6	40
Southern Tablelands DSF Average		**15.40**	**94.44**	**1.94**	**35.34**	**75.08**	**1.37**	**18.08**	**47.30**	**0.35**	**3.43**	**18**	**122**