FUEL DYNAMICS IN SHRUB-DOMINATED LANDSCAPES

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Abstract

Changes in wildland fuels with time since fire affect the behaviour and impact of bushfires. The majority of research into fuel dynamics has generally been limited to changes in the load of fine dead surface fuels in forest ecosystems. Fuel dynamics in shrub dominated ecosystems are more complicated as most available fuel is comprised of living vegetation. Shrubland fuel dynamics relating to stand structure and proportion elevated dead fuel are important to shrubland fire behaviour.

This paper reviews the current knowledge of shrubland fuel dynamics and focuses on the potential impact of pyric succession and fire regime factors that may affect these. Fuel dynamics in species rich shrublands are influenced by plant compositional changes during pyric succession. Fire regime characteristics, such as between fire intervals, influence the presence of plant functional response types in post fire assemblages and the physical structure of regrowth. These factors have not been linked with bushfire fuel hazard before and should be explored further so that the impacts of fire management in shrub dominated ecosystems can be better understood.

Introduction

Vegetation communities with biomass dominated by shrubs include open and closed heath, open and closed scrub, and low shrubland listed in Specht's (1970) vegetation classification, as well as woodlands that have significant shrub layer present as an understorey. They are renowned for their diversity and many of the plant species found in these vegetation types are highly flammable and reliant on fire for regeneration (Gill and Groves 1981, Specht 1981, Bradstock et al. 1997, Keith et al. 2001). Heathlands are more flammable than other vegetation types and they can support high intensity fires in relatively moderate conditions and are often able to burn within a few days after rainfall (Catchpole et al. 1998a, Catchpole 2001, Fernandes 2001, Keith et al. 2001).

The bulk of the fuel available to fires in shrub-dominated communities is living vegetation. In other vegetation types, such as forests and grasslands, fires mainly burn in dead fuels such as leaf litter and cured grass, with living fuel burning only when mixed with dead fuels or during crown fires which only occur under extreme conditions. The dynamics of combustible fuel in vegetation communities with significant shrub components are complicated and have received less attention than that of litter layers in forests.

This paper presents a brief review of fuel dynamics in shrub-dominated communities of southeastern mainland Australia. Research investigating pyric succession and fire regimes in these communities has also been reviewed, in order to determine what effects these may have on fuel characteristics in postfire regeneration. The majority of this research has been undertaken in heathlands (vegetation dominated by shrubs less than two metres tall (Specht 1970)), though much would also be applicable to floristically similar taller shrubland communities and the shrub layers present in some heathy woodlands.

Shrubland fuel dynamics

Fundamental characteristics of bushfire fuels change with time since fire. Such characteristics include the mass, structure, and composition of the fuel array. Fuel accumulation, the net build up of above ground biomass (fuel load) over time, has dominated research into fuel dynamics. The accumulation of shrub fuels is more complicated than litter accumulation in forests and grasslands as there is more influence from the species present at a site and associated growing conditions. There are a number of published fuel accumulation models for shrub-dominated landscapes (eg: Rothermel and Philpot 1973, Burrows and McCaw 1990, Conroy 1993, Marsden-Smedley and Catchpole 1995, Fernandes and Rego 1996, Morrison et al. 1996, McCaw 1997). Most of these are logarithmic equations fitted to discrete data sets for particular shrublands. The upper asymptote, which represents a steady-state fuel load for these models varies from 0.74 kg m-2 (total fuel load) for *Banksia* low woodland (Burrows and McCaw 1990) to 4.5 kg m-2 for medium productivity buttongrass moorlands (Marsden-Smedley and Catchpole 1995). All changes in fuel characteristics have been modelled using time since last fire as the only predictor. However other factors, such as seasonal rainfall variation and grazing, could potentially influence fuel accumulation and require investigation.

More detailed characterisation of the fuel bed is required to better understand and predict shrubland fire behaviour. Characteristics such as the proportion of standing dead fuel, fuel height, and fuel density are important to fire behaviour, particularly in shrublands. Many authors have linked the flammability of older shrublands with high proportions of elevated dead fuels (eg: Rothermel and Philpot 1973, Green 1981, Keeley 2002). Heathlands with a substantial mass of dead elevated fuel are capable of burning during dry spells even in the coolest and wettest parts of the year (Keith et al. 2001). Vegetation height has been linked with shrubland fire behaviour and subsequently used in some spread rate models (Catchpole et al. 1998a, Fernandes 2001) because it is easily assessed and highly correlated with other vegetation parameters such as fuel load and density. There have been suggestions in the scientific literature that bulk density, or another fuel porosity descriptor, would probably give a better explanation of the effect of fuel on shrubland fire behaviour than load and height (Fernandes et al 2000, Fernandes 2001) based on evidence from laboratory experiments (eg: Catchpole et al. 1998b). There are relatively few studies that explore the post-fire changes of these fuel dynamics in shrublands.

