Fire and fuel in Tasmanian buttongrass moorlands:
regimes, characteristics, behaviour and management

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution and to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text.

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February 1998

Authority of access

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Abstract

The aims of this thesis are to examine the fire regimes, fuel characteristics, fire behaviour and fire management of Tasmanian buttongrass moorlands. Major changes have occurred to the fire regime of southwest Tasmania over the past 170 years. The fire regime has changed from an Aboriginal regime of mostly frequent low intensity buttongrass moorland fires to the early European fire regime of frequent high intensity fires in all vegetation types, to a regime of low to medium intensity buttongrass moorland fires and finally to the current regime of very few fires. Buttongrass moorland fuel accumulation rates in western and southwestern Tasmania can be divided into two productivity groups, based on geological type. Within each productivity group, the vegetation cover and/or the time since the last fire can be used to model fuel load and the dead fuel load. Dead fuel moistures in buttongrass moorlands can be predicted from the relative humidity and dew point temperature. The main influences on buttongrass moorland rates of fire spread are wind speed, dead fuel moisture and age. Flame height in these moorlands is highly correlated with the fuel consumption rate, which in turn is controlled by the rate of fire spread, fuel load and dead fuel moisture. Operational fire behaviour models have been developed which use the wind speed, temperature, relative humidity, age and site productivity to predict the fire spread rate and flame height. The prescriptions for burning buttongrass moorlands have also been refined. Wildland fire management is a major problem in western and southwestern Tasmania. This is mainly due to the extensive area of fire-adapted and fire-dependent vegetation, the small area burnt by natural fires, the high incidence of arson in some areas and across much of the region, the old-growth nature of the buttongrass moorland vegetation. If we are going to preserve the ecological values of the region whilst minimising the economic and social costs of management, we are going to have to reintroduce fire into the region. Such reintroductions of fire will need to be performed in a highly sophisticated manner in order to maximise the potential that they will achieve the desired outcomes.

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1. Introduction

After much fatigue in getting through, we suddenly, on reaching the top of the hill, opened into ground recently burnt, with a most beautiful valley extending SW, beneath us. The whole of this ground had been burnt, apparently immediately before the late snow, and I conclude, by the natives. The valley had the appearance, at a distance, of undergoing all the processes of agriculture, - some parts looking like freshly ploughed fields; and again, other parts possessing the most beautiful verdure from the sprouting of the young grasses and rushes.
William Sharland on the Loddon Plains in 1832.

1.1 Background

Recurrent fire is a characteristic part of many wildland environments. This is particularly the case in southwestern and western Tasmania, where many thousands of years of human land use have contributed towards the genesis of a rich mosaic of fire-tolerant and fire-sensitive vegetation types. These communities are typically juxtaposed and range from the highly fire-tolerant and fire-dependent buttongrass moorlands, through the increasingly fire-sensitive wet scrub, wet eucalypt forest, rainforest and coniferous heath communities.

Worldwide, there is an increasing need for active fire management in fire-adapted vegetation. This is due to its dependence on fire, cessation of burning by traditional societies, enhanced awareness of ecological values, increasing human pressures (both economic and population) and wildland fragmentation.

This thesis examines the fire regimes, fuel characteristics, fire behaviour and fire management of Tasmanian bnttongrass moorlands. These moorlands are a fire-dependent and fire-promoting vegetation assemblage, covering extensive areas of Tasmania. Fire management is a major problem in these moorlands due to their dependence on fire for their maintenance, ability to bnrn over a very wide range of conditions, and their potential to carry fires to other, more fire-sensitive vegetation types.

1.2 Fire and vegetation dynamics

In many of the world's vegetation types, fire is a major environmental disturbance factor. Worldwide, large areas of vegetation are either maintained or extensively modified by fire (Goldammer and Crutzen 1993). This is especially the case in Australia where fire is probably the dominant environmental disturbance factor (e.g. see Gill et al. 1981), and has been for many thousands of years (Singh et al. 1981; Singh and Geissler 1985; Pyne 1991).

Fire-dependent vegetation typically has its own characteristic, community-dependent fire regime (Bond and van Wilgen 1996). These fire regimes normally have several major components, in particular the fire frequency, but also fire intensity and degree of fire seasonality. Fire frequencies can range from short (i.e. one to a few years) in grasslands, sedgelands, moorlands and heathlands to long (i.e. decades to centuries) in forests. In such fire-adapted vegetation, changes to the fire regime will normally result in fundamental changes to the composition and structure of the vegetation (Christensen 1993; Bond and van Wilgen 1996). In addition, in fire-adapted vegetation, the nature of the fuel array will normally ensure that as communities age towards the top end of their fire frequency, their fuel characteristics will also change in such a way that the vegetation becomes more flammable, and is hence more likely to carry a fire. This will in most cases ensure maintenance of the original community type (Bond and van Wilgen 1996; see also Jackson 1968; Johnson and Fryer 1989).

In western Tasmania, Jackson (1968) has proposed a probabilistic model predicting how the different vegetation types will interact with the fire frequency and soil type. In this model, changes in the fire regime will result in the community type present at a site undergoing changes so that it remains in tune with the prevailing fire regime. Explicit within Jackson's (1968) model is the assumption the each community type will have its own characteristic, community specific fire frequency. In addition, implicit within Jackson's (1968) model is the assumption that as communities age towards the top end of their fire frequency, they will become more flammable and so in most cases, will be burnt, maintaining the original community type.

In the absence of fire, marked changes normally occur to the structure, floristics and fuel characteristics of fire-adapted vegetation. These changes normally include modification of the fuel array structure such that the available fuel increases (e.g. higher dead to live ratios and/or heavier fuel loads) and the fuel array becomes more continuous (i.e. fewer bare patches in the fuel array). The result of these changes is that if (or in most cases, when) a fire occurs in such vegetation, the nature of the fuel array will normally ensure that the fire intensity is higher than normal. These high fire intensities often result in the killing of many of the species that would normally survive fires (e.g. Cook and Williams 1995). These changes also typically result in marked changes to the community ecology. Therefore, in fire-adapted vegetation, in order to maintain structural and species diversity, fire will be required as a disturbance agent. In the absence of fire, the larger and/or longer lived species would be expected to dominate, normally at the expense of the smaller and/or shorter lived species. This would result in reductions in the number of species present at a site. For a discussion on the merits and practicalities of conserving biodiversity see Beattie (1995) and Burbidge and Wallace (1995).

For example, the fire regime over the last several thousand years in the Ponderosa pine, larch and Douglas fir forests of the northwestern USA was one of low-intensity fires every five to 30 years. However, fire exclusion over most of this century has resulted in marked changes to the community floristics and structure from open mixed stands of open Ponderosa pine, larch and Douglas fir to closed dense stands dominated by Douglas fir. These changes in community floristics and structure have allowed for large scale forest die-back resulting from insect attack and the development of extensive areas with high levels of standing dead fuel (Brennan and Hermann 1994; Haggstrom 1994; Mutch 1994; Brown and Sieg 1996; Savage 1997). When the inevitable fire occurs in these old-growth forests, the fire behaviour is such that it is typically an uncontrollable, highly destructive stand-replacing fire. In addition, due to the nature of the fuel array, it is often impossible to perform low-intensity prescribed fires. This is because the large amounts of fuel in association with the highly continuous nature of the fuel array results in even low-intensity fires quickly becoming stand replacing high-intensity fires (Brennan and Hermann 1994; Mutch 1994; Savage 1997). In these closed dense Douglas fir dominated stands of the northwestern USA, it is probable that there has been a change in the vegetation's fundamental fire regime and it may not easily be possible to return to the previous low-intensity fire regime (Brennan and Hermann 1994; Haggstrom 1994; Mutch 1994).

Similar changes to those observed in the Douglas fir forests of the northwestern USA have been observed in many other fire-dependent vegetation types world-wide. These include grasslands (Lunt 1995; Leach and Givnish 1996), heathlands and moorlands (Hobbs and Gimingham 1984; Fox and Fox 1987; Bradstock

1990; Harris 1991; Keith and Bradstock 1994; van Wilgen et al. 1994; Keith 1996; Morrison et al. 1996), and forests (Givnish 1981; Johnson and Fryer 1989; Johnson et al. 1990, 1995, 1996; Crutzen and Goldammer 1993; Bond and van Wilgen 1996).

Spatially and temporally, wildland fires tend to be highly variable. The typical situation is that in most years, few wildfires occur and their area and/or intensity tends to be relatively low. In a few years, however, there may be several large high-intensity fires which burn the majority of the area that has been subjected to recurrent fires (e.g. see Luke and McArthur 1978; Tasmanian Fire Review Committee 1994; Johnson et al. 1995, 1996; Kitzberger et al. 1997).

In areas with a record of recurrent fire, historical data show that large high-intensity fires tend to follow the development of old-growth vegetation (e.g. see Christensen et al. 1989; Romme and Despain 1989). For example, in the greater Yellowstone area between about 1700 and 1988, major fires occurred about every 40 to 60 years with few fires being recorded outside these major fire years (Romme and Despain 1989). A similar situation occurred in Tasmania over the last half century, with major wildfires occurring about every ten years with large highly destructive fires occurring about every 30 years (Luke and McArthur 1978; Tasmanian Fire Review Committee 1994).

Hence, in fire-adapted vegetation, it is neither desirable nor probably feasible to exclude fires. Such fire exclusions typically result in modifications to community dynamics and changes to the vegetation's fuel characteristics (Gill et al. 1981; Christensen 1993; Bond and van Wilgen 1996). A better solution is to ensure that fire-adapted vegetation burns within a fire regime consistent with its ecological requirements.

Buttongrass moorlands are a good example of a fire-adapted vegetation assemblage. These moorlands will burn over a very wide range of conditions and have long been considered to be a highly pyrogenic vegetation assemblage. For example, J. E. Calder in 1837 and 1840 stated that:

> . . . The herbage seems very inflammable (see Gowlland and Gowlland 1976).
>
> . . . it went into a blaze such only as the herbage of the west could create, which when thoroughly dry a-top is as inflammable as old okum (Calder 1860b).

1.3 Wildland fire regimes and fire management

1.3.1 Fire regime

A fire regime can be characterised according to its frequency, intensity and seasonality. The fire frequency is made up of the time period between fires and the time since the last fire. Both of these fire frequency factors have important influences when considering the ecological and/or management effects of a fire. The degree of variability in the fire frequency may also have important ecological implications, with the available evidence suggesting higher levels of biodiversity in areas that have been subjected to a variable fire regime (e.g. Keith and Bradstock 1994; Keith 1996; van Wilgen et al. 1994). The fire intensity is the heat release per unit time while the fire season is the time of the year within which a fire occurs.

Wildland fires can be classified by the part of the fuel array they consume. The three main types are ground fires, surface fires and crown fires (Albini 1993). Ground fires burn the sub-surface peat and duff layers with normally slow rates of spread (e.g. less than several metres per day) and little or no flaming combustion. Surface fires burn the fuels above but coutiguous with the ground, and typically have low to moderate rates of spread and intensities. Crown fires burn throughout the whole above ground fuel array typically with moderate to high rates of spread and intensities.

Typically an uncontained fire will go through three distinct stages: ignition, then acceleration followed by a quasi-steady state rate of fire spread. Following ignition the length of a fire's acceleration phase will depend on several factors including the prevailing weather conditions, fuel characteristics and fire size. The acceleration phase is typically short for fires in open non-forest vegetation such as grasslands, moorlands and heathlands, and longer in more closed vegetation such as forests. A quasi-steady state is reached when the level of fire behaviour is essentially stable with relatively constant rates of spread and intensities. It should also be noted that a fire may go through many acceleration phases in response to changing environmental conditions, such as changes in the weather, fuel conditions and/or topography, resulting in a range of quasi-steady states. The different stages of fire growth and acceleration have been reviewed by Cheney and Gould (1997).

1.3.2 Interactions between the fuel array and fire behaviour

The characteristics of the fuel have very important influences on fire behaviour, particularly fuel particle size, fuel moisture, relative proportion of live and dead material and the fuel distribution (Luke and McArthur 1978; Albini 1993). Within the flaming zone of a fire front, only fuel particles with a diameter of less than about 6 mm burn. The relative proportions of dead-to-live fuel may also be important with the fire being carried by the dead fuel, and the live fuel only burning when sufficiently dried out by the combustion of the dead fuel (Albini 1993). This is due to live fuel typically having moisture contents of 70 to 200% of oven dry weight (Pyne 1984; Bond and van Wilgen 1996). Fuel discontinuities (i.e. breaks in the fuel array distribution) may also have a significant effect on fire behaviour, with fires often failing to propagate in discontinuous fuels. The relationships between different aspects of fire behaviour and fuel array dynamics have been reviewed by Albini (1993) and Cheney (1996).

In low open vegetation types such as grasslands, sedgelands, moorlands and heathlands, the ratio of dead to live fuel is probably the most important aspect of the fuel array influencing the rate of fire spread (McArthur 1966, 1977; Dupuy 1995; McAlpine 1995; Cheney 1996). The ratio of dead to live fuel is normally referred to as the degree of curing in annual grasslands and the percentage of dead fuel in other vegetation types. For fire intensity, the total fine fuel load and the dead fuel moisture are probably the most important factors. In forested vegetation, the equivalent part of the fuel array influencing the rate of fire spread is probably the distribution, height and/or moisture content of the near surface dead fuel, while in common with open vegetation types, the total fine fuel load and the dead fuel moisture are probably the most important factors influencing fire intensity. The near surface fuels are the fuels in the 0.5 to one metre zone above the ground surface and are normally comprised of a mixture of horizontal and vertical leaves, bark and twigs (Gould 1993).

Variation in total fuel load has only a minor influence on the rate of fire spread (Dupuy 1995; McAlpine 1995). As a result, the fuel continuity, ratio of dead to live fuel, bulk density and fuel height are better indicators for determining when a site should be hazard reduced than is the total fuel load (Tolhurst 1996).

In buttongrass moorlands, the time since the last fire has a major influence on the fuel continuity, ratio of dead to live fuel and bulk density, and therefore, a major influence on both the fire intensity and rate of spread. As a result, the window within which effective fire management can be performed will be wider in recently hazard reduced areas than in non-hazard reduced areas (see Chapter s 6 and 7).

1.3.3 Fire behaviour modelling

The development of methods for describing fires for fire behaviour modelling has advantages not only for fire managers, but also for ecologists wanting to relate fire behaviour to its ecological effects. It is no longer acceptable to describe fires subjectively using terms such as 'cool', hot', 'slow moving' or 'fast moving', with the more appropriate objective measures being flame height (metres), flame length (metres), residence time (seconds or minutes), fireline intensity (kW m^{-1}) or fire rate of spread (m sec^{-1}, m min^{-1} or km hr^{-1}). Methods for quantifying fire behaviour have been described by Alexander (1982), Burrows (1984) and Gill and Knight (1988).

Throughout this thesis, rates of fire spread will be expressed in m min^{-1}, flame heights in metres and wind speeds in km hr^{-1}. These are the units most easily understood by field practitioners and for buttongrass moorland fires, result in inputs and outputs of the same order of magnitude.

Fire behaviour modelling has progressed in recent years with the development of fire management systems for many vegetation types. All of the fire behaviour models developed to date are at least to some extent empirically based models. Attempts have been made to develop fire behaviour models with a stronger physical basis, with the best examples being the Rothermel Fire Behaviour Model (including its derivative BEHAVE, Rothermel 1972; Andrews 1986; Andrews and Chase 1989) and the second generation United States Fire Behaviour Model (W. R. Catchpole personal communication). Such models treat each of the controlling variables independently and then attempt to model their relationships to produce fire behaviour predictions. However, due to limitations in fire behaviour theory and the available fire behaviour data, the operational utility of such physical fire behaviour models is very limited. For example, the Rothermel Fire Behaviour Model has been shown to be over-sensitive to variation in fuel height (Gould 1991) and to poorly explain the data used to generate the model (W. R. Catchpole personal communication). In addition, the Rothermel Fire Behaviour Model was generated using very short fireline lengths (one to three metres) in a wind tunnel. Since fireline length has been shown to have highly significant effects on fire behaviour (Cheney and Gould 1997), and due to problems associated with turbulence and radiation measurement in the wind tunnel used to generate the Rothermel Fire Behaviour Model (W. R. Catchpole personal communication), the utility of this model in explaining the fire behaviour of free burning fires in the open is questionable. This is supported by the poor performance of the Rothermel Fire Behaviour Model in explaining both North American and Australian grass fire data (see results in Sneeuwjagt and Frandsen 1977; Gould 1991).

A more cost and time effective strategy is probably to examine how different aspects of the fuel array, weather conditions and site factors affect fire behaviour, and then determine the mathematical form of these relationships. For example, Catchpole et al. (1995) showed that the relationship between wind speed and rate of fire spread approximated a power function (see also Beer 1991, 1993) while the relationship between fuel moisture and rate of fire spread approximated a negative exponential function. These relationships can then be used in regression modelling to create empirical models with a stronger physical basis. These models can then be used to develop fire behaviour prediction systems.

1.3.4 Buttongrass moorland fire management strategy

Buttongrass moorlands are managed for two main purposes: conservation and asset protection. Where the moorlands are being managed for conservation, the primary management aims are to maintain high levels of species and/or structural diversity, or in selected areas, maintain and/or promote the occurrence of selected species.

At present, fire is not being used to maintain species and structural diversity in Tasmanian buttongrass moorlands, with the exception of burning to maintain suitable habitat for orange-bellied parrots (*Neophema chrysogaster*, see Stephenson 1991; Parks, Wildlife and Heritage 1992; Marsden-Smedley 1993b). Where moorlands are managed for asset protection, frequent hazard-reduction burning is normally performed. The main aim of hazard-reduction burning is to ensure that if fires occur, their intensity and spread rates are such that they either do not sustain or are controllable by fire crews.

A major problem associated with fire management is our imperfect knowledge of fire in natural systems. Fire has markedly different effects (both in the cases of fire behaviour and fire ecology) in different vegetation types. In buttongrass moorlands, relatively frequent fire may be ecologically beneficial with long unburnt sites possibly having reduced species and structural diversity. In rainforest and alpine areas the reverse situation is the case, with any fire having deleterious effects.

In the past, fire has caused significant damage to the ecological values of western and southwestern Tasmania. For example, large areas of fire-sensitive vegetation have been degraded (Jarman et al. 1984; Brown 1988; Peterson 1990; Robertson and Duncan 1991) along with possibly, extensive areas of peat soils (Pemberton 1988, 1989; Hannan et al. 1993). An example of the difference between different vegetation types in the response to fire are from Birchs Inlet and the Tarn Shelf at Mt Field. The Birchs Inlet fire of 1985 burnt approximately 37 600 ha, most of which was buttongrass moorland (along with some small areas of wet scrub and eucalypt forest; see Blanks 1991). This fire occurred when the soils were wet and probably resulted in minimal long term ecological damage. In contrast, the Tarn Shelf fires at Mt Field in 1966 burnt about 100 ha of montane coniferous rainforest resulting in the long term (i.e. greater than 500 years) removal of the coniferous species along with much of the organic soil (see Kirkpatrick and Dickinson 1984a). Fires may also transgress buttongrass moorland boundaries and burn other more sensitive vegetation types. For example, a hazard-reduction burn in the Vale of Rasselas in 1984 escaped and burnt subalpine communities near Lake Rhona in the Denison Range.