Pyric succession and fuel dynamics

The accumulation of above ground biomass in heathlands is often much more complex than is suggested by models that assume steady-state conditions can be achieved. Floristic and structural changes due to pyric succession can lead to changes in the total fuel load. In heathlands that experience distinct stages of plant regeneration, the relationship between time since last fire and fuel load may not be smooth. Pyric succession involves the gradual ascendance of long-lived species present in the pre-fire stand rather than replacement of pioneer species with new species. In southeastern Australia, the early successional stage (two to three years) is dominated by monocots, such as sedges, restioids, *Xanthorrhoea* spp. and geophytes, with annual species also present in the first year (Ingwersen 1977, Gill and Groves 1981). Shrub species that regenerate vegetatively from rootstocks and a range of undershrub species prevail up to about five or six years (Gill and Groves 1981). The proportion of fuel load from long-lived obligate seeders (species that retain seeds on the mature plant and are killed when their crowns are completely scorched) increases with time since fire (Specht et al. 1958, Ingwersen 1977, Specht 1981, Benson 1985, McCaw 1997, Keith et al. 2001) as they generally take longer to establish. They become dominant as the vegetative regenerators decline (Ingwersen 1977, Gill and Groves 1981). Floristic biodiversity is usually the greatest in the first few years after fire when all of these life forms are present, although there is variation in relationships of observed species richness with time since last fire (Gill et al. 1999).

Specht (1966, 1981) and associated researchers (Specht et al. 1958, Groves 1965, Groves and Specht 1965, Jones 1968a, 1968b, Jones et al. 1969) found a range of relationships between biomass and time since last fire in a number of heathlands in South Australia (Keith, Dark Island) and Victoria (Frankston, Tidal River and Barry's Creek). Many of their results show complex relationships that defy the assumption of a steady-state, and these are reproduced in Figure 1. The saddle shaped curves for heathlands at Keith and Tidal River (Groves and Specht 1965) and wet heathlands (Specht 1981) are a result of successional change of plant species in heathlands. In these cases there is a sharp increase in biomass in the first few years that is followed by a plateau before a second increase. The plateau represents a time when the pioneer species associated with the early stages of pyric succession are in decline and the longer-lived shrubs that dominate the long-term fuel load are still developing. This effect can be clearly seen in Figure 2a (Specht et al. 1958), where the delayed return of resprouting species (*Casuarina* spp., *Leptospermum* spp.) and sub shrubs (*Phyllota* spp.) are largely responsible for the second increase in biomass, during the decline of a number of small shrub and herb species (eg: *Leucopogon* spp.). The long-lived seed regenerating *Banksia ornata* dominates the community biomass afterwards, with the community becoming senescent after about 40 years. The trend for a community where a dominant species constitutes the bulk of the biomass from early ages on is much less complex, as is the case for mallee boombush shrubland illustrated in Figure 2b (Specht 1966). Ingwersen (1977) found a similar trend with the proportion of obligate seeder species (*Banksia ericifolia*, *Allocasuarina distyla* , and *Hakea teretifolia*) to increasing with time since last fir e in a coastal heathland at Jervis Bay NSW.

The decline of a dominant species as it reaches the end of its life cycle can result in a decrease in total biomass and a sharp increase in the proportion of dead aerial fuel. The degradation of senescing shrubs in long unburnt shrublands can open space for the establishment of herb and grass species. The lifespan of a given plant is generally species specific, but may be influenced by site and climate, as well as the presence of competing plants. The structural and floristic changes from pyric succession can be impacted by disturbances such as grazing (Gill and Groves 1981).

Figure 1: Heathland biomass accumulation (Jones et al., 1969; Specht, 1981).

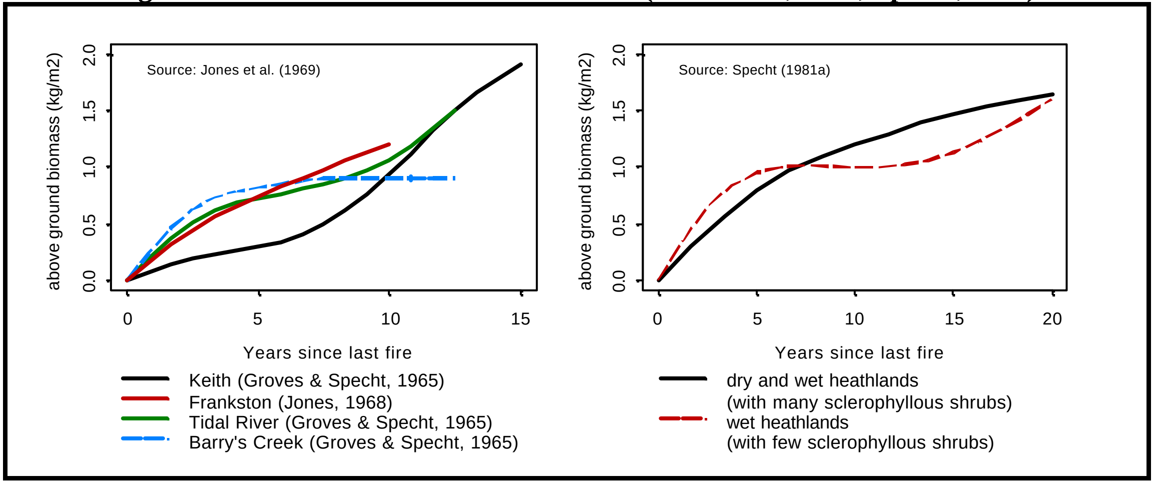
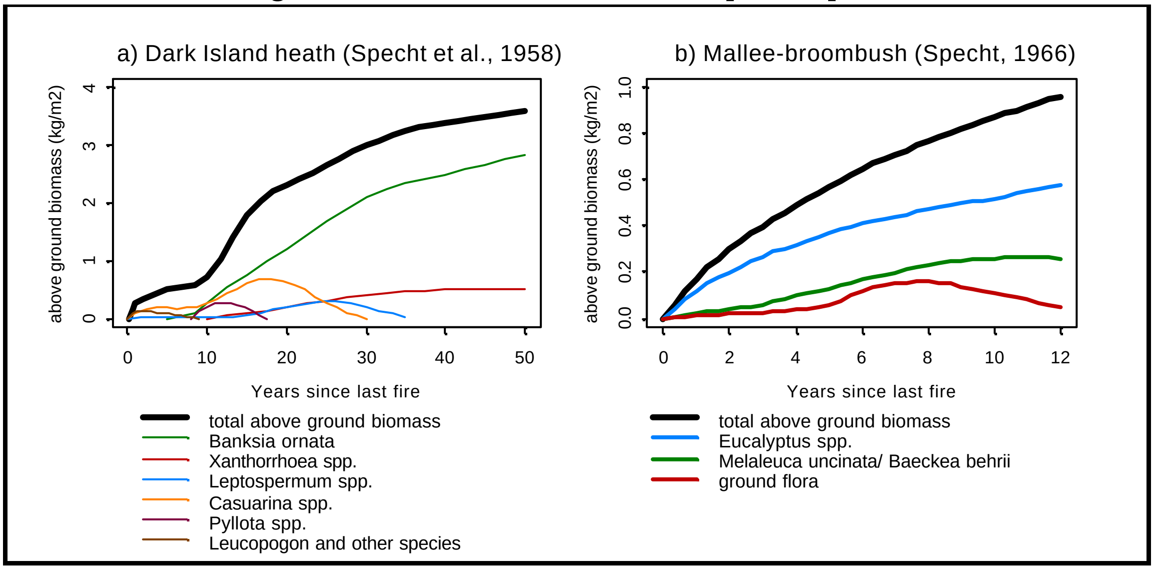


Figure 2: Biomass accumulation of component species.



Fire regimes and fuel accumulation

The suite of plant species present at a site is influenced by fire history. Of the four fire regime determinants (Gill 1975), fire frequency probably has the greatest effect on the composition of plant communities. The season and intensity of previous fires can also influence regeneration. Prescribed fires are usually applied in cooler seasons due to safety considerations. Regeneration of obligate seeder species is often poor after low intensity cool-season burns as there may not be enough heat to open seed capsules, some plants may be in flower or have immature fruit, and seedlings may experience greater mortality due to increased predation and heat and water stresses over the following summer (Gill and Groves 1981). Obligate seeders are often dominant shrub species in older heathlands (Specht et al. 1958, Specht 1981, Bradstock et al. 1998). Morrison et al. (1996) found that fire intensity to affected fuel accumulation in shrub-dominated communities in the Sydney basin, with fuels accumulating to hazardous levels more quickly after low intensity fire than after high intensity fire. Morrison (2002) found fire intensity also affected the species composition in these communities.

The flora of sites that have experienced frequent fires may be dominated by plants that have short maturation periods or by shrubs that resprout from stems or roots (Specht 1981). Remnant vegetation surrounded by urban development tends to experience frequent fires due to the high probability of ignition (Keith et al. 2001). These sites are at risk of losing late maturing obligate seeder species as they are at higher risk of being killed before they can reproduce (eg: Gill and Groves 1981, Noble and Slatyer 1981, Bradstock et al. 1997). If the frequency of fire is very high, repeated fires can also result in the decline of vegetative resprouters (Bradstock and Myerscough 1988). Repeated fires at short intervals can simplify the structure and composition of heathlands towards an open herb or sedgeland (Ingwersen 1977, Gill and Groves 1981, Noble and Slatyer 1981, Bradstock et al. 1997). In terms of fuel load accumulation, a short interval fire regime may lead to fuel load increasing at a very rapid rate soon after fire, then reaching a reduced steady-state due to the absence of late maturing large shrubs. In this scenario fuel accumulation would probably be similar to the case of Dark Island heath (Specht *et al*. 1958) with *Banksia ornata* absent (Figure 2a). Even though the steady-state fuel load may be lower in this case, replacement fuels may be prone to fire in all seasons, due to higher proportions of dead and very fine fuels. Fires in this resultant fuel scenario would be more likely to behave like a grassfire.

In the absence of fire, the increasing domination of large obligate seeders in long unburnt heathlands can lead to a heathland taking the form of a tall shrubland (eg: Specht et al. 1958, Noble and Slatyer 1981, Specht 1981 1981d, Keith 1995) (Figure 2a). The long absence of fire in these landscapes can lead to the loss of the short-lived pioneer species that require fire for reproduction (Bradstock et al. 1997) as well as vegetative resprouters. The seeds of these species are present in the soil after the plants have died, but may not be viable after long periods of time. Obligate seeder species can also be lost if fire is absent for long periods and these species reach senescence (Gill and McMahon 1986, Keeley 2002). Obligate seeder species are advantaged by a fire frequency occurring at intervals longer than the primary juvenile period, but shorter than the plant's lifespan (Gill and Groves 1981). The fuel load of sites that have long fire intervals might experience slower accumulation, due to a reduction of short lived pioneer and resprouting species, but may attain a higher load in the long term, as long-lived seed regenerators mature. In this case fuel accumulation would probably be similar to that of *Banksia ornata* in Figure 2a. The peak fuel load would depend on the dominating species and how it grows at a particular site. The type of fires in these taller shrubland fuels would depend on the fuel structure and the openness of the canopy. If the canopy is open, and separated from the ground, surface fires may occur in mild conditions. If the canopy layer is dense and connected to the ground either directly or through ladder fuels, then the whole vegetation stand is more likely to burn and fires might only spread in extreme conditions, as the litter may be unavailable for burning under most conditions.

Fire frequencies on managed lands would usually lie somewhere between the extremes described previously. The intervals between prescribed fires are generally a balance between fuel reduction and maintenance of biodiversity (eg: Morrison et al. 1996, Bradstock et al. 1998, Keeley 2002). These objectives are often in conflict as they can be impossible to achieve simultaneously (Morrison et al. 1996, Bradstock et al. 1998). Managed fire regimes may aim to vary the fire frequency and include patchy fires in order to maximise the plant diversity at a site (eg: Bradstock et al. 1998). Fire intervals are often tailored to suit the requirements of significant flora or fauna species. In areas adjacent to assets fire is often applied more regularly to keep fuel loads low.

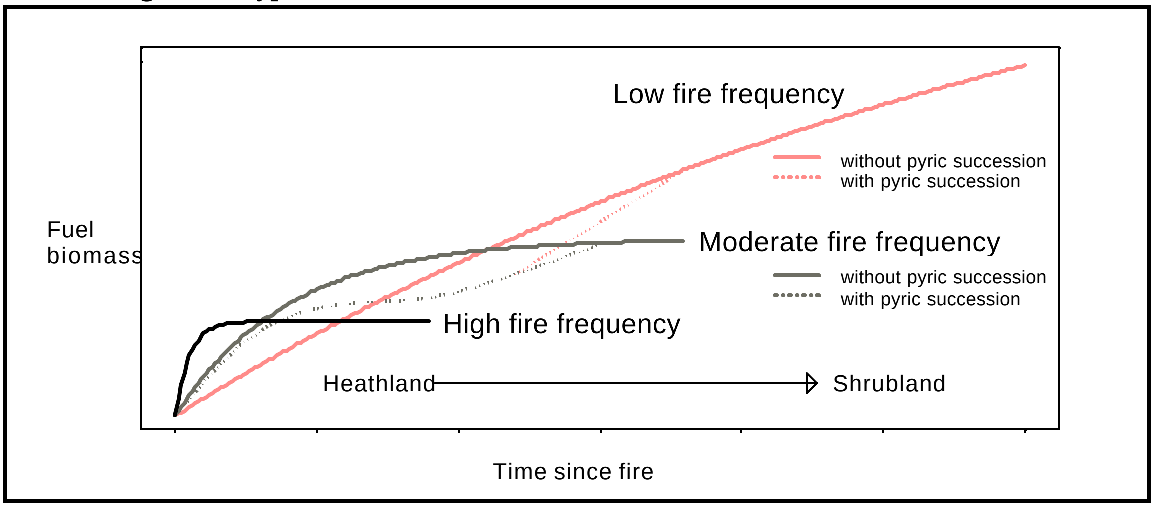
Seed from plants found outside the burned area may also germinate after fire. Some species do not store seed or resprout and rely entirely on seed dispersal in their reproduction. The seeds from these species must come from unburned areas. The post-fire environment also opens niches for the establishment of seedlings from seed dispersing species and provides an opportunity for the invasion of weed species. Many weed species have the ability to grow much faster than native species after fire and can build up substantial populations relatively quickly. Invasive species can change the fuel characteristics, and subsequently the fire regime of an area. In particular, the invasion of annual grasses can lead to higher fire frequencies. Fire can also be used to control woody weed invasions in conjunction with other treatments.

Hypothetical fuel accumulation curves are illustrated in Figure 3. The majority of ideas discussed here are hypotheses (see Table 1) and require data to verify. The degree of increase and timing of the levelling of the logarithmic curve to an equilibrium biomass will depend on individual situations. Given the potential influence that fire regimes might have on plant populations and subsequently on fuel load and fire hazard in such diverse communities, data collection for this purpose should be a research priority.

Table 1. Hypothetical fuel and fire effects from different fire frequencies in shrublands.

Historical frequency	Low	Moderate (managed)	High
Reproductive types	Predominately long lived obligate seeders	All types present in varying proportions	Resprouters, short lived seeders, sedge and grass
Fuel accumulation rate	Slow	Moderate/ depending on species	Fast
Steady state fuel load	Very high	High, depending on species	Lower than others
Steady state structure	Tall shrubland	Heathland/ shrubland	Grass/ sedgeland
Fire type	Crown fire or surface fire (depending on fuel structure and weather)	Shrub crown fire	Grass fire
Fire intensity	Very high (if crown fire), low (if surface fire)	High	Moderate
Fuel availability/ season	extreme weather (crown fire); or moderate weather (surface fire)	High, will burn in moderate weather	Very high, will burn most of the time

Figure 3: Hypothetical fuel accumulation for different fire interval histories.



Conclusions

There is currently only a crude understanding of the dynamics of fuels in heathland communities, particularly those in the living vegetation. Heathland fuel dynamics are much more complex than those of forests and grasslands as they are affected by pyric succession which is strongly influenced by fire regime history. It is likely that fuel properties, such as percent dead fuel, fuel height and fuel density, are also affected by pyric succession, however their relationships are poorly understood. Research should be undertaken to gain a better understanding of these aspects of fuel dynamics in shrublands and to link aspects of fire ecology with fuel hazard and fire behaviour.

Acknowledgements

The author wishes to thank Ross Bradstock, Malcolm Gill, Wendy Anderson and Bob Conroy. This work was supported by an Australian Research Council and New South Wales National Parks and Wildlife Service funded SPIRT grant.

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