Very frequent fires (i.e. repeated fires less than five to eight years apart) may also be causing adverse impacts to buttongrass moorland ecological values. For example, frequent fires could result in reductions to the seed regenerating heaths swamp paper-bark (*Melaleuca squamea*) and *Leptospermum glaucescens* (see Jarman et al. 1988b) and/or result in a reduction in the cover and abundance of heath component of the vegetation. Frequent fires may place these species at a competitive disadvantage compared to more fire-tolerant species, possibly resulting in long term changes in vegetation composition. These impacts could be associated with fire frequencies which were too regular (i.e. insufficient variability in the fire frequency) or too high (i.e. too short a period between fires). Concerns have also be raised that frequent burning may be having deleterious effects on organic soils (Pemberton 1988, 1989). Alternatively, too low a fire frequency (i.e. too long a period between fires) could result in reductions in buttongrass moorland biodiversity through the senescence and/or shading out of the smaller sedge, forb and grass species by taller trees, shrubs and heaths (e.g. Brown and Podger 1982a; Jarman et al. 1988a, 1988b; Marsden-Smedley 1990, 1993b; Marsden-Smedley and Williams 1993).

In contrast, in some buttongrass moorlands which occur at high altitude (i.e. above 900 m), the major disturbance factors may be climatic (e.g. frost, wind and/or ice glazing), with fire only playing a secondary role. These moorlands are probably maintained by these climatic factors, in combination with infrequent fires (see Section 7.7.2).

Buttongrass moorland fires may also have markedly different effects in different seasons. For example, spring and autumn fires often leave a thick mat of unburnt thatch which frequently comprises up to 25% of the pre-fire fuel load. This thatch layer possibly acts to reduce soil drying and probably would also form a suitable seedling germination site. In contrast, summer fires typically burn almost all of the fuel load, leaving the soils exposed. One effect of this is that following summer fires, the soils probably dry out to a much larger extent, possibly promoting peat degradation and reducing the potential for seedling regeneration. In addition, if fires occur over very dry soils, the peat itself may burn, resulting in long term impacts to the site (Bowman and Jackson 1981; Marsden-Smedley 1993a). As a result, in buttongrass moorlands, it is highly probable that spring and autumn fires are ecologically less damaging than summer fires.

1.3.5 Hazard-reduction burning

The aim of hazard-reduction burning is to broaden the weather conditions within which effective fire suppression can be performed and within which fires will not sustain. Implicit within bazard-reduction burning, is the assumption that wildfire control is the most important factor being managed for, and that ecological considerations are of secondary importance. As a result, within the hazard reduced area ecological impacts may be permitted, which if they occurred across broad areas, would be unacceptable (see Gledhill 1993).

The first proposals to conduct hazard-reduction burning in Tasmania were probably made by Perrin (1887) and Mitchell (1898). For example, Mitchell (1898) proposed that:

> The only security against destructive fires is to continually burn in seasons when timber is not too dry . . .

> My proposal to prevent bush fires is to allow persons to burn in winter with due care; and in the event of the fire spreading and doing damage, yet if the magistrates are satisfied that good judgement and care were exercised, the originator of the fire should not be held responsible for possible damages (Mitchell 1898).

In buttongrass moorland hazard-reduction burning, the aim is normally to reduce 70% of the vegetation over 70% of the site (see Forestry Tasmania, Parks and Wildlife Service, Tasmania Fire Service 1996).

Hazard-reduction burning acts to change the fuel characteristics present at a site so that the ratio of dead to live fuel, bulk density, fuel continuity, fuel height and the total fuel load are all reduced. This in turn acts to reduce the rate of spread and intensity of subsequent fires (Cheney 1996).

A major problem with hazard-reduction burning is that within the conditions in which burns are normally performed (i.e. low wind speeds, mild temperatures and moderate to high relative humidities), sites will not normally sustain fires at less than five to seven years of age. However, under periods of moderate to high fire danger, even recently burnt sites may carry uncontrollable fires. This was demonstrated during the 1982 Savage River fires in western Tasmania, when under extreme levels of fire danger, the Whaleback burnt with high rates of spread despite the moorland having been hazard reduced two years previously. McCaw et al. (1992) describes a similar situation in eucalypt forest where under extreme weather conditions a fire burnt with high rates of spread and intensities despite the area having been fuel-reduced three years previously. As a result, at high levels of fire danger, hazard-reduction burns may only provide limited protection.

1.3.6 Habitat-management burning in buttongrass moorlands

As regards the fire requirements of faunal species in buttongrass moorlands, information is only available for orange-bellied parrots, ground parrots (*Pezoporus wallicus*) and to a limited extent, small mammals. In Tasmania burning for faunal management is only performed in buttongrass moorlands for maintaining orange-bellied parrot habitat.

Orange-bellied parrots are present in Tasmania between October and March. Whilst in Tasmania, they require buttongrass moorland and scrub communities in the age range from three to 12 years since fire (Brown and Wilson 1984). Due to the large areas involved, the only feasible method for manipulating buttongrass moorlands for orange-bellied parrots is burning (Marsden-Smedley 1993b). Ground parrots have been observed in moorlands and heathlands with vegetation ages ranging from one to 90 years of age, with a maximum occurrence between four and 15 years of age (Bryant 1991).

Only very limited information is available on the effect of fire on small mammals in buttongrass moorlands. To date, only one study (Arkell 1996) has specifically looked at the effect of different fire age on small mammal distributions. Limited information is also available from several other sources, (e.g. Driessen and Comfort 1991; Taylor and Comfort 1993), but since all of these other studies examined small mammal distributions in different vegetation types which had different vegetation ages, their results must be used with caution.

In general very few or no small mammals occur in moorlands of less than about two years of age, probably as a result of the low levels of cover. The swamp antechinus (*Antechinus minimus*) feeds on lizards, frogs and insects and is found in moorlands throughout Tasmania (Brown 1993). The swamp antechinns appears to have its maximnm abundance in six to ten year old moorlands, with significant populations in moorlands older than about three years. The swamp or velvet-furred rat (*Rattus lutreolus velutinus*) is a generalised herbivore and omnivore found in a variety of vegetation types including open and closed forests (including rainforests), woodlands and moorlands. This species appears to be present in moorlands with a wide range of ages. The broad-toothed mouse (*Pseudomys fuscus fuscus*) is best known from older moorlands but since this species is uotorious for being trap shy, any comments made as to its distribution and ecology must be made with caution. From the evidence available, the broad-toothed mouse appears to be widespread in moorlands with moderate to high covers, which typically occur in sites older than 20 years of age. Very little information is available on the size of small mammal ranges in Tasmanian buttongrass moorlands. From what is available, it is probable that small mammal home ranges are in the order of 0.15 to 0.25 ha with the males tending to disperse more widely than the females (B. Arkell and M. Driessen personal communication). The eastern quoll (*Dasyurus viverrinus*) and spotted-tail quoll (*Dasyurus maculatus*) have been observed by the author in moorlands with a wide range of ages while the eastern quoll has been reported to be more abundant in younger than older moorlands (Taylor and Comfort 1993).

1.4 Thesis aims

Resulting from the concerns that inappropriate fire regimes could be having adverse ecological, management and economic effects in buttongrass moorlands, a research project was initiated to address these issues.

To this end, the major questions asked were:

1. How have the fire regimes of southwest Tasmania changed since the removal of the indigenous Tasmanian Aborigines in the 1830s, and what is the current state as regards fire regime and fire age in this region?
2. How do buttongrass moorland fuel characteristics change in different sites, and at different times since fire?
3. How do site and weather factors influence buttongrass moorland fuel moistures?
4. How do fuel, site and weather factors affect buttongrass moorland fire behaviour?
5. What are the implications of this research to the fire management of buttongrass moorlands and other vegetation types, both within western and southwestern Tasmania and in other parts of the world?

In order to address these issues, this thesis has examined changes in fire regime over the last 170 years in southwest Tasmania and the interactions between environmental factors and buttongrass moorland fire behaviour. The thesis is divided into eight chapters. These chapters cover the characteristics of the study sites (Chapter 2), changes in the fire regime of southwest Tasmania (Chapter 3), buttongrass moorland fuel characteristics (Chapter 4), buttongrass moorland dead fuel moisture (Chapter 5), buttongrass moorland fire behaviour (Chapter 6), buttongrass moorland operational fire management (Chapter 7) and finally, some of the implications of this research are discussed in Chapter 8.

2. Study sites and ecological background

2.1 Background

Buttongrass (*Gymnoschoenus sphaerocephalus*) is a component of wet heaths, swamps and moorlands throughout south-eastern Australia, while within Tasmania such vegetation is normally referred to as buttongrass moorland. These moorlands dominate the landscape in the wetter southwest, west and northwest of Tasmania while only occurring as small isolated pockets in Tasmania's drier north and east. In total, buttongrass moorlands cover more than one seventh of Tasmania's landmass or about 1.1 million ha (see Kirkpatrick and Dickinson 1984b).

In the last 35 years upwards of 70 papers, reports and books have been written concerning buttongrass moorland. About 45 of these publications have addressed fire-vegetation interactions (in particular see Jackson 1968; Mount 1979; Brown and Podger 1982a, 1982b). Prior to the work performed for this thesis (and its associated report, Marsden-Smedley 1993a), with the exception of Gellie (1980), little work has been published regarding buttongrass moorland fire behaviour and management.

A comprehensive review of the ecology of buttongrass moorlands has been undertaken by Brown (1993), while Jarman et al. (1988b) extensively covered buttongrass moorland floristics. Gellie (1980), Marsden-Smedley (1993a), Marsden-Smedley and Catchpole (1995a, 1995b, 1995c) and Marsden-Smedley et al. (1995, 1996, 1998) addressed buttongrass moorland fire behaviour and management.

2.2 Vegetation of lowland areas of western and southwestern Tasmania

The vegetation of lowland western and southwestern Tasmania consists of a complex mosaic of moorland, wet scrub, wet sclerophyll forest and rainforest communities. The range of vegetation assemblages found in Tasmania have been described in Jackson (1981), while species names and authorities follow Buchanan (1995).

2.2.1 Buttongrass moorland

The term 'moorland' has been used in the literature to refer to both heaths and wet bogs (Gore 1983), while in Tasmania the term has been applied to a wide variety of largely treeless communities dominated by sedges and low heaths (Figure 2.1; Table 4.1). The major plant species in buttongrass moorlands are buttongrass, *Lepidosperma filiforme*, *Empodisma minus*, *Leptocarpus tenax*, *Lepyrodia tasmanica*, *Restio complanatus*, *Restio hookeri*, sprengelia (*Sprengelia incarnata*), shiny tea-tree (*Leptospermum nitidum*), manuka (*Leptospermum scoparium*), swamp paper-bark (*Melaleuca squamea*), scented paper-bark (*Melaleuca squarrosa*), white waratah (*Agastachys odorata*) and banksia (*Banksia marginata*).

Figure 2.1. Buttongrass moorland near Melaleuca in southwest Tasmania.

Jarman et al. (1988b) defined buttongrass moorland to be:

a) any treeless or near treeless vegetation containing buttongrass (*Gymnoschoenus sphaerocephalus*), except communities where only a few isolated obviously adventive buttongrass plants are present;

b) vegetation in which buttongrass is common but which contains widely spaced emergent trees;

c) small recurring islands (mostly less than 50 x 50 m) of non-alpine treeless vegetation which do not contain buttongrass but which are surrounded by communities of the type described in a) or b) above. Small strips of similar vegetation (about 20 to 30 m wide) along creeks or in gullies are also included as buttongrass vegetation providing that communities of type a) or b) border them on either side.

Jarman et al. (1988b) divided Tasmanian buttongrass moorlands into 25 associations, primarily on the basis of their floristic composition, but with their structural form, climate and soil type also being important. These associations fall into two broad types, blanket moorland versus eastern moorlands.

2.2.2 Wet scrub

Although a comprehensive survey of wet scrub communities has not yet been undertaken in western and southwestern Tasmania, the major associations have been described by several authors (Jarman et al. 1982, 1988b; Brown and Podger 1982a; Bowman 1980; Bowman et al. 1986; Pemberton 1989; Marsden-Smedley 1990). These communities normally consist of closed vegetation two to ten metres tall, dominated by Smithton peppermint (*Eucalyptus nitida*), tea-tree (*Leptospermum* spp.), paper-bark (*Melaleuca* spp.), acacia (*Acacia* spp.) and/or banksia (*Banksia marginata*). Such communities require fire for their regeneration, and frequently occur as a distinct zone between moorland and forest communities, or as large patches within other vegetation types (Balmer 1990; Marsden-Smedley 1990).

2.2.3 Wet eucalypt forest

The grouping wet eucalypt forest contains both wet sclerophyll forest and mixed eucalypt forest communities. These forests are normally dominated by eucalypts (*Eucalyptus* spp.) with a well developed understorey of hard leaved shrubs and/or small trees, and in some situations, rainforest species. Fire is required in these forests for their regeneration (Gilbert 1959). Detailed descriptions of these forests have been made by Kirkpatrick et al. (1988), and in the context of other surveys by Jarman et al. (1982), Brown and Podger (1982a) and Pemberton (1989).

2.2.4 Rainforest

In lowland western and southwestern Tasmanian habitats, rainforests consist of closed forest communities dominated by myrtle (*Nothofagus cunninghamii*), sassafras (*Atherosperma moschatum*), leatherwood (*Eucryphia lucida*), King Billy pine (*Athrotaxis selaginoides*), Huon pine (*Lagarostrobos franklinii*) and/or celery-top pine (*Phyllocladus aspleniifolius*). These forests do not require fire for their regeneration (Jarman and Brown 1983) and are normally degraded floristically and/or structurally by fire (see Barker 1991). Detailed descriptions of these communities have been made by Jarman et al. (1984), and in the context of other surveys by Kirkpatrick (1977), Jarman et al. (1982), Pedley et al. (1980), Brown and Podger (1982a), Hill (1982), Davies (1983), Hill and Read (1984), Gibson (1986) and Pemberton (1989).

2.3 Buttongrass moorland distribution and ecology

The dominant ecological processes controlling the distribution of buttongrass moorland have been attributed to drainage and topography (e.g. Davis 1940), or more recently, to fire and edaphic factors (e.g. Jackson 1968; Mount 1979).

In many parts of the world, fire is a natural landscape factor with vegetation dynamics being dependent on periodic fire in order to maintain the vegetation's floristic composition. Tasmanian buttongrass moorlands are a good example of this dependence on fire with it being postulated that in the absence of fire, buttongrass moorlands will be transformed into rainforest in the wetter parts of Tasmania (Jackson 1968; Macphail 1980) or wet scrub in the drier parts of the state (Marsden-Smedley and Williams 1993).

Two main descriptive theories have been proposed to explain ecological processes in the vegetation of southwestern and western Tasmania: ecological drift (Jackson 1968) and stable fire cycles (Mount 1979). They attempt to explain the apparent contrast between the land area considered climatically suitable for rainforest, compared with its observed distribution. For example, sites with greater than 50 mm precipitation in the driest month have the potential to support rainforest (Jackson 1968), but approximately 47% of these sites are occupied by sclerophyll communities, with about 30% occupied by moorland communities (Jackson 1981). However, major questions have been raised as to how applicable either model is in the highly oligotrophic moorland and scrub communities of lowland western and southwestern Tasmania (e.g. Maclean 1978; Jarman et al. 1988b; Pemberton 1989; Marsden-Smedley 1990). For further discussions of the ecological processes in the vegetation in this region see Bell (1983) and Jarman et al. (1988b).

2.4 Climate

The lowlands of western and southwestern Tasmania have a cool temperate maritime climate dominated by the prevailing northwest to southwest wind regime (Nunez 1978). Average temperatures range from a maximum of about 20°C in summer, down to a minimum of about 2°C in winter, with frost days common between the months of May to October. The region receives about 2 500 to 3 500 mm of precipitation per year, spread over about 250 days (Table 2.1).

Table 2.1 Average monthly and annual temperatures, frost days, precipitation, most common wind directions and surface wind speeds for Strathgordon (southwest Tasmania) and Queenstown (western Tasmania).

	Strathgordon					Queenstown				
	Jan	Apr	Jul	Oct	mean	Jan	Apr	Jul	Oct	mean
temp, max °C	19	14	10	13	14	21	17	12	16	16
temp, min °C	9	7	3	6	6	8	6	2	5	6
frost days, (min ≤2.2°)	0	0	7	1	20	0	1	10	4	46
precipitation, mm	144	228	273	228	2524	152	2257	260	227	2521
precipitation, days	17	22	25	23	253	16	19	22	21	230
wind direction	NW	N/NW	N/NW	N/NW		SW	WSW	NW/SW	N/SW	
wind speed, km hr^{-1}	1 to 5	1 to 5	1 to 5	1 to 5		1 to 5	1 to 5	6 to 10	6 to 10	

Note: mean = annual mean; source: Bureau of Meteorology, Hobart, Tasmania.

2.5 Landforms

Western and southwestern Tasmania is a region with highly variable topography. The topography varies from extensive plains, often covered by buttongrass moorlands to highly dissected ridges, mountains and valleys covered in all of the regions vegetation types. The altitude of the region varies from sea level up to between 1 200 and 1 400 meters (e.g. Mt Sorell 1144 m, Frenchmans Cap 1445 m, Mt Anne 1425 m, Federation Peak 1224 m and Precipitous Bluff 1120 m). Most of the region lies below 300 m in altitude with less than 5% being alpine (Kirkpatrick et al. 1993; see also Table 3.4).

2.6 Geology and soil types

Buttongrass moorlands occur in habitats that are frequently oligotrophic, or subject to frequent disturbance (typically fire, but wind, frost and snow may also be important). In western and southwestern Tasmania these communities are often underlain by siliceous substrates, with Precambrian quartzite being the most common substrate, but other low nutrient substrates (e.g. Owen

Conglomerate) are also important. In some areas, moorlands may occur on the higher fertility fluvioglacial outwash, normally in flat sites, where the dominant controlling factors are probably fire, waterlogging, frost and snow-lie.

In buttongrass moorlands acidic and low nutrient blanket bogs (i.e. peats, see Gore 1983) are the dominant soil formation (Maclean 1978; Bowman 1980; Pemberton 1989; Hannan et al. 1993; Bridle and Kirkpatrick 1997). The P1 horizon of these soils ranges from very poorly drained, black, structureless muck peats through intermediate peats, well drained, fibrous brown peats to mineral soils over gravel. A P2 horizon is normally absent. Buttongrass moorland soil depths tend to be highly variable. Soil depths are typically in the range of 10 to 35 cm in most sites, but may range from less than five cm in sites with skeletal soils to more than 200 cm in some areas (Maclean 1978; Bowman 1980; Pemberton 1989; Marsden-Smedley 1990; Hannan et al. 1993; Bridle and Kirkpatrick 1997). Soil depths tend to be greatest in flat and southerly facing sites and least in steep northerly facing sites (Pemberton 1988).

3. Fire regimes in southwestern Tasmania

3.1 Background

Southwestern Tasmania is an extensive area of wildland, yet its vegetation patterns are far from unaffected by humans. In this region, humans are responsible for the majority of fires (Table 3.1), and variation in fire regime is one of the dominant factors determining the balance between the major vegetation assemblages. In the absence of fire, rainforests and rainforest scrub would dominate the vegetation, with the only significant exceptions probably being sites with highly waterlogged soils and/or extreme levels of climatic exposure. Fire acts to modify these vegetation distributions, greatly increasing the area of the fire adapted moorland, wet scrub, wet eucalypt forest vegetation types (see Jackson 1968, 1981).

This is not to say that fires are the only influence on the distribution of vegetation in this region. Although in the long term climatic change would be expected to be the dominant factor shaping vegetation distributions (e.g. see Macphail 1980, 1981), within the relatively climatically stable current interglacial period, variation in fire regime (in interaction with variation in soil type) is probably the dominant factor shaping the mosaic of different vegetation distributions (Jackson 1968; Macphail 1981).

There is considerable anecdotal evidence for major changes in the fire regime of southwestern Tasmania since the removal of the indigenous Tasmanian Aborigines in the 1830s. Historical and contemporary reports suggest that there were frequent fires before about the 1940s with major fires occurring in the 1890s and 1930s. There are also very extensive areas of fire-sensitive vegetation which appear to have been degraded by fire (see Brown 1988; Peterson 1990; Robertson and Duncan 1991).

If such changes in fire regime had occurred, then this would have major implications for fire management and ecological processes in southwestern Tasmania. This would be due at least in part to the interactions between time since fire and fire behaviour (see Section 1.2). For example, should we be performing active fire management in southwestern Tasmania or maintaining the current policy of benign neglect (see Brown 1996)?

Therefore, in order to objectively assess the options for management in southwestern Tasmania, information is required as to the fire history of the region. As a result, the aims of this chapter are to assess temporal changes in southwestern Tasmanian fire regimes, to develop fire history maps of the region and to assess the area of different vegetation types burnt in different time periods.

3.2 Recorded fires in southwestern Tasmania

The fire records held by the Parks and Wildlife Service have a good record of fires dating from the 1975/76 summer. Since this time (and probably prior to this period as well), humans have been the main cause of fires, accounting for about 78% of known fires and about 88% of the area burnt. Natural fires (i.e. lightning) on the other hand, only accounted for about 9% of known fires and about 2% of the total area burnt (Table 3.1; see also Bowman and Jackson 1981). However, the number of lightning fires in these records would be an underestimate since there is a considerable number of small to very small lightning fires that are extinguished by rain prior to being recorded. These unrecorded lightning fires are typically less than 0.1 ha in size and rarely more than about 50 ha in size. For example, in southwestern Tasmania there were only two known fires which can be reasonably attributed to lightning which were discovered after they had been extinguished. Both of these fires had areas of less than 30 ha (see Figure 3.1). As a result, although the number of lightning fires is almost certainly underestimated (possibly by a factor of ten), the area attributed to lightning fires is probably reasonably accurate.

Table 3.1. Area burnt and number of fires by different fire types in southwestern Tasmania between 1975/76 and 1995/96.

Type	Area burnt		Number of fires		Average per fire Mean	Average per fire Median	Average per year Mean	
	ha	%	number	%	ha	ha	ha	number
Accident	1 830	1.8	2	1.2	915	-	87	0.1
Arson	46 705	46.3	106	65.0	441	2.3	2 224	5.0
Escaped campfire	107	0.1	13	8.0	8	0.1	5	0.6
Escaped management	39 550	39.2	4	2.5	9 888	-	1 883	0.2
Lightning	2 152	2.1	15	9.2	143	0.2	103	0.7
Other	100	0.1	2	1.2	50	-	5	0.1
Unknown	10 514	10.4	21	12.9	501	10.0	501	1.0
Totals	100 958	100.0	163	100.0	616	1.0	4 808	7.8

Source: Parks and Wildlife Service unpublished fire records; median areas for accident, escaped management and other causes not given due to the small sample size.

Figure 3.1. Site burnt by a lightning ignited fire in the Hardwood Valley, southwestern Tasmania.
Note: fire burnt in about 1987/88 and was discovered in 1993; photograph taken by D. Heatley and S. Rundle.

Arson and escaped management burns account for the majority of the area burnt in southwestern Tasmania. It should be noted, however, that these figures for arson and escaped management are highly skewed by two fires. These two fires, Birchs Inlet in 1985, which was an escaped management burn, and Mulcahy Bay in 1986, which was an arson fire, together burnt more than 60 000 ha (see Blanks 1991).

The small area burnt by lightning fires in southwestern Tasmania is primarily the result of naturally ignited fires tending to be associated with frontal systems and hence significant rain events. This tends to result in small, short lived fires (median size of lightning fires between 1975/76 and 1995/96 is 0.2 ha; Table 3.1). For example, J. E. Calder on Christmas Eve in 1840 described a lightning fire:

> Late on the night in question we were startled from the heavy sleep we were in by the most awful and long continued thunder storm I was ever the witness of. For some considerable space it lightened only, there being neither rain nor thunder at the first onset of the tempest. The flashes of light succeeded each other very quickly, only a few seconds of darkness interposing between the discharge of the electric fire. They were very vivid, shewing with all the distinctness of noon-day the rugged features of the wild landscape around us. It was quite impossible to sleep amidst such a discharge of fireworks which, knocked up as we were, we all turned out to have a look at. As we were watching the storm from the top of the rock, where we were perched, we were witnesses to a scene of very unusual occurrence, namely, the kindling of fire by lightning. The recent parching weather of midsummer had scorched the long herbage of the plain to perfect dryness, when a flash more tremendous than any that had preceded ignited it, and off it went into a blaze such only as the herbage of the west could create, which when thoroughly

> dry a-top is as inflammable as old okum. In our present situation the surprise this threw us into was not an agreeable one, as a quick running fire coming down on us in a night as wild and dark as tempest could make it, and in a utterly strange place, are little matters that don't produce pleasant sensations. We were relieved however, before we had any serious occasion for alarm, for after raging violently for about an hour a sudden deluge of rain (that drove us all to quarters in a twinkling) extinguished it almost as quickly as it was kindled.
>
> This remarkable circumstance gave a name to the plain we were camped on, that is "Lightning Plain" . . . (Calder 1860b; see also Calder 1849; Binks 1980).

Add humans into the environment and the situation is vastly different. Historical and contemporary records show that humans tend to light fires under dry conditions, greatly increasing the potential for the fires to sustain. This increase in widespread fire is probably the primary reason for the extensive areas of sclerophyll vegetation in areas otherwise suitable for rainforest.

3.3 Methods of assessing fire regimes

Information on the fire regime of southwestern Tasmania was collated from published papers, fire history records, historical records, aerial photographs and site records. The area assessed consisted of South–West and Franklin–Lower Gordon National Parks and those parts of the South–West Conservation Area that are on Cape Sorell, and adjacent to the King River and Macquarie Harbour. This region has a total area of about 1 227 200 ha.

Attempts were also made to characterise the likely fire regime utilised by the Tasmanian Aborigines. This fire regime was determined using published papers, fire behaviour theory and observations of ecological processes in southwestern Tasmania.

3.3.1 Published papers

Historical records of fires were assessed. In these records, up until about the 1930s, the prevailing attitude was that it was an advantage to burn-off the country when performing exploration and/or building access tracks (see below). As a result, about two thirds of these records contain extensive references to the areas burnt and the type of fires used. In particular, the following were used: Tasmanian House of Assembly Journal; Legislative Council Journal; Mercury Newspaper; Explorers of Western Tasmania (Binks 1980); Trampled Wilderness (Gowlland and Gowlland 1976); Tasmanian Mail; Forest types and fire history (Gilbert 1978); Fires in the Tasmanian bush (Gilbert 1979) and History of

Emergency Events, issue 1 (State Emergency Service 1990). The unpublished records in the Archives Office of Tasmania were also extensively used. The historical records (i.e. records predating the 1930s) assessed for fire histories are listed in Appendix 1.

These records give a good indication of when and where fires occurred between about the 1850s and the 1930s, but only contain limited information on fire size. These records also mainly document 'official' exploration and track cutting parties and so give only limited information on private parties. Therefore, the historical records need to be used with caution. For example, in some areas, there was considerable private exploration, particularly for Huon pine (*Lagarostrobos franklinii*), which may have been associated with extensive burning-off. This situation would have probably been most marked in the lower Gordon and Davey River regions (see Perrin 1887, 1898). As a result, although it is not possible to determine the area burnt from the historical records, they probably do give a reasonable indication of when the major fires occurred.

3.3.2 Field data and aerial photograph interpretation

Site age (i.e. time since the last fire) information was collated from a total of 161 sites from published sources (in particular, Jarman et al. 1988a). Fire ages were then sampled from an additional 107 sites to target areas where there were gaps in the stem aging. The ages of sites assessed are in Appendix 2. The fire history maps held by the Fire Management Branch, Parks and Wildlife Service, Tasmania were also used for checking the ages recorded from different sites. Sites were aged in the field using the methods detailed in Section 4.2.2.

In most parts of southwestern Tasmania, major problems occurred in mapping fires older than the 1930s. This was due to the very extensive area burnt in the 1930s, which removed much of the evidence of the older fires. As a result, the area burnt in the 1890s has only been estimated and all other fires older than the 1930s have been recorded descriptively. From the 1930s on, fire boundaries and areas burnt have been identified from aerial photographs and/or fire history maps.

All available aerial photographs taken of the study area between 1946 and 1970 in the Department of Environment and Land Management Land Information Bureau were examined for fire boundaries (Table 3.2). These aerial photographs were arranged in projects, typically containing five to 18 runs, each of about 30 to 40 photographs. In addition, aerial photographs of the Port Davey, Wedge and King William areas taken in the mid to late 1970s were examined to assess areas inadequately covered by the earlier photographs. In total, about 7 000 aerial photographs were examined for fire boundaries.

Table 3.2. Aerial photographs examined for fire boundaries.

Project	Run(s)	Date	Project	Run(s)	Date
King William	1 to 12	1946	Pedder	1 to 8, all ties	1949
Styx	1 to 14	1946	Pillinger	1 to 7	1949
St Clair	6 to 12	1947	Rocky Point	1 to 4, east tie	1949
Adamsons	1 to 14	1948	King-Franklin	1 to 10	1953
Arthur	1 to 3	1948	King William	5 to 9	1953
Bathurst	1 to 10, all ties	1948	Macquarie Harbour	1 to 7	1953
Huntley	1 to 5	1948	Gordon	1 to 6	1958
Maatsuyker	1 to 4	1948	Tasmania southwest	1 to 15, all ties	1960
Picton	1 to 16	1948	Port Davey, F367	1 to 9	1973
South Cape	1 to 7	1948	Wedge, F366	1 to 4	1973
Lyell	1 to 14	1949	King William, F585	1 to 4	1978

Aerial photographs and fire history maps were used together in order to standardise the recording of fires on the older aerial photographs. This system also largely overcomes a problem with the fire history maps from the 1960s and to a lesser extent the early 1970s, when only the larger and/or higher intensity fires were mapped. In general, fire history maps were used for fires after 1975 whilst aerial photographs were used for fires before 1975. The ages estimated from aerial photographs were also checked against fire history records and other aerial photographs taken of the same location at different times. Where possible, the fires identified from aerial photographs were aged to the nearest year using the data from the site records. For some of the fires, however, this was not possible, and fires were allocated a decade. Appendix 3 contains a list of all recorded fires in southwestern Tasmania from the 1920s to 1995/96.

The area of different vegetation types burnt in different decades was assessed by comparing the fire history maps generated in this project (see below) with a vegetation map of the region. This map was based on a map produced by Kirkpatrick and Brown (1991) and showed areas of rainforest, eucalypt forest and non-forest. This map also showed the original vegetation type in areas flooded for hydro-electric schemes.

In order to assess the amount of subalpine and alpine vegetation burnt, these communities were assumed to occur at altitudes greater than 100 m below the local treeline (J. B. Kirkpatrick personal communication). The height at which the treeline occurred was assessed from the published literature (e.g. Kirkpatrick 1982, 1984a, 1984b; Kirkpatrick and Brown 1987; Kirkpatrick et al. 1996; Bridle and Kirkpatrick 1997). This height above which the subalpine and alpine vegetation was assumed to occur, varied from 600 m in the far southwestern corner of the region (e.g. Mt Rugby, Mt Counsel, South West Cape Range), 800 m in the central and eastern part of the region (e.g. Southern Ranges, Eastern and Western Arthur Ranges, Frankland Range) to 1 000 m in the western and northern parts of the region (e.g. West Coast Range, Frenchmans Cap, Spires, King William Range). The resulting vegetation map of the study area is shown in Figure 3.2 while the area of different vegetation types are in Table 3.3.

Table 3.3. Area of different vegetation types in southwestern Tasmania.

Vegetation assemblage	ha	%
Moorland and wet scrub	704 179	57.4
Wet eucalypt forest	225 594	18.4
Rainforest	245 867	20.0
Subalpine and alpine	51 562	4.2
Total	1 227 202	100.0

3.3.3 Fire history map production

The information gained from the published papers, fire history records and aerial photographs was used to generate 1:100 000 scale fire history base maps for southwestern Tasmania. These base maps were used to produce a 1:250 000 fire history map of the whole region, which was then digitised. Fires were assigned to one of the following age classes: 1890s, 1930s, 1940s, 1950s, 1960s, 1970s, 1980s, 1990 to 1996. As has already been mentioned, it was not possible to map the area burnt between the 1890s and 1930s.

3.3.4 Fire regimes in the different vegetation types of southwestern Tasmania

It should be noted that as regards fire frequency, the terms low, medium or high fire frequency refer to different fire intervals in different vegetation types, as shown in Table 3.4. For example, a high fire frequency in buttongrass moorlands would refer to a period between fires of less than about 15 years, whilst in rainforests, a high fire frequency would refer to a period between fires of less than about 80 years. The fire frequencies in Table 3.4 have been modified from Jackson (1968) and Marsden-Smedley (1990).

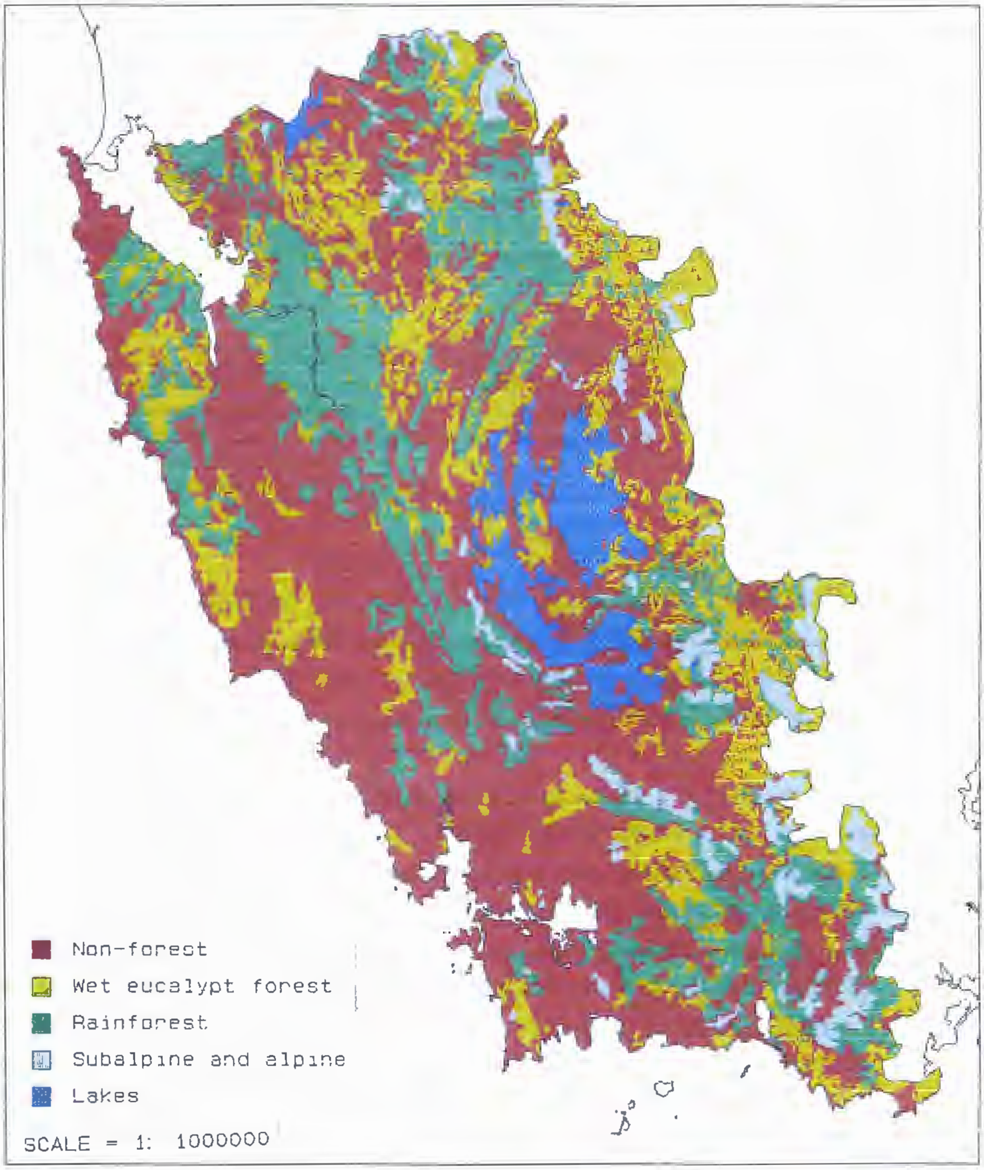


Figure 3.2. Vegetation map of southwestern Tasmania showing non-forest, wet eucalypt forest, rainforest, and subalpine and alpine areas. Map based on Kirkpatrick and Brown (1991).

Table 3.4. Fire intervals for the terms fire frequency, old-growth, mature and re-growth in southwestern Tasmanian vegetation types.

Fire frequency (period between fires)	Vegetation description in the different age classes	Vegetation type: Buttongrass moorland	Wet scrub	Wet eucalypt forest	Rainforest subalpine and alpine
Low	Old-growth	>35	>65	>250	>500
Medium	Mature	15 to 35	15 to 65	25 to 250	80 to 500
High	Regrowth	<15	<15	<25	<80

Fire frequencies follow Jackson (1968) and Marsden-Smedley (1990); fire intervals in years.

There are several ways in which fire frequency, fire intensity and season of burn can vary, as shown in Table 3.5. It should be noted, however, that variation in fire regime forms a continuum.

Table 3.5. Different fire frequency and fire season options.

Fire frequency and intensity	Fire season
1 high frequency and low intensity	A fires mainly in autumn and spring
2 medium frequency and medium intensity	B fires in all seasons
3 low frequency and high intensity	
4 high frequency and high intensity	

The different options for managing fire have major implications for the resulting fire regime. From the different fire frequency and fire season options shown in Table 3.5 there are seven basic fire regime options, as shown in Table 3.6. It should be noted that the fire regimes shown in Table 3.6 form a continuum.

Over relatively short time periods (i.e. less than about 50 to 150 years) it may be possible to perform high frequency and high intensity fires in forest community types. Such fires wonld only be possible under summer conditions. However, such a fire regime would not be ecologically sustainable and would result in the transformation of the forest to a sedge and/or grass dominated community type. Extensive areas of forest which has been degraded to wet scrub and/or sedgeland can be observed near the King River and Queenstown in western Tasmania. Many of these communities consist of a low open rainforest scrub, *Acacia* spp. and teatree scrub whilst some other areas closer to the mining areas around Mt Lyell (and hence having probably had a higher fire frequency) have the appearance of a sparse wheat field. It should be noted that some of these areas may also have been affected by heavy metal pollution from the Mt Lyell copper smelters. For example, at Victoria Pass on the Lyell Highway, E. A. Innes in

1887 describes a closed myrtle - King Billy pine rainforest, L. K. Ward in 1908 (and hence following the 1897/98 fires, see Section 3.4.2) describes the same area as being devoid of vegetation, while currently its vegetation consists of a mixture of rainforest scrub and wet scrub without King Billy pine two to ten metres tall (Innes 1887; Ward 1908; Brown 1988).

Table 3.6. Possible fire regimes in southwestern Tasmanian vegetation types.

Option	Fire regime
1A	frequent and low intensity autumn and spring burns in moorlands with a low fire frequency in wet scrub and wet eucalypt forest and a very low fire frequency in rainforest and alpine vegetation;
1B	frequent and low intensity burns in all seasons in moorlands with a medium to high fire frequency in wet scrub, wet eucalypt forests and rainforest and alpine vegetation;
2A	medium frequency and medium intensity autumn and spring burns in moorlands with a low to medium fire frequency in wet scrub and wet eucalypt forest and a very low fire frequency in rainforest and alpine vegetation;
2B	medium frequency and medium intensity burns in all seasons in moorlands, wet scrub and wet eucalypt forests with a high frequency of fires in rainforest and alpine vegetation;
3A	low frequency and high intensity autumn and spring burns in moorlands with a medium fire frequency in wet scrub and wet eucalypt forest and a very low fire frequency in rainforest and alpine vegetation;
3B	low frequency and high intensity burns in all seasons in all vegetation types;
4B	high frequency and high intensity burns in all vegetation types in summer;

Note: fire frequencies and fire seasons based on the options in Tables 3.4 and 3.5; option 4A (i.e. high frequency and high intensity burns in autumn and spring) is not considered feasible, and is therefore omitted.

Alternatively, some other areas which have been subjected to very high fire frequencies have been transformed from forest and/or closed wet scrub to a very sparse sedgeland. For example, Howard Plains, (near Queenstown airport), was described by C. Gould in 1862 as being covered by a mixture of wet eucalypt forest, closed wet scrub and low open wet scrub dominated by eucalypts, tea-tree and cutting grass. This scrub was described as being very thick before C. Gould's party burnt it, in that it was not possible to travel through more than about one and a half miles of the scrub per day (Gould 1862a). Today, this same site consists of a very sparse, open sedgeland dominated by *Leptocarpus tenax* with occasional *Restio tetraphyllus* and *Acacia* spp. and few other species.

3.4 Results

There is strong evidence for major changes in fire regime across southwestern Tasmania in the last 170 years. This period can be divided into four broad categories: pre-1830 (Aboriginal), about 1830s to 1930s (early European), 1940 to about 1970 (middle European) and post-1970 (current).

3.4.1 Aboriginal fire regime

There has been some conjecture in the literature regarding Aboriginal occupation of southwestern Tasmania during the late Pleistocene and Holocene. Some authors suggest the region was in fact largely unoccupied since about 8 000 to 12 000 years BP (e.g. see Plomley 1966; Cosgrove et al. 1994) while other authors suggest at least seasonal occupation until historical times (e.g. see Kiernan et al. 1983; Flanagan 1985; Jones 1993; Thomas 1993a). Whilst little, if anything, can be deduced from the work reported on in this thesis regarding the social and/or cultural importance of fire for the Tasmanian Aborigines, much can be deduced as to whether Aborigines occupied the region and if so, the type of fire regime utilised and its effects on the region's ecology.

At the time of European settlement, there were extensive buttongrass plains throughout southwestern Tasmania (Goodwin 1828; Little 1833; Frankland 1835, 1836; Burn 1842; Lewis and McPartlan 1859; Calder 1860a, 1860b, 1860c; Sharland 1861; see also Plomley 1966; Gowlland and Gowlland 1976; Binks 1980). Ecologically, it is highly unlikely that such extensive plains would have persisted in the absence of human mediated fires for more than about 250 to 1000 years (see Jackson 1968; Jarman et al. 1988b; Marsden-Smedley 1990). In addition, many of the early reports describe recently burnt buttongrass moorlands. These include J. Kelly in 1815, J. Goodwin in 1828, G. A. Robinson in 1830 and 1833, W. S. Sharland in 1832 and J. E. Calder in 1840 on Cape Sorell, Vale of Rasselas, along the south and west coasts of Tasmania, Port Davey, Loddon Plains, Wombat Glen and Navarre Plains (Kelly 1816; Goodwin 1828; Plomley 1966, 1991; Calder 1847, 1849, 1860a, 1860b, 1860c; Sharland 1861; see also Gowlland and Gowlland 1976; Binks 1980). For example, in March 1828, J. Goodwin describes what appears to be a patch-work of Aboriginal fires in the Vale of Rasselas:

> . . . near the Huon River [Gordon River in the Vale of Rasselas] we saw a number of native fires on the hills, and the grass appeared to have been burnt recently and frequently (Goodwin 1828).

A similar situation is described by W. S. Sharland in 1832 near the upper Franklin River, when his party followed what he considered to be an Aboriginal track:

> We followed the said marsh [Painters Plain] and some burnt ground until it brought us out to a bare hill where a fire had been made by the blacks . . . (Sharland 1861).

As a result, the Aborigines must have been active, at least seasonally, throughout the majority of southwestern Tasmania in the early 1800s. Similar conclusions regarding Aboriginal land practices have also been made by Thomas (1993a, 1993b).

An indication of just how open the country must have been in the 1820s and 1830s is also given by the speed at which the first Europeans moved across the country. At this time, such open country is highly unlikely to have been the result of European burning and is far more likely to be the result of thousands of years of Aboriginal fire management. For example, William Sharland in 1832 travelled from Lake Vera to near the present location of Bronte Park in two days (Sharland 1861) while Alexander McKay in 1830 travelled from Sarah Island to Elliott Bay in three days (Plomley 1966). In order to achieve such travelling times, the country must have consisted of a series of continuous or near continuous open young buttongrass moorlands. This is supported by the observations by G. A. Robinson in 1833 of the country between Birchs Inlet and Elliott Bay where he describes what appears to be eroded gullies and very open moorlands (Plomley 1966).

The proposed Aboriginal fire regime is one of mostly low intensity fires under conditions when forested vegetation is too wet to burn. Although fires would have been lit in all seasons (see Stockton 1982), in most cases, fires would probably have been restricted to spring, autumn and dry periods in winter. Fires were probably only lit in summer during wetter periods, when fires would have gone out when they burnt up to the moorland - forest boundary. This regime would have resulted in frequent low intensity moorland burns, only occasional fires in eucalypt forest and very few fires in rainforest and alpine vegetation. This regime must have been highly sophisticated and directed towards specific outcomes. The observations of G. A. Robinson on Bruny Island in April 1829, and near Nye Bay on Tasmania's west coast in March 1830 (Plomley 1966) and W. Sharland on the Loddon Plains in March 1832 (Sharland 1861) also support this regime.

The Aborigines also probably used fires to flush game when hunting and to create access tracks (Davies 1846; Roth 1899; Plomley 1966, 1991). There are also several reports describing recently burnt trees with only their bases fire-scarred (see Thomas 1991). This would support the proposal that the Aborigines were lighting many small low intensity fires rather than a few larger higher intensity fires.

This regime of low intensity fires mainly in spring and autumn is analogous to the regime of firestick farming proposed by Jones (1969) and is similar to the fire regime currently being practiced by Aborigines in Northern Australia (Jones 1995; Braithwaite 1995; Bowman 1995; see also Plomley 1966; Stockton 1982; Binks 1980; Thomas 1991; Thomas and Hope 1994; Kohen 1995). In such a fire regime, the aim would probably have been to create a large number of small recently burnt areas surrounded by thicker vegetation.

There are several ways in which the Aborigines could have achieved this control of fire. From the evidence presented by Thomas (1991), it appears that fires were normally lit under conditions when they would be of low intensity and would self-extinguish, although in some cases it appears that fires may have been beaten out using branches (Plomley 1966). This fire management technique is similar to that aimed for in the current low intensity habitat-management burning regime (see Marsden-Smedley 1993a, 1993b; Chapter 7).

The Aboriginal fire regime during the 1830s to 1930s would have been one of mostly frequent low intensity fires mostly in moorland vegetation (i.e. type 1A from Table 3.6).

3.4.2 Early European fire regime between 1830 and 1940

Following the removal of the Aborigines it appears that initially, few Europeans visited southwestern Tasmania (i.e. between about 1830 and 1850). During the 1830s to 1840s, exploration in southwestern Tasmania is only recorded from the middle Gordon River, Lake Pedder, Arthur Plains and upper Franklin River areas (see Binks 1980). This was probably due to the small number of Europeans present in Tasmania at that time, the region's remoteness and official discouragement of exploration in order to maintain the isolation of the penal settlement at Sarah Island (Franks 1958; McRae 1960; Binks 1980; McGowan 1993). When compared to the fire frequencies and intensities utilised by the

Aborigines, the low numbers of people visiting the region in the 1830s and 1840s would have resulted in a major reduction in fire frequency and a corresponding increase in fire size and intensity when fires did occur.

By about the 1850s and 1860s, there was an extensive network of tracks and routes which allowed for the re-opening up of the region (Cotton 1850; McRae 1960; Gowlland and Gowlland 1976; Binks 1980). Leading on from this opening up of the country was a major change in fire regime which resulted in the burning of the majority of southwestern Tasmania.

In the available literature, there are numerous references regarding the use of fire in southwestern Tasmania from this period. It appears that the normal method of moving through the region was to burn out a section of country, then follow the resulting easy path. In order to facilitate such burning, it appears that a large number of fires were lit in hot dry (and probably windy) weather, resulting in large high intensity fires in all vegetation types. This fire management regime is in marked contrast to the Aboriginal fire management practices.

The earliest reports of Europeans lighting fires in southwestern Tasmania are probably by J. E. Calder and A. McKay in the middle Gordon River, Lake Pedder and Arthur Plains in March 1837 (Gowlland and Gowlland 1976). Calder's diary describes their fires:

> We burned the ground well filling the atmosphere with smoke . . . Fired a vast tract of country. never saw such a conflagration. . . (see Gowlland and Gowlland 1976).

Parts of the Southern Ranges between Mount Alexandra and Adamsons Peak were probably burnt in the first half of the 1800s (Perrin 1887). The damage caused by these fires was attributed to the effects of the 1837 frost by Perrin (1887, see also Calder 1860a), but fire is a more likely explanation due to the lack of observations of frost damage in other nearby areas which would be expected to be more susceptible, the distance from which the dead trees were observed (several kilometres) and the extremely frost resistant nature of the species in question (*Athrotaxis* spp.). Fires also occurred in the Southern Ranges near Mt La Perouse in 1887/88 (Mercury Newspaper 11 January 1888), 1897/98 and 1933/34 (see below).

The Arthur, Huon and King William plains and in the Vale of Rasselas were burnt in 1850 by the Colonial Survey Office (Cotton 1850, 1851). In 1851, the first large scale fire reported in southwestern Tasmania occurred. This fire burnt from the Pieman River to Maydena (Gilbert 1979). However, it is possible that the 1851 fire in fact occurred in 1850 and formed part of attempts to modify the region's buttongrass moorlands such that they would be more suitable for sheep grazing.

In January to May 1859, H. T. Lewis and F. McPartlan led an extensive gold and other minerals search of the Davey River, Hardwood River, Crossing River, Lake Pedder and south coast of Tasmania. During this time, despite the generally very wet weather, they lit a fire in moorland near the Davey and Hardwood Rivers (Lewis and McPartlan 1859). In March 1860 J. E. Calder lit large fires near Lake Pedder (Calder 1860c). These fires burnt with high intensities, probably because the area had not been burnt for many years (Lewis and McPartlan 1859).

The Loddon Plains were burnt, probably in 1857 by mineral prospectors (Tully 1859). Major fires also occurred in the valleys of the upper Franklin and Collingwood Rivers during W. A. Tully's prospecting expedition of January to March 1859 (Tully 1859). Tully's party in 1859 lit fires which burnt extensive areas, as described in his report of the expedition:

> The fire of the previous night had travelled far, burning a large extent of country, and was now raging violently behind us. . . vast sheets of flames coming down like an avalanche scarcely one hundred yards distant, and roaring like the seas on a rock-bound shore . . . The fires now burning on both sides of the river roared through the scrub, and sheets of flame danced in the thick forest below us, and swept the leaves off the highest trees in an instant. . . The country was black for miles; not a speck of green could be seen, except the myrtle forest which clothed the side of Mount Gell (Tully 1859).

Extensive burning was performed in the King River and Linda Valleys by C. Gould's party in 1862, as described in his report:

> . . . upon the 16th [February] proceeded along the plains bordering the Kings River, for a distance of six miles, firing them whenever possible . . . (Gould 1862b).

The Arthur Plains were burnt in February and March of 1871 by J. R. Scott, W. C. Piguenit and F. McPartlan on their expedition to Port Davey. The 1871 fires were described by J. Hay in March 1871:

> I may mention that had it not been for Mr. Scott's fires running over and clearing a vast deal of the country, we would not have got over the extent of the ground we did in the time (Hay 1871; see also Scott 1871).

In 1876 G. C. Meredith led a mineral exploration party to western Tasmania. Their party was prevented from landing at the Pieman River by heavy seas, and so they travelled overland from Macquarie Harbour. Whilst at Macquarie Harbour they lit fires on Cape Sorell (Meredith 1876).

In February to early March 1879, T. B. Moore burnt much of the country between Birchs Inlet and Port Davey (most of which consists of buttongrass plains). However, T. B. Moore's attempts in mid March and April of the same year to burn the country to the east of Port Davey, including the Crossing and Old River valleys were thwarted by the consistently wet weather.

Extensive fires were lit by track construction parties in the Lake Pedder, Serpentine River, Frankland Range, Rookery Plain and Olga River areas 1881 and in 1894 (Jones 1881; Innes 1896; Gowlland and Gowlland 1976; Binks 1980). For example, D. Jones whilst cutting a track from the lower Gordon River to the Huon River in 1881:

> Took advantage of fine day and went ahead to look out best route and fire button-rush. . . Whenever we could get a fine day we burned what we could, and the benefit to us was incalculable, rendering the travelling comparatively easy (Jones 1881).

J. B. Walker in his recreation trip of 1887 noted that near the Franklin and Collingwood Rivers:

> . . . hill and valley densely wooded, save for lighter spots of open country, and variegated with reddish patches, the mark of extensive bushfires . . . To the tourist it is exasperating to see the exquisite native beauty of these forests desecrated and turned into grim blackness by fires which during this hot summer have swept over so many miles of bush. But doubtless the prospector views it with other eyes, and after reading the graphic legend inscribed on a blazed tree at the foot of Mount Arrowsmith, . . . we were forced to admit that even these disfiguring fires might have their use in opening up the country, facilitating exploration and diminishing the hardships of these pioneers . . . (Walker 1887; see also Innes 1887).

The fires near Frenchmans Cap referred to by J. B. Walker in 1887 may have been the fires lit by T. B. Moore in February 1887 while cutting a route from the King River to Frenchmans Cap via the Governor River and Mt Fincham, where they:

> . . . sent James [Moore] out on the previous day . . . to put a match into the country, which is clothed with button grass and tea tree . . . We found the fire had done excellent work and was still blazing ahead . . . The fires burnt for a week, and cleared the hated button grass and bauera splendidly, in all directions for miles . . . (Moore 1887).

Very extensive areas of the buttongrass moorland and wet scrub between Frodshams Pass on McPartlan's South Gordon Track and Joe Page Bay in Bathurst Harbour along with forests on the slopes of Mt Bowes were burnt in

February 1898 (Marsden 1898). From the available information, it appears that these fires were not lit during the construction of the Port Davey Track by E. A. Marsden, but are part of a much larger series of fires which burnt very extensive areas throughout southwestern Tasmania that summer.

The 1897/98 fires in western and southwestern Tasmania were extensively reported on in the Mercury Newspaper (e.g. 31 December 1897; 4, 6, 15 January 1898; 6, 10 February 1898) and in the Tasmanian Mail (e.g. 8, 15 January 1898; 19, 26 February 1898). The effects of these fires can also be seen in photographs which were taken between the 1890s and 1920s and are held in the Archives Office of Tasmania (e.g. Figures 3.3 and 3.4). In total, the 1897/98 fires appear to have burnt much of the country between the West Coast Range, Hartz Mountains and the Southern Ranges. If so, then these would have been the largest fires in Tasmania's recorded history, with an area of about 1 000 000 ha within southwestern Tasmania (Table 3.10; Figure 3.6).

Fires were also lit around Cox Bight and Melaleuca in 1898 by G. C. Meredith and his brother during a mineral prospecting trip (Meredith 1898). These fires were unlikely to have been major fires due to the generally wet weather preceding the fires.

In January to March 1900, T. B. Moore again led a party from Birchs Inlet to Port Davey, and in common with the 1879 trip, extensive fires were lit (see Binks 1980; McShane 1982).

In March 1906, W. H. Tyler and W. T. Harper marked out a track along the south coast from Cockle Creek to Cox Bight. During this trip, they burnt Black Hole Plain and reported that between Surprise Bay and Rocky Boat Inlet, the country had been fairly recently burnt, probably in 1897/98 (Tyler and Harper 1906).

In 1907/08 R. Marriott burnt extensive areas between the Vale of Rasselas and the Prince of Wales Range, including the Gell River, Mt Curly and the Denison River (Twelvetrees 1908; see also Marriott 1908).

In December 1908, R. A. C. Thirkell cut a track from the Linda Track to the lower Franklin River, via the Loddon Plains, Calders Pass, Lightning Plains, Acheron River and Jane River. His report of the track noted that his track cutting party had:

. . . been able to fire the country well, and this will be of great assistance to the prospector next summer (Thirkell 1908).

Figure 3.3. Destruction of forested vegetation by fire near Mt Read in western Tasmania. Note: fire occurred in December 1897; photograph taken about 1900; Mt Read is located about 20 km to the northwest of the study area; source: Wallace (1901).

Figure 3.4. Burnt vegetation in the Southern Ranges in the 1920s. Note: fire probably occurred in 1897/98; photograph number 30/4834, Archives Office of Tasmania.

In 1933/34 there were very extensive fires on the Raglan Range, Loddon and Lightning Plains and near where the Frenchmans Cap track leaves the Linda Track (Mercury Newspaper 3 March 1934; Thwaites 1934; Johnson 1935; Warren 1936; photographs in Philp 1937). In 1936, fires are reported to have been lit near Philps Lead and Lake Vera (Warren 1936), probably by piners and/or mineral exploration parties re-opening J. L. Moore's 1900 and R. A. C. Thirkell's 1908 track to the Jane River (see also Abel n.d.). Warren (1936) also reported observing the smoke from fires near the Jane River, Raglan Range, Eldon Range and to the west (probably in the West Coast Range).

Between about 1910s to 1930s, in marked contrast to the preceding 60 years, there was a major decrease in the amount of prospecting and exploration activity in southwestern Tasmania. The only significant exception to this decrease appears to be the development of the Adamsfield osmiridium field (Gowlland and Gowlland 1976) along with small mining fields at Cox Bight (see Twelvetrees 1906), Melaleuca, Osmiridium Beach and the Jane River. This decrease in activity was probably due to the realisation, that in southwestern Tasmania with a few exceptions, the potential for significant mineral deposits and/or good agricultural land was very low. This reduction in exploration activity is reflected in the prospecting accounts of Twelvetrees (1908, 1909, 1915), Ward (1908, 1909) and Howard (1927), all of which report that the access tracks had become very overgrown and blocked with fallen timber. The reduction in exploration activity is also reflected in the Department of Lands and Surveys annual reports for 1910 to 1932 (Parliament of Tasmania Journals). All of these annual reports call for additional track construction to be performed, but all of them also report that in southwestern Tasmania, no existing tracks had been cleared, or new tracks constructed. Only five major tracks are known to have been cut during this period. Two of these tracks, Condor's 1915 west coast track and Hales' 1918 track, were cut by the Department of Mines. Condor's 1912 to 1915 west coast track went from Double Cove in Macquarie Harbour to the west coast near Albina Rock, and then south to Port Davey and north to Cape Sorell (Hills 1914; Condor 1915), while Hales' 1918 track went from the Gordon River to the Port Davey track (Hales 1918). In 1910, J. Philp marked out a track from the Linda Track to Frenchmans Cap via the Loddon Plains, Philps Lead and Lake Vera (Philp 1937). No official record appears to exist of the other two tracks which were put in during this period, except that they are shown on the 1960 sketch map of southwestern Tasmania (Department of Mines Tasmania 1960). Both of these tracks were located in the Weld River valley, and linked the Huon River valley with the Port Davey Track, with one track linking via the upper Weld

River valley and the other via the Snake River valley. The Snake River route is marked on the 1960 map as Giblin's 1924 route. The Weld River track may have been put in by C. and D. King (who are better known as tin miners at Cox Bight and Melaleuca) with this track also being used by a Mr Roberts to access the Jubilee Range for cattle grazing. The length of access tracks constructed in southwestern Tasmania in different periods are shown in Table 3.8.

The prevailing sentiment of the 1800s and early 1900s appears to have been that it was advantageous to the prospector to burn sites in order to expose mineral strata, fire would not hurt healthy forest, and that buttongrass moorlands could be transformed into more productive agricultural land by burning, sowing with pasture grasses and stocking with sheep and cattle. For example, the Chief Government Geologist W. H. Twelvetrees proposed in 1908 that areas of moorland, wet scrub and eucalypt forest could:

> . . . be burned off in broad belts, and if this is done much track-making is unnecessary at first. The prospector can see by the line of burned country which way to follow; he can, moreover, get over the country easily, and prospect without difficulty where he desires. Money spent in burning the country in this way is well spent, and benefits the explorer even more than does the cutting of tracks (except of course through timber) (Twelvetrees 1908).

In 1860 J. E. Calder questioned whether fire would cause deleterious effects to the vegetation:

> . . . do bush fires destroy the forests, or even seriously injure sound and living trees? and do we not see the contrary in a hundred cases every summer? If such indeed were the case we ought not to have a tree left in Tasmania (Calder 1860a).

C. Gould in 1862 also held to the belief that buttongrass moorlands could be transformed, in that he proposed that the extensive plains in the lower Gordon River and near Macquarie Harbour could:

> . . . afford moderate pasture, and are probably susceptible of the same improvement which is found to follow continuous burning and stocking in other parts of the Colony (Gould 1862a).

These attitudes are also reflected in the Colonial Survey Office reports. For example, H. Cotton in 1850 described the grazing potential of the buttongrass moorlands on the Arthur, Huon, King William Plains and in the Vale of Rasselas:

> The rough herbage upon these plains have been burnt for the encouragement of the grasses which are found to take its place, and in some parts, especially near Lakes Pedder and Edgar and in the Gordon Valley, the pasture is rich and luxuriant (Cotton 1850).

Such was the destruction of forest and other vegetation types by wildfires during this period that the issue was addressed by parliamentary reviews of the Tasmanian timber industry in 1887 and 1898 (e.g. Perrin 1887, 1898; Counsel 1898). For example, the Surveyor-General and Secretary for Lands E. A. Counsel reported that:

> . . . one of the main points to which I desire to direct especial attention in this Report is the enormous consumption of valuable timber which is in process of being destroyed in the Mining Districts, particularly on the West Coast . . . there is a wholesale and reckless destruction of the forest growth, young and old, by bush fires in all directions during many months of the year . . . (Counsel 1898).

Counsel (1898) also called for changes in the policies for managing forested areas, including:

> 3. That regulations be framed and especial care taken to protect young pine and other trees and plants from destruction.
>
> 4. That stringent measures be enacted for prohibiting the lighting of bush fires on unoccupied Crown Lands (Counsel 1898).

In the accompanying report on forest conservation and management by the Victorian Conservator of State Forests G. S. Perrin, these issues were reiterated in the strongest manner:

> The bush fires about Lyell, Zeehan, the Pieman and Lake Dora, &c. have already destroyed timber which it will cost shareholders in the mines many thousands of pounds more than they would otherwise have had to pay . . .
>
> All through, however, indiscriminate felling and fierce bush fires have already destroyed large quantities of the useful timber I saw in this district [Zeehan and Mount Lyell] ten years ago, and have completely changed the face of the country (Perrin 1898).

Perrin (1898) also stated that fire protection in state forests was of the highest importance:

> This is a matter of urgent moment to the future of Tasmanian timber supplies. . . A stringent Fire Act should be drafted with as little delay as possible. . . The presence of the miner on the West Coast has, of course, resulted in the usual gross carelessness, and sometimes malicious vandalism, with which it has been associated elsewhere, and, unless the matter is dealt with promptly and vigorously, timber in this district for mining and other purposes will be completely exhausted within a very few years. . . In order to clear prospecting claims it is quite an ordinary custom for the prospector to set fire to the timber and let the flames spread at will over as much of the surrounding country as they can reach (Perrin 1898).

As a result, large and/or high intensity fires burned across the majority of western and southwestern Tasmania. In particular, major fires are known to have occurred in 1851, 1897/98, 1914, 1933/34 and 1939, with numerous additional fires in other years. It should be noted, however, that the large area burnt in these

these fires were probably the result of several smaller fires. The fires recorded between the 1830s and 1930s are shown in Table 3.7, while the areas burnt in the 1890s and 1930s are shown in Figures 3.6 and 3.7.

Table 3.7. Recorded fires in western and southwestern Tasmania between the 1820s and 1930s.

Location	Date	Major fire	Reference
Aboriginal fires			
Vale of Rasselas	1828	no	Goodwin 1828
Port Davey, Lower Hut Plains, Nye Bay	1830	no	Plomley 1966
Loddon Plains	1832	no	Sharland 1861
Birchs Inlet - Elliott Bay	≈1833	no	Plomley 1966
European fires			
middle Gordon R., L. Pedder, Arthur Plains	1837	yes	Gowlland and Gowlland 1976
Mt Alexandra to Adamsons Peak	early 1800s	?	Perrin 1887
Loddon Plains	1849?	?	Tully 1859
Arthur, Huon and King William Plains	1850	?	Cotton 1850, 1851
Vale of Rassalas	1850	?	Cotton 1850, 1851
Pieman River to Maydena	1851	yes	Mercury 10-2-1934, 1-2-1939
Hardwood R., Davey R.	1859	no	Lewis and McPartlan 1859
upper Franklin and Collingwood Rivers	1859	yes	Tully 1859
L. Pedder, Frankland Ra., Hardwood R.	1860	?	Calder 1860c
King River and Linda Valley	1861/62	yes	Gould 1862a
Arthur Plains	1870/71	?	Hay 1871; Scott 1871
Cape Sorell	1876	?	Meredith 1876
Birchs Inlet to Port Davey	1878/79	no	Binks 1980; McShane 1982
L.Pedder, Frankland Ra., Hardwood R.	1881	no	Jones 1881
D'Entrecasteaux River	1886/87	no	Perrin 1887
King River, Mt Fincham, Frenchmans Cap	1887	yes	Moore 1887
upper Franklin and Collingwood Rivers	1887/88	yes	Innes 1887; Walker 1887
Mt La Perouse	1887/88	?	Mercury 11-1-1888
L. Pedder, Frankland Ra., Hardwood R.	1894	no	Innes 1896
Mt Bowes, Arthur Plains, Huon River	1897/98	yes	Marsden 1898
Crossing and Spring Rivers, Melaleuca	1897/98	yes	Appendix 3
Southwest Cape Range, Cox Bight	1897/98	yes	Appendix 3
Mt Bobs-Boomerang	1897/98	yes	Kirkpatrick and Harwood 1980
Lake St Clair	1897/98	yes	Mercury 6-1-1898
Queenstown, Zeehan, Strahan, Tyndall Ra.	1897/98	yes	Mercury 4-1-1898
Raglan Ra., King R., Mt Owen, Mt Lyell	1897/98	yes	Ward 1908
Lake Vera, Philps Peak	≈1897/98	yes	Philp 1937
Flat Rock Plain	1897/98	yes	Appendix 3
Surprise Bay, Tylers Ck, Rocky Boat Inlet	1897/98	yes	Tyler and Harper 1906
Menzies Bluff	1897/98	yes	Appendix 3
Pindars Peak, Gordon Gorge, Hartz Mtn	≈1897/98	yes	Archives Office of Tasmania photo
Mt Read, Mt Darwin, Queenstown	≈1897/98	yes	Archives Office of Tasmania photo
Cox Bight - Melaleuca	1898	no	Meredith 1898
Birchs Inlet to Port Davey	1899/1900	no	Binks 1980; McShane 1982
Black Hole Plain	1905/06	no	Tyler and Harper 1906
Gell River, Mt Curly, Denison River	1907/08	no	Twelvetrees 1908
Jane R., Lightning and Loddon Plains?	1907/08	no	Thirkell 1908
Raglan Ra., Loddon and Lightning Plains	1933/34	yes	Thwaites 1934; Johnston 1935
Linda and Frenchmans Cap Tracks junction	1933/34	yes	Philp 1937
Loddon Plains, Lake Vera, Raglan Range	1935/36	?	Warren 1936
Eldon Range, Jane River	1935/36	?	Warren 1936
West Coast Range, Frenchmans Cap	1938/39	yes	B. Bradshaw pers. comm.

Major fire: yes = large and/or high intensity fire, no = small and/or low intensity fire, ? = fire size and/or intensity unknown.

Some of these fires were very large, in particular the 1851, 1897/98 and 1933/34 fires. The 1851 fires are reported to have burned from the Pieman River to Maydena (a distance of over 150 km in a straight line; Mercury Newspaper 10 February 1939; Gilbert 1979). However, as already mentioned, it is possible that the 1851 fire occurred the previous year, and formed part of the fires lit by the Colonial Survey Office which were aimed at opening up western Tasmania for sheep grazing (see Cotton 1850, 1851). The 1897/98 fires burnt extensive areas near Frenchmans Cap, Huon River, New River Lagoon and many other parts of southwestern Tasmania (see Table 3.7; Figure 3.6). The 1933/34 fires burned from the West Coast Range and the Lower Gordon River to Southport Lagoon (a distance of over 200 km in a straight line, Figure 3.7). However, it has not been possible to map the northwestern part of the 1933/34 fires accurately (i.e. around the Raglan Range, Frenchmans Cap and Lightning Plains areas) since this area was reburnt in the much higher intensity 1938/39 fires.

The 1897/98, 1933/34 and 1939 fires all had periods of very high intensity fire behaviour. For example, the 1933/34 fires caused darkness in Hobart between 4 and 5 pm on 9 February 1934 (Mercury Newspaper 10 February 1934), while the 1939 fires burned large areas of rainforest with crown fires (in contrast to most rainforest fires which rarely burn more than about three quarters of the forest canopy).

The map of the 1890s fires (most of which burned in 1897/98) shown in Figure 3.6 was compiled from the the information in Table 3.7, newspaper and other historical records, site ages, historical photographs in the Archives Office of Tasmania and the author's personal knowledge of southwestern Tasmania. Since many of the areas burnt in the 1890s were also burnt in the 1933/34 and/or 1938/39 fires, it has not been possible to determine accurately the degree to which the different vegetation types were burnt in the 1890s fires (i.e. the relative proportions of burnt to unburnt areas within the fire's boundaries). Therefore, the fire boundaries shown in Figure 3.6 and the areas shown as burnt in Tables 3.9 and 3.10 should only be taken as a guide. For the purposes of this thesis, within the area shown as burnt in the 1890s, reasonable estimates of the degree in which the different vegetation types burnt are about 95% for non-forest, about 90% for wet eucalypt forest and about 75% for rainforest, alpine and subalpine areas. For the same reason, (i.e. re-burning by the 1930s fires) it has not been possible to map the fires of the 1900s, 1910s and 1920s. It should also be noted that the 1890s, 1933/34 and 1938/39 fires burned very extensive areas outside this project's study area.

These very large fires would best be described as landscape scale fires in that they burnt very extensive areas, probably taking several weeks to months to do so. Landscape scale fires appear to have only been contained by major geographic boundaries, such as the major rivers and/or large areas of rainforest, especially those on the lee sides of mountain ranges and/or the coast.

The landscape scale fires during this period were probably responsible for the destruction of extensive areas of highly fire-sensitive coniferous forest and heath that have been burnt since European settlement in Tasmania (see Mercury Newspaper 4 Jan 1898; Perrin 1898; see also Brown 1988; Peterson 1990; Robertson and Duncan 1991). These fires may also have had major impacts on the region's peat soils (Pemberton 1988, 1989; Hannan et al. 1993; Pemberton and Cullen 1995).

The fire regime during the 1830s to 1930s would have been one of mostly high intensity fires in all vegetation types in all seasons (i.e. type 4B from Table 3.6).

3.4.3 Fire regime between 1940 and 1970

Between about 1940 and 1970 another change in the fire regime appears to have occurred. During this time fires were generally small, with the notable exceptions of three fires in the 1950s (i.e. the Old River, Spires and Lake Pedder fires; Figure 3.9). Two of these large fires were lit by mineral exploration parties (i.e. Old River Fire, Mercury Newspaper; Lake Pedder Fire, D. Pinkard personal communication). The cause of the Spires fire (see Figure 3.5) is unknown, but mineral exploration parties were active in this area at this time (Mines Department annual reports for 1950 to 1953). Another major change in fire regime during this period is a change to primarily moorland fires with little forest being burnt (Table 3.10). This change in fire regime is probably the result of changes in cultural attitudes, whereby southwestern Tasmania was starting to be valued more for its natural assets and less for its mineral and grazing potential, and therefore, fewer fires were being lit. The fire regime during the 1940s to 1960s would most probably have been one of mostly medium intensity fires in spring and autumn, mainly in moorland communities (i.e. type 2B from Table 3.6).

Figure 3.5. Area burnt in the 1950 Spires fire. Note the extensive areas of bare ground and burnt scrub. Photograph taken from Shining Mountain looking north in 1953 by D. Pinkard.

Table 3.8. Length of access routes and tracks constructed in different periods in southwestern Tasmania

Early European period 1830s to 1930s				Middle European period 1940 to 1970		Current period post-1970	
Decade	Km	Decade	Km	Decade	Km	Decade	Km
1830s	41	1890s	285	1940s	138	1970s	242
1840s	79	1900s	486	1950s	56	1980s	89
1850s	53	1910s	254	1960s	111	1990/96	0
1860s	126	1920s	85				
1870s	118	1930s	120				
1880s	207						

3.4.4 Post 1970 fire regime

Since the 1970s there has been a shift to a combination of prescribed burns in selected areas of buttongrass moorland and effectively a fire exclusion policy (including the suppression of wildfires) across the rest of the region (see Parks and Wildlife Service 1992). It should be noted, that there have been marked reductions in the area burnt in prescribed fires in the past decade (Table 3.10). The end result of these practices has been the maintenance of young moorlands in the Lyell Highway, Birchs Inlet, Elliott Bay, Port Davey, Melaleuca and Cox Bight regions, and the development of old-growth moorlands and wet scrub across most of the rest of the area. In common with the period 1940 to 1970, few forest fires occurred. The majority of the fires during this period were low intensity, although some fires did have short periods of medium intensity fire behaviour. For example, the Birchs Inlet and Mulcahy Bay fires both burned about half of the total area during the final afternoon of fire run, resulting in about 30 000 ha being burnt out in two four hour periods (i.e 25% of the total area burnt between 1980 and 1995/96, burned during about eight hours). The fire regime in the post 1970 period would most probably have been one of mostly low intensity fires in moorland communities in autumn and spring (i.e. type 3A from Table 3.6).

3.4.5 Fire regimes and area burnt in different time periods

As was discussed in Sections 3.4.1 to 3.4.4 (see also Figures 3.6 to 3.13), major changes in fire regime of southwest Tasmania have occurred over about the last 170 years. The fire regime has probably gone from one of frequent low intensity fires in the moorlands with only the occasional high intensity forest fires to one of frequent moderate to high intensity fires in all vegetation types, to low to medium intensity moorland fires.

It should also be noted that there were probably few large fires between about the 1830s and 1851, and between about 1908 and the 1930s. Although there was a considerable number of fires between the 1850s and 1890s (Table 3.7), it is probable that the majority of the region was left unburnt. The deduced fire regimes during different periods are shown in Table 3.9. There have been marked changes in the area of different vegetation types burnt since the 1930s (Table 3.10). As can be seen in Table 3.10, large amounts of all of the different vegetation types were burnt in the 1890s and 1930s. Since that time there have been marked reductions in the area burnt, particularly in the case of wet eucalypt forest, rainforest, subalpine and alpine vegetation types. The relatively small area burnt in the 1940s is possibly a reflection of the very extensive 1930s fires, which would have resulted in much of the region consisting of regrowth vegetation in the 1940s (and hence being less flammable). The area of moorland burnt in the 1950s is almost entirely the result of three fires. The effects of the change in fire regime in the 1970s with the introduction of extensive hazard-reduction burns, and equally the reduction in the area burnt in these hazard-reduction burns in the early 1990s can also be seen in Table 3.10. The large area of moorland burnt in the 1980s is mainly the result of two fires, which together burnt more than 60 000 ha (see Blanks 1991).

Another effect of the reduction in the area burnt since the 1930s is the formation of very extensive areas of old-growth moorland. This is because in southwestern Tasmania, the majority of non-forested lowland vegetation types consist of buttongrass moorland, and more than 75% of these areas are more than 35 years of age (Table 3.11). The age categories in Table 3.11 are based on the time required for selected moorland species to set seed (see Marsden-Smedley 1990) and on the dynamics of moorland fuel accumulation and fire behaviour (see Chapters 4 and 6). This increase in fire age is not restricted to buttongrass moorland vegetation types, and is occurring in all of the region's vegetation assemblages.

Table 3.9. Fire regimes during different periods in southwestern Tasmania.

		Vegetation assemblage					
		moorland and wet scrub		wet eucalypt forest		rainforest	
Period	Regime	Frequency	Intensity	Frequency	Intensity	Frequency	Intensity
Before 1830	1A	high	low	low	high	low	high
1830-1940	4B	high	high	high	high	high	high
1940-1970	2B	low	low/med	low	high	low	high
After 1970	3A	low	low/med	low	high	low	high

Note: fire regimes follow Table 3.6.

Table 3.10. Area of different vegetation types burnt in the 1890s and since the 1930s.

	Vegetation assemblage								
	moorland and wet scrub		wet eucalypt forest		rainforest		subalpine and alpine		Total
	ha	%	ha	%	ha	%	ha	%	ha
estimated 1890s	690 676	90.3	188 516	83.3	94 192	38.3	25 913	50.3	999 296
1930s	489 625	64.0	51 161	22.6	59 364	24.1	28 906	56.1	629 056
1940s	8 257	1.1	2 158	1.0	356	0.1	80	0.2	10 851
1950s	71 384	9.4	4 755	2.1	5 096	2.1	2 497	4.8	83 732
1960s	25 743	3.4	3 860	1.7	3 739	1.5	394	0.8	33 736
1970s	92 349	13.1	7 835	3.5	4 649	1.9	390	0.8	105 223
1980s	88 947	12.6	8 307	3.7	7 595	3.1	379	0.7	105 228
1990 to 1996	380	0.1	456	0.2	142	0.1	19	0.0	997
Total burnt	1 467 361	-	267 048	-	175 133	-	58 578	-	1 968 119

Table 3.11. Area of lowland non-forested vegetation in different age categories.

		Area	
Vegetation category	Age, years	ha	%
Regrowth	less than 15	89 247	12.7
Mature	15 to 35	80 693	11.5
Old-growth	greater than 35	534 239	75.9

Note: see Table 3.4 for definitions of the terms regrowth, mature and old-growth.

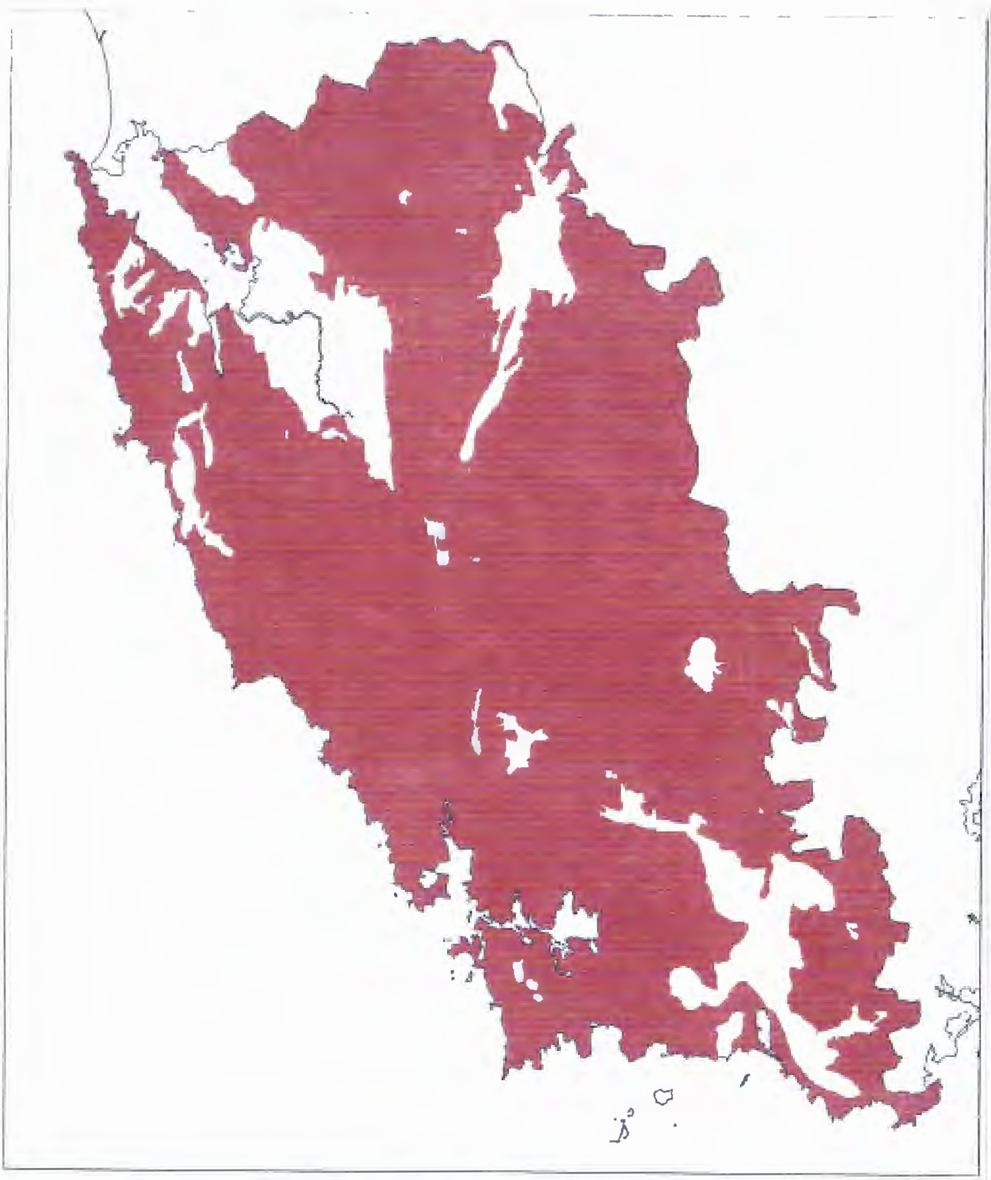


Figure 3.6. Estimated extent of the 1890s fires in southwest Tasmania.
Note: the 1890s fires also burnt very extensive areas outside the study area shown on this map.

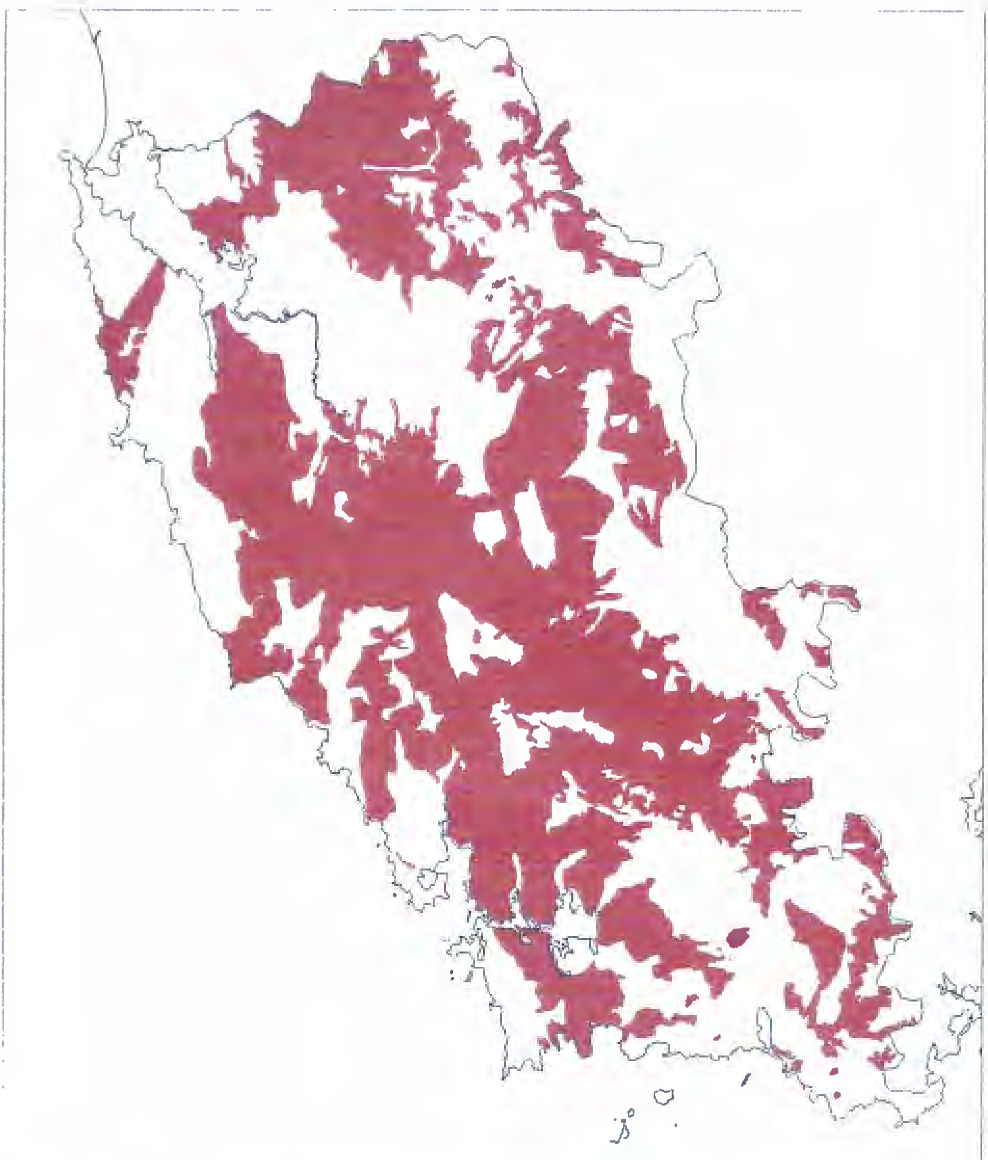


Figure 3.7. Extent of fires in southwest Tasmania between 1930 and 1939. Note: the 1930s fires also burnt very extensive areas outside the study area shown on this map.

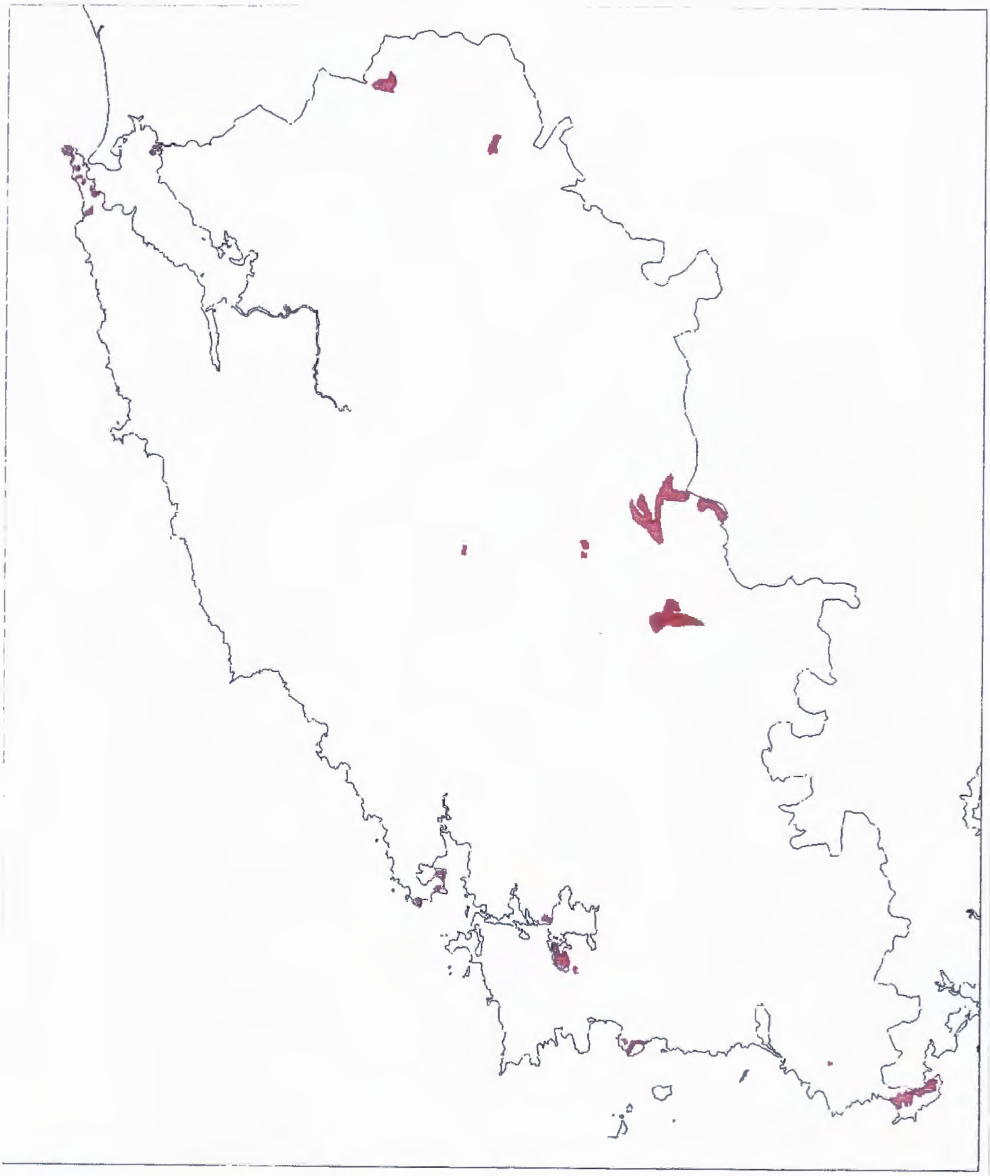


Figure 3.8. Extent of fires in southwest Tasmania between 1940 and 1949.

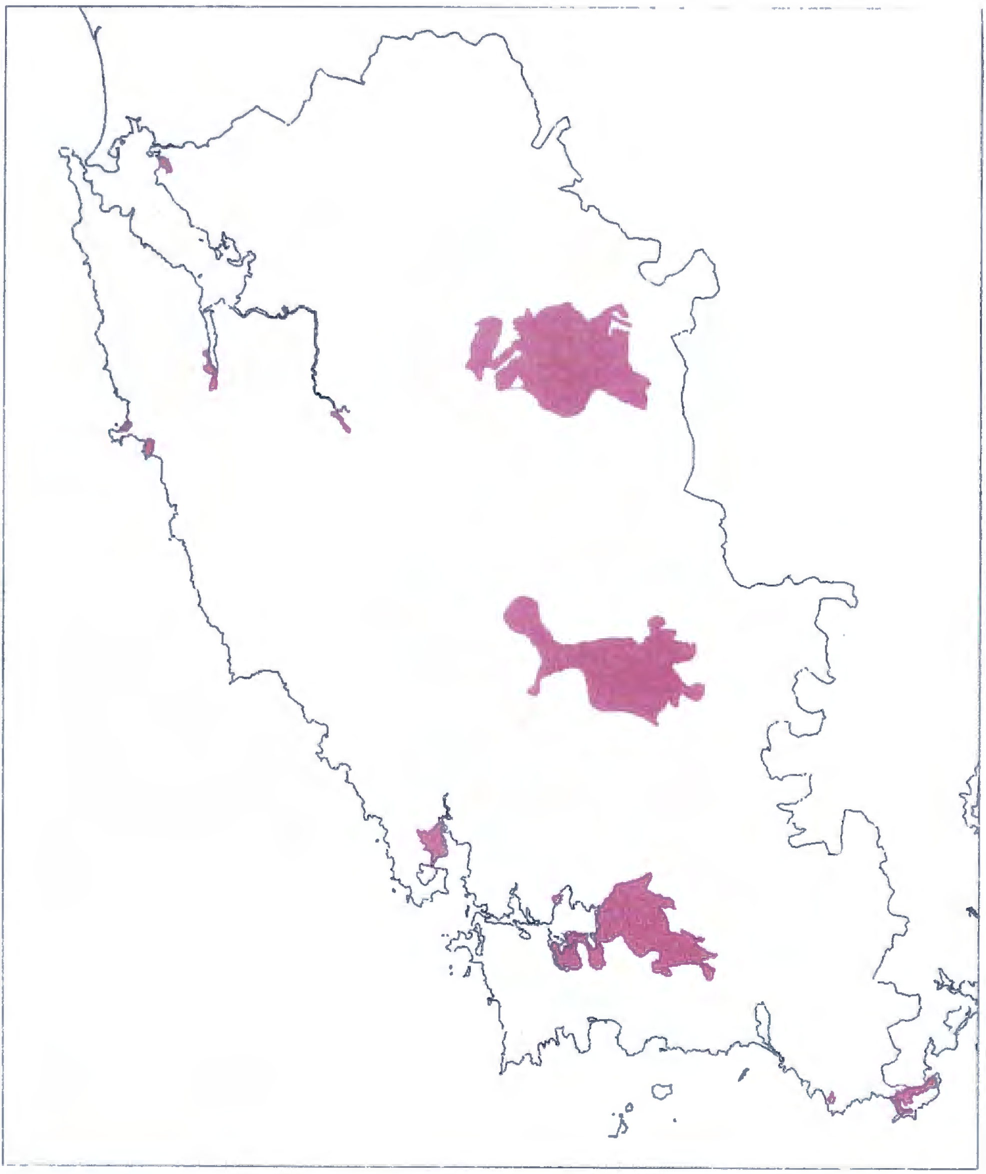


Figure 3.9. Extent of fires in southwest Tasmania between 1950 and 1959.

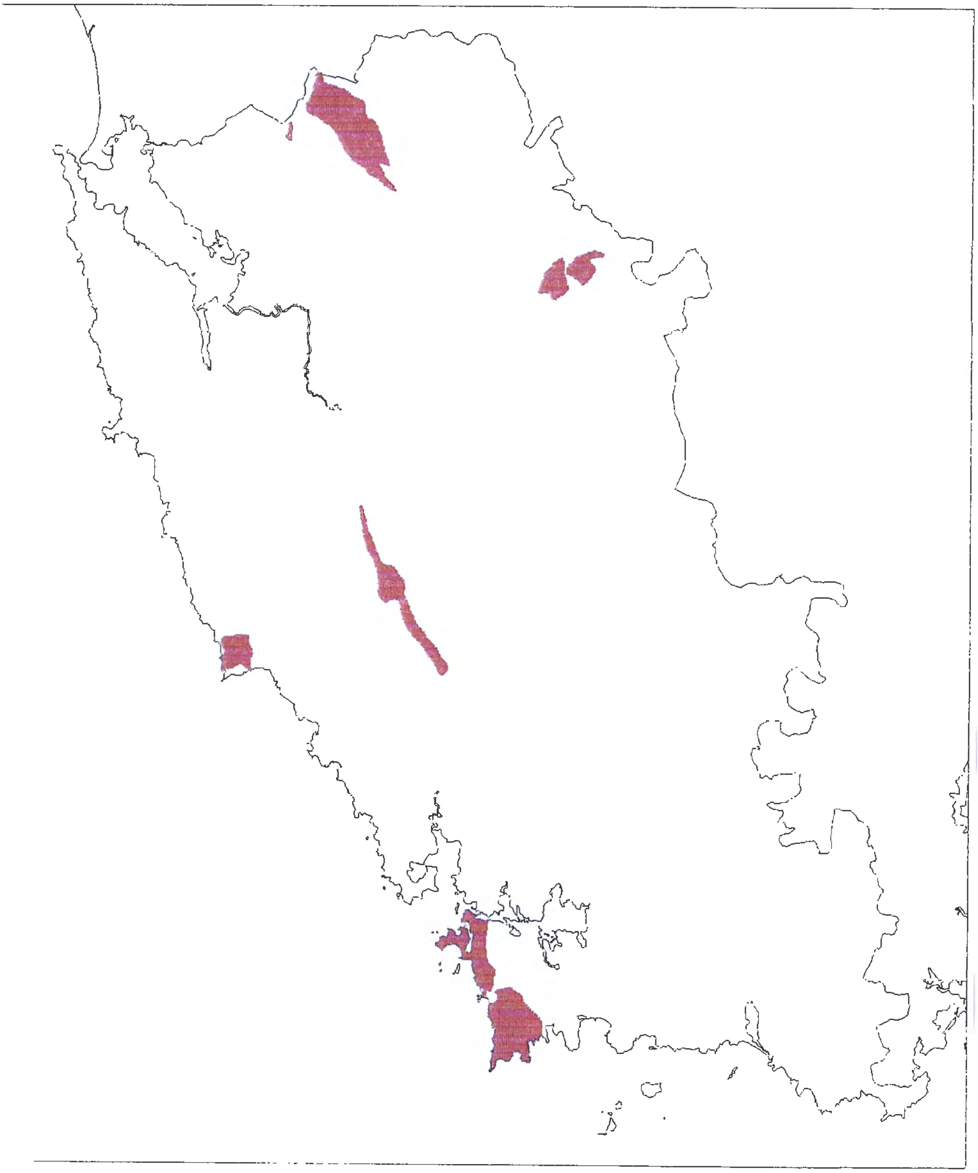


Figure 3.10. Extent of fires in southwest Tasmania between 1960 and 1969.

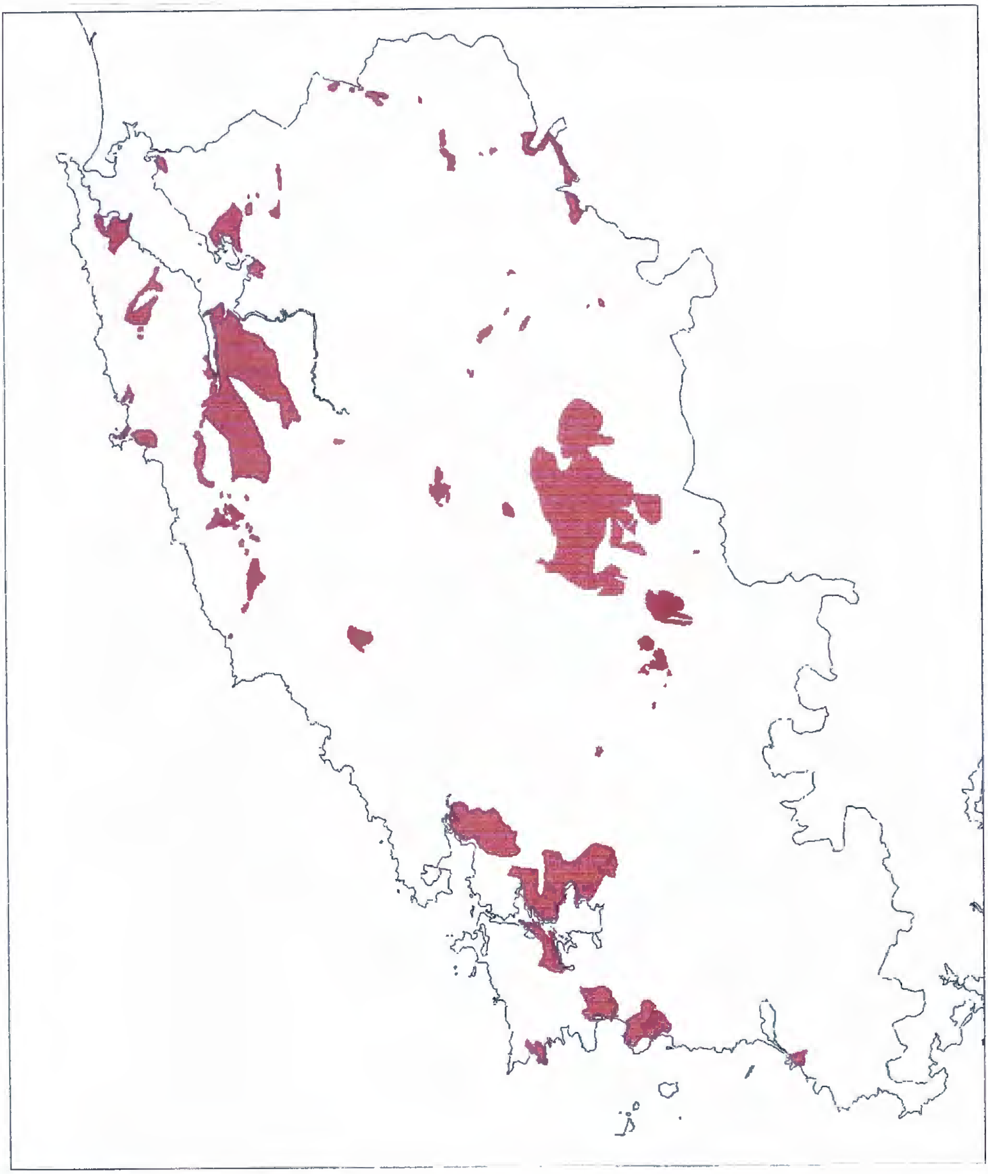


Figure 3.11. Extent of fires in southwest Tasmania between 1970 and 1979.

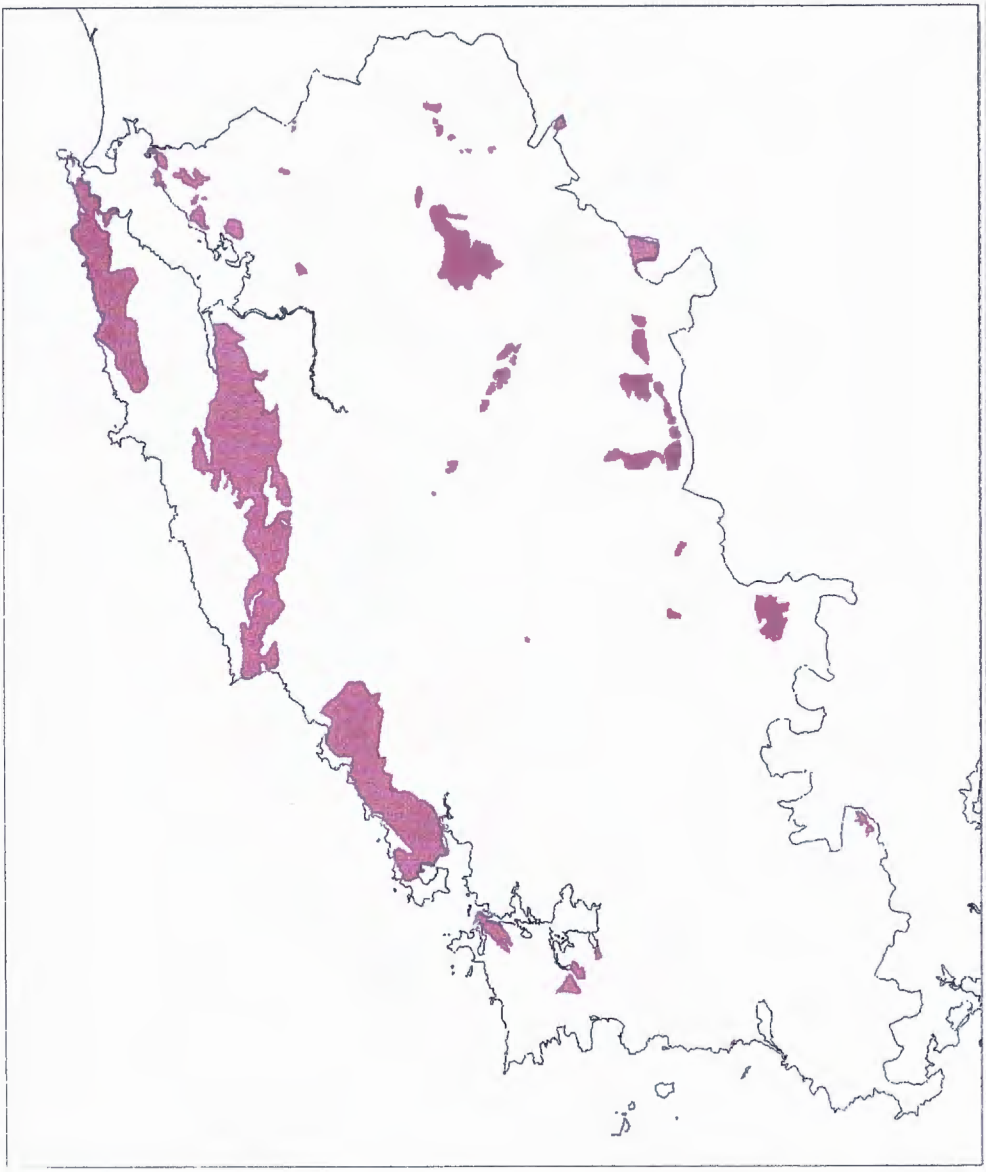


Figure 3.12. Extent of fires in southwest Tasmania between 1980 and 1989.

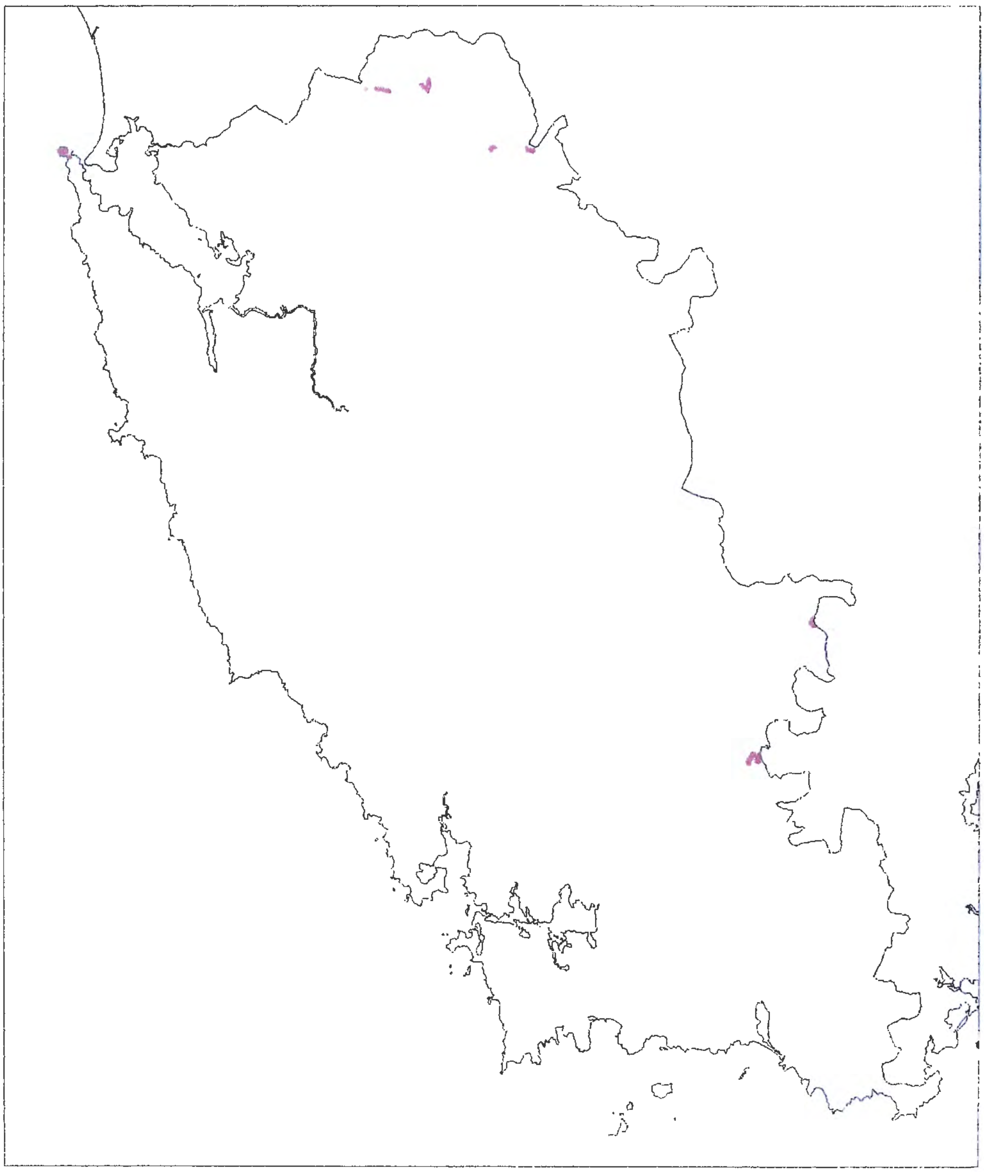


Figure 3.13. Extent of fires in southwest Tasmania between 1990 and 1996.

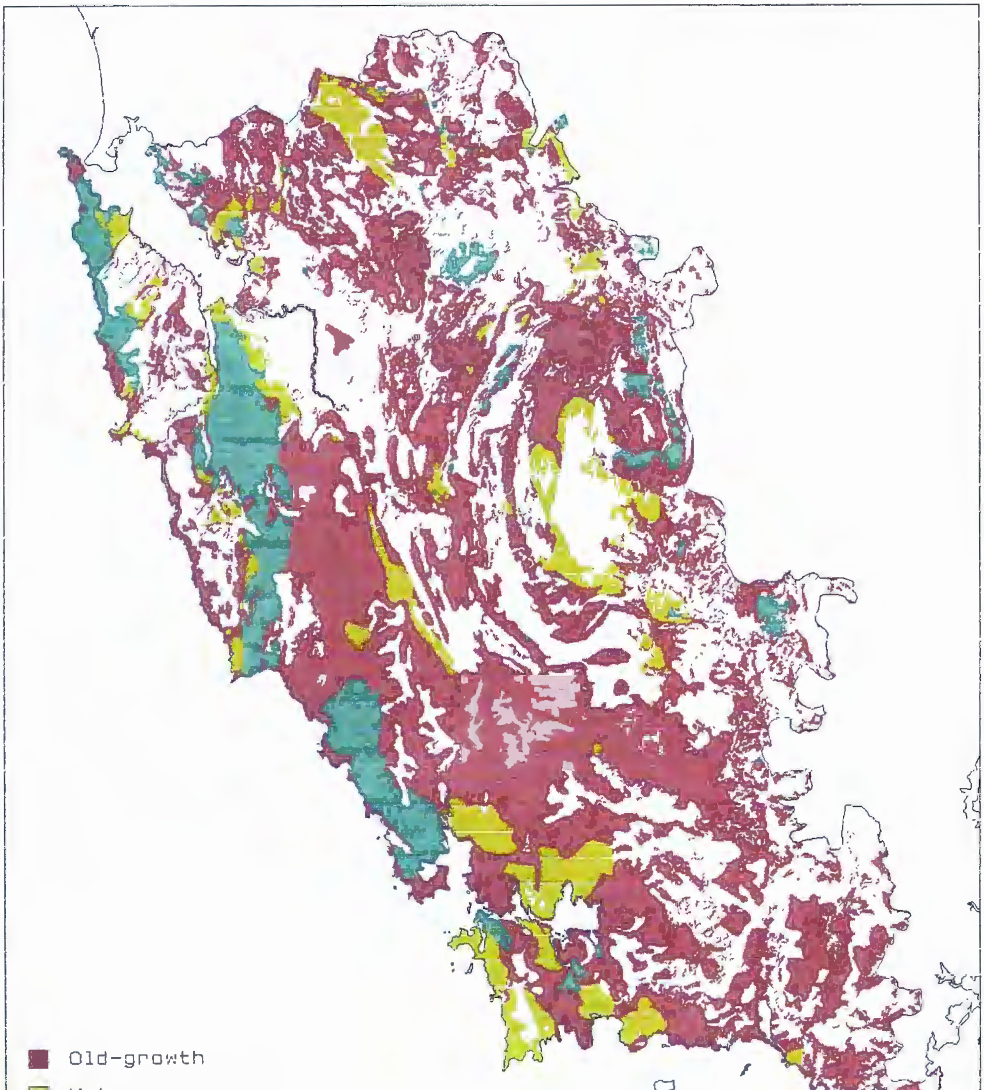
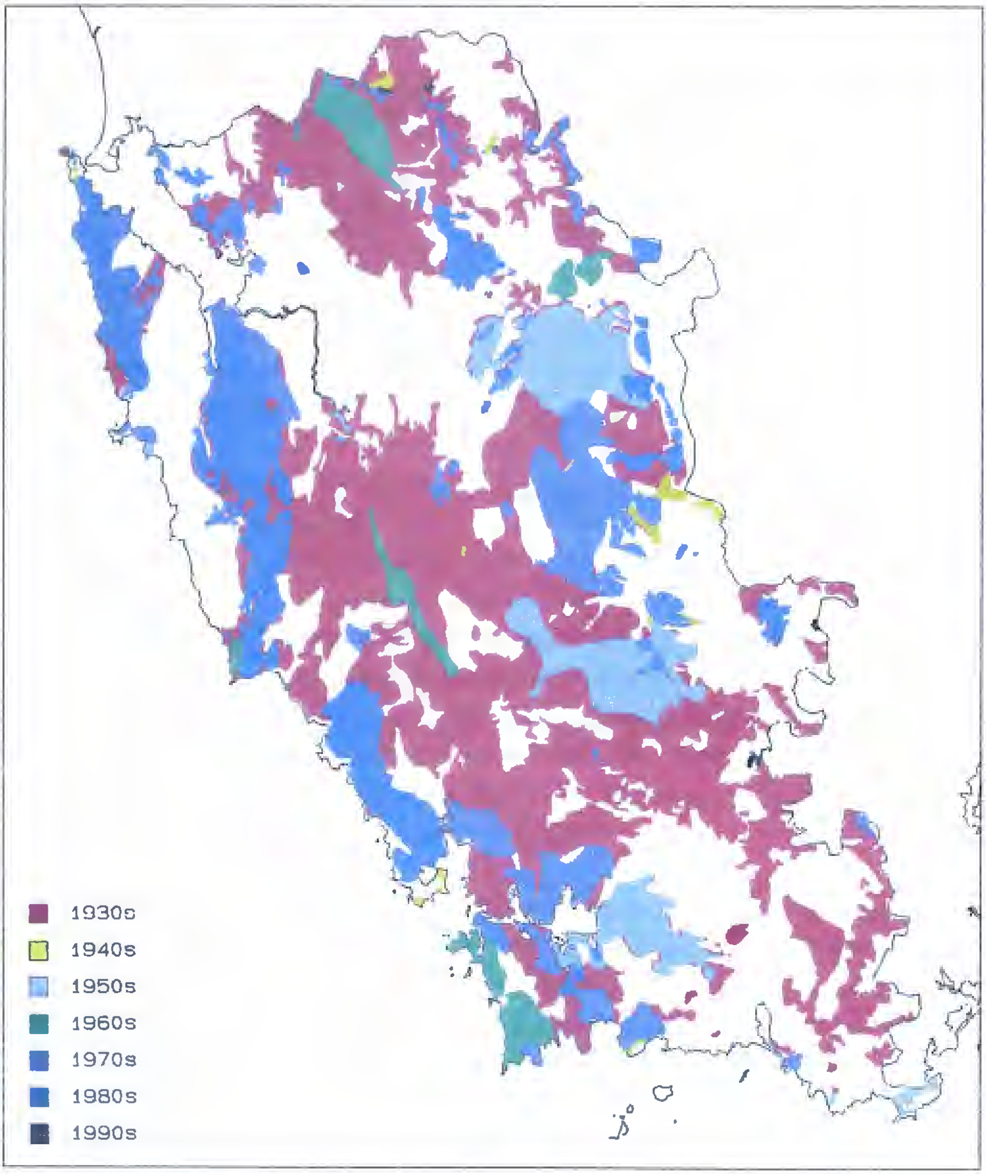


Figure 3.14. Area of non-forest in different age classes.



3.15. Decade last burnt in southwestern Tasmania.

3.4.6 Interactions between drought years and area burnt

Due to the short time period over which weather data are available for western and southwestern Tasmania (see Table 3.12) and the correspondingly limited number of fire events that have occurred during this time (Table 3.7; Figures 3.6 to 3.13), any observations as to the frequency of different types of fire events must be made with caution.

Table 3.12. Percentage of Summers (December to March) in different fire and precipitation categories in southwestern and western Tasmania.

Fire category	Class	Zeehan	Lake Margaret	Maatsuyker Island	Queens-town	Waratah
Rainforest	1 month<50 mm	20.8	1.2	54.3	21.1	39.4
Wet eucalypt forest	1 month<75 mm	52.1	8.3	83.8	46.7	74.6
Landscape scale	2 months<75 mm	13.0	0.0	58.1	11.1	28.0
Record length (years)	77	84	105	90	97	
Site altitude (metres)	160	800	100	180	560	

Note: Length of records and station altitude also shown; source: Bureau of Meteorology, Hobart, Tasmania.

From the information that is available, some general comments can be made. For example, the years in which major rainforest fires are known to have occurred (e.g. 1897/98, 1938/39, 1960/61, 1980/81, 1981/82) all had at least one month with less than 50 mm of precipitation. The years in which major wet eucalypt (but not rainforest) fires are known to have occurred (e.g. 1914, 1921, 1933/34, 1964), all had at least one month with less than 75 mm of precipitation. The two years within which major landscape fires are known to have occurred and precipitation data are available (i.e. 1897/98 and 1933/34) both had two months with less than 75 mm of precipitation. It should also be noted that a major landscape fire also occurred in 1851 (Table 3.7).

As was discussed above, there have been three landscape scale fires in southwestern Tasmania over the past 170 years (viz. 1851, 1897/98 and 1933/34). From the information that is available, it appears that each of these landscape scale fires was preceded by a period of lower fire frequency, 20 to 50 years in length. It should also be noted, for the past about 60 years, only limited areas have been burnt in southwestern Tasmania, indicating that in all probability, suitable conditions currently exist for a landscape scale fire to occur.

These precipitation categories do, however, make ecological and fire behaviour sense. For example, rainforests are normally assumed to require a minimum of

50 mm of precipitation in the driest month (Jackson 1981) and so precipitation amounts below this level would be expected to place the rainforest community under drought stress. A parallel situation has been reported in the *Nothofagus* rainforests in Patagonia (see Kitzberger et al. 1997). For wet eucalypt forests, a SDI (i.e. soil dryness index, see Mount 1972) of greater than about 25 is required for the forests to be dry enough to burn (see Forestry Tasmania, Parks and Wildlife Service, Tasmania Fire Service 1996). This would require a month with less than about 75 mm of precipitation. For landscape scale fires to occur, at least four fire runs (and hence four to six weeks) would be required for fires to travel the distances required.

From the available precipitation data it appears that suitable conditions occur for major rainforest fires in about 20 to 40% of years, major wet eucalypt forest fires in about 50 to 80% of years. Provided there are suitable fuel array conditions (i.e. extensive areas of old-growth moorland and wet scrub) suitable conditions for landscape fires occur in about 10 to 30% of years (see Table 3.12). Hence, in southwestern and western Tasmania, as was also discussed in Section 3.2 and Table 3.1, the main factor controlling the different types of fire is the ignition source (i.e. humans).

It should also be noted that the precipitation data from the only long term high altitude site (i.e. Lake Margaret, Table 3.12) suggests that in this area, the conditions suitable for forest and landscape scale fires are rare, which explains the perpetuation of extensive areas of coniferous rainforest in the Tyndall Ranges. This is despite the Tyndall Range's close proximity to major mines, it being highly geologically prospective and hence having a large number of ignition sources (Parks and Wildlife Service 1997).

3.5 Discussion

As was discussed in Section 3.4, there have been major changes in the fire regime of southwestern Tasmania over about the last 170 years. These changes in fire regime are unlikely to be the result of climatic changes since with the exception of the last 25 years (which has been drier than the previous about 150 years, and during which time no major fires occurred in southwestern Tasmania), the climate over the last 170 years has not been unusual when compared to the previous several thousand years (Cook et al. 1992, 1996). It should also be noted that comparable conditions to those that occurred in 1897/98 and 1933/34 occur about every five to ten years (Table 3.12). As a result, these changes in fire regime are probably a reflection of changes in cultural attitudes and technology.

The aim of the Aboriginal fire management regime would have been to modify the environment to be more suitable for their utilisation. As such, it should be noted that the Aboriginal burning regime was not a natural or hazard-reduction burning regime, but rather it was closer to a habitat-management regime (see Section 1.3.8). It should also be noted that the generally slow rate of vegetation succession in southwestern Tasmania would mean that the distribution of the majority of the current vegetation and soil types would be the result of Aboriginal land use practices. Therefore, the current distribution of vegetation and soils in this region should uot be described as 'natural' and a better description would be a cultural landscape.

Considerable information as to the characteristics of the Aboriginal fire regime can also be gained from observations of the dynamics of peat formation and vegetation distributions in southwestern Tasmania. Conditions have been suitable for peat formation in southwestern Tasmania for about the past 10 000 to 12 000 years (Thomas 1995), with the formation of peat soils requiring 3 000 to 12 000 years at a rate of about 1 to 2 cm per century (Pemberton and Cullen 1995). However, due to differences in fuel moisture, fires tend to burn different amounts and types of fuel in different seasons. Spring and autumn fires normally leave a mat of unburnt thatch (often consisting of the majority of the lower parts of the fuel array), which is in contrast to summer fires, which typically burn most of the fuel array (see Chapter 7). In addition, if fires occur in dry summers, the peat itself may burn (see Bowman and Jackson 1981; Marsden-Smedley 1993a). One effect of this is that significant peat formation is unlikely to occur in a regime of summer fires, due to the lack of suitable peat precursor material and the high probability that any pre-existing peat will be burnt.

The coexistence of extensive areas of buttongrass moorland in adjacent to highly fire-sensitive rainforest and alpine heaths also supports the proposal that the Aborigines must have had a tradition of lighting fires when wet scrub and forest communities were too wet to burn. This is especially the situation with rainforests and heaths containing coniferous species such as King Billy pine (*Athrotaxis selaginoides*), Huon pine and pencil pine (*Athrotaxis cupressoides*). Due to the time periods required for successional processes (see Jackson 1968; Jarman et al. 1988b; Marsden-Smedley 1990) and soil formation (see above), these communities must have coexisted for thousands of years.

The fire management aim of the early Europeans was very different. Their aim was to open up the country in order to expose potential mineral deposits, improve access and to make the vegetation more economically productive. These efforts to open up the region are reflected in the figures for track construction (Table 3.8), with the peak period of track construction closely following the major mineral discoveries in western Tasmania (see Binks 1982; Blainey 1993). It should also be noted that the early European fire regime was almost certainly non-sustainable and was probably only maintained through the burning off of the fuel and soil nutrient capital which had accumulated during periods of lower fire frequencies. Evidence of this can be seen in the aerial photographs from the 1940s, where there are extensive areas of what appear to be degraded moorland, scrub and forest. As a result of this extensive burning, the early European fire regime would have caused massive vegetation change. For example, 32% of King Billy pine, 8% of Huon pine and a significant amount of deciduous beech (*Nothofagus gunnii*) were destroyed by fire during this period (Brown 1988; Peterson 1990; Robertson and Duncan 1991). There may also have been extensive areas of peat soils destroyed during this time (Pemberton 1988, 1989; Hannan et al. 1993; Pemberton and Cullen 1995). However, the observation that extensive areas of peat soils have been lost due to European burning needs to be made with caution, since there is no quantitative evidence that the areas which currently have gravel soils, ever had more extensive organic soils. This is reflected in the observations of extensive areas of gravel soils by G. A. Robinson on the south and west coasts, and near the Wanderer River (Plomley 1966), J. E. Calder on the White Hill Plain (Calder 1849) and J. R. Scott on the Arthur and Crossing Plains and near Port Davey (Scott 1871, 1875). Therefore, it is possible that a proportion of the skeletal soils in western and southwestern Tasmania could be a product of the region's low fertility, past glacial events and/or Aboriginal fires. At this point it is worth noting that the White Hill Plain appears to currently have a well developed organic soil cover (D. Heatley and S. Rundle personal communication).

It should also be noted that once rainforests have been burnt, major changes occur to their fuel arrays such that they become far more flammable. This is mainly due to increases in the amount of dead fuel, opening up of the canopy and changes to the floristics and structure of the community (see Barker 1991).

In marked contrast to the fire management practices of the early Europeans, the current utilisation of southwestern Tasmania mainly for recreation (reflected in the marked increase in bushwalking track and route construction in the 1970s and

1980s, Table 3.8) results in few fires. This is primarily the result of changes in attitudes, whereby the major values of the region are considered to be its natural (especially wilderness) values.

In parallel to the changes reported on in this chapter, major changes in fire regime resulting from changes in cultural and land-use practices have also been reported in the rainforests, woodlands and grasslands of Patagonia and in the chaparral of southern California and northern Baja. In Patagonia, prior to the 1890s, the indigenous Indians practised a fire regime of frequent low intensity fires in the xeric woodlands and grasslands with few fires in rainforests. Following the removal of the Indians in the 1890s, European settlers introduced widespread fire to the region's rainforests in an attempt to transform the forest into grassland for the purposes of cattle ranching. Again in common with southwestern Tasmania, the success of the European's attempts to burn the rainforest communities was largely dependent on the degree of seasonal drought, with major fires occurring in the drought years of 1911 to 1917 (Kitzberger et al. 1997). In the chaparral of southern California and northern Baja, active fire suppression over the past about 70 years in southern Californian chaparral has resulted in a shift from frequent small low intensity fires to infrequent large high intensity fires, often under extreme fire weather conditions. In contrast, in the chaparral of northern Baja where fire suppression has not been as effective, there has been a maintenance of frequent small low intensity fires (Minnich and Chou 1997).

Therefore, fire management practices will have a major influence on the ecology of southwestern and western Tasmania. For example, if fires are mainly lit in autumn and spring and at a frequency in keeping with the ecological requirements of the vegetation (e.g. the proposed Aboriginal fire regime), then it is highly probable that fire-sensitive vegetation and soils could coexist with fire tolerant vegetation. In contrast, if fires are lit in all seasons (e.g. the early European fire regime), then in all probability, there will be a sufficient number of years in which the vegetation and soils will be dry enough for fires to burn all of the different vegetation types. This would result in major impacts to the region's ecological processes.

Under the current fire regime where the majority of the region has not been burnt since the 1930s, major ecological changes are probably occurring in fire adapted vegetation due to the increasing average time since fire (see Section 1.3.7; Figures 3.14 and 3.15; Table 3.10). This reduction in the area burnt has been particularly marked during the 1990s (Table 3.10; Figure 3.13). As a result, the majority of the buttongrass moorlands in southwestern Tasmania would be classified as old-growth (Table 3.11; Figure 3.14).

Leading on from the changes in fire regime that have occurred over the past 170 years is an urgent need to conduct active fire management in southwestern Tasmania's fire adapted vegetation types. The next three chapters of this thesis will outline the modelling of different aspects of buttongrass moorland fire behaviour, the region's most extensive vegetation type. Chapter 7 will discuss the methodologies improving buttongrass moorland fire management while Chapter 8 will discuss some of the wider implications of this research and the interactions between fire management practices and vegetation ecology.

4. Fuel load

4.1 Background

Head fires are carried by the fine fuel. Therefore, for the prediction of head fire behaviour, it is information on the fuels less than about 6 mm in diameter that is required. In these fuels, accumulation dynamics are governed by the balance between biomass production and decomposition (e.g. see Luke and McArthur 1978; Walker 1981).

The type of vegetation has a marked effect on the balance between biomass production and decomposition. In fire-sensitive vegetation (e.g. Tasmanian rainforests, see Jarman et al. 1984), biomass production is normally balanced by rapid decomposition, resulting in little fuel accumulation. By contrast, biomass production in fire-adapted vegetation tends to be rapid following fire with decomposition tending to increase more slowly (Walker 1981; Mercer et al. 1995; see also Section 1.2). This results in most fire-adapted vegetation having rapid fuel accumulation following fire, with fuel loads reaching a plateau when biomass production reaches an equilibrium with biomass decomposition.

Fuel accumulation at a site can be described using a continuous exponential model which assumes that the amount of fuel will approach an asymptote at some given level. Such models have been described by Olson (1963) and utilised by many researchers (e.g. Walker 1981; Fox et al. 1979; Fensham 1992; Conroy 1993; Mercer et al. 1995). These models have been shown to be a robust and easily utilised method of predicting fuel loads which provide good predictions over the range of values required. The models also have the advantage of providing real-time predictions of fuel load and dead to live fuel ratios from other, more easily measured environmental variables, such as time since the last fire, vegetation cover and/or vegetation height. The outputs of these models can then be used for operational fire management.

The main aims of this chapter are to examine the dynamics of fuel accumulation rates and ratios of dead to live fuel in Tasmanian buttongrass moorlands. The models developed in this chapter will then be used in the fire behaviour modelling and fire management sections (Chapters 6 and 7) of this thesis.

4.2 Methods

4.2.1 Study site locations

The majority of buttongrass moorlands in Tasmania fall into the blanket moorland type, but major problems occur with fire management in areas consisting of lowland sedgy moorland and highland sedgy moorland (see Jarman et al. 1988b for a discussion of different community types). In addition, observational estimates suggest higher fuel accumulation rates in sedgy moorlands (both lowland and highland) than in blanket moorlands.

The major differences between these buttongrass moorland types are associated with variation in community floristics and structure, in particular, the cover and dominance of heath species. Blanket moorlands are normally dominated by sedge species with emergent heath species (Figure 4.1). In contrast, sedgy moorlands typically have a low to very low cover of heath species. The typical ranges of the dominant species covers and heights in Tasmanian buttongrass moorlands are shown in Table 4.1.

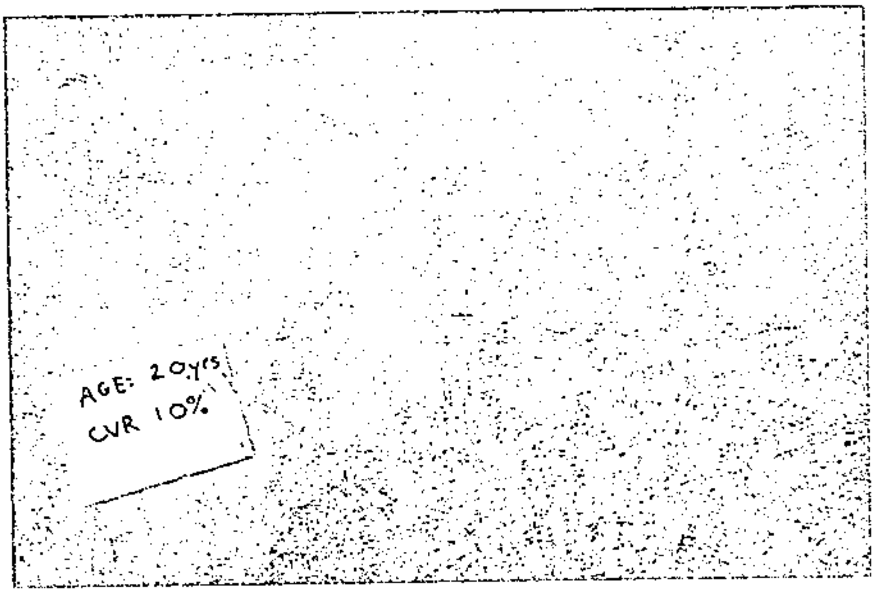


Figure 4.1. Buttongrass moorland fuel structure at McPartlan Pass in southwest Tasmania. Blanket moorland shown.

Fuel sampling was done in all three types of moorland (i.e. blanket moorland, lowland sedgy moorland and highland sedgy moorland). Sites were located in four regions: Melaleuca, in the far southwest of Tasmania; near the Gordon River Road in central southwest Tasmania; near the Franklin and Collingwood Rivers in western Tasmania and on the Navarre Plains in western Tasmania (Figure 4.2; Table 4.2). Descriptions of the sites used to model fuel characteristics are in Appendix 4.

Table 4.1. Typical covers and heights for the dominant species in blanket and sedgy moorlands.

Taxa		Blanket moorland Cover %	Blanket moorland Height metres	Sedgy moorland Cover %	Sedgy moorland Height metres
Monocotyledons					
Cyperaceae	*Gymnoschoenus sphaerocephalus*	25 to 50	0.2 to 1.5	25 to 75	0.2 to 1.5
	Lepidosperma filiforme	5 to 25	0.2 to 1.0	5 to 25	0.2 to 1.0
Restionaceae	*Empodisma minus*	1 to 5	0.2 to 1.0	5 to 25	0.2 to 1.0
	Leptocarpus tenax	1 to 5	0.2 to 1.0	5 to 50	0.2 to 1.0
	Lepyrodia tasmanica	1 to 5	0.2 to 1.0	5 to 25	0.2 to 1.0
	Restio complanatus	1 to 5	0.2 to 0.5	1 to 5	0.2 to 0.5
	Restio hookeri	1 to 5	0.2 to 0.5	1 to 5	0.2 to 0.5
Dicotyledons					
Epacridaceae	*Sprengelia incarnata*	5 to 25	0.5 to 1.5	1 to 5	0.5 to 1.5
Myrtaceae	*Leptospermum nitidum*	5 to 25	0.5 to 1.5	1 to 5	0.5 to 1.5
	Melaleuca squamea	5 to 25	0.5 to 1.5	1 to 5	0.5 to 1.5
Proteaceae	*Agastachys odorata*	<1	0.5 to 1.5	not present	not present
	Banksia marginata	<1	0.5 to 2.0	<1	0.5 to 2.0

Note: information on the dominant species and their covers are from Jarman et al. (1988b) and Marsden-Smedley (1990).

Table 4.2. Sites used to model fuel load.

Site number	and name	Number	Region	Altitude	Community type
1	Airstrip Rd	10	Gordon River Road	320	blanket moorland
2	Island Rd	10	Gordon River Road	320	blanket moorland
3	Sandfly Cr.	10	Gordon River Road	320	blanket moorland
4	McPartlan Pass	10	Gordon River Road	320	blanket moorland
5	Edgar	10	Gordon River Road	320	blanket moorland
6	Melaleuca 3	5	Melaleuca	<10	blanket moorland
7	Melaleuca 4	5	Melaleuca	<10	blanket moorland
8	Melaleuca 2	5	Melaleuca	<10	blanket moorland
9	Melaleuca 5	5	Melaleuca	<10	blanket moorland
10	Melaleuca 1	5	Melaleuca	<10	blanket moorland
11	Lyell Highway P1	5	Franklin/Collingwood	470	lowland sedgy moorland
12	Lyell Highway P10	5	Franklin/Collingwood	410	lowland sedgy moorland
13	Lyell Highway P4	5	Franklin/Collingwood	380	lowland sedgy moorland
14	Lyell Highway P9	5	Franklin/Collingwood	390	lowland sedgy moorland
15	Stonehaven Cr	5	Franklin/Collingwood	380	lowland sedgy moorland
16	King William Saddle 2	5	Navarre Plains	800	highland sedgy moorland
17	Coates Creek	5	Navarre Plains	730	highland sedgy moorland
18	King William Creek	5	Navarre Plains	780	highland sedgy moorland
19	King William Saddle 1	5	Navarre Plains	800	highland sedgy moorland

Note: Number = number of plots at each site; Altitude = metres above sea level.

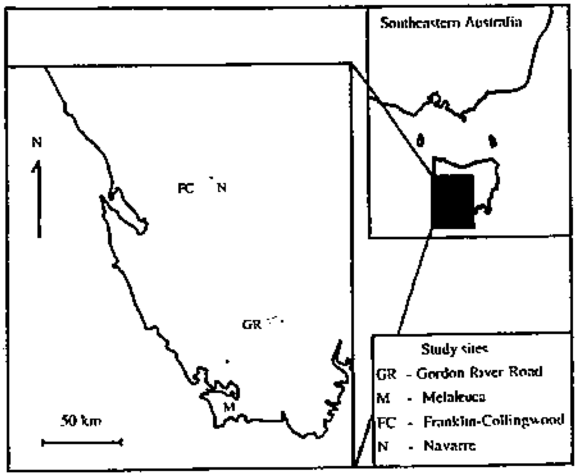


Figure 4.2. Study site locations in western and southwestern Tasmania.

The Melaleuca sites and Gordon River Road sites consist of blanket moorlands underlain by Precambrian quartzite. The Franklin and Collingwood Rivers sites consist of lowland sedgy moorland underlain by Quaternary till containing Jurassic dolerite inclusions. The Navarre Plains sites consist of highland sedgy moorland on fluvioglacial outwash underlain by Jurassic dolerite.

In each region, flat sites with as wide a range of ages as possible were sampled. Flat regions were chosen because the experimental fires used to determine fire behaviour were restricted to flat areas for logistic and safety reasons.

4.2.2 Site age

In Tasmanian buttongrass moorlands there tends to be a pulse of regeneration following fire, resulting in the above ground parts the vegetation being even-aged (MacLean 1978; Marsden-Smedley 1990, 1993a). For most sites the age since fire can be quickly determined from fire records (e.g. from fire management plans, see Lands, Parks and Wildlife 1988a, 1988b) or in the field from banksia (*Banksia marginata*) nodal counts. The ageing of buttongrass moorlands has been discussed by Bell (1983), Jarman et al. (1988a) and Marsden-Smedley (1990).

Where sites were aged from species annual rings, counts were made whenever possible from tea-tree species due to their reliable, easily counted rings. The tea-tree species used included shiny tea-tree (*Leptospermum nitidum*), manuka

(*Leptospermum scoparium*), *Leptospermum glaucescens* and woolly tea-tree (*Leptospermum lanigerum*). Where tea-tree species were not present, white waratah (*Agastachys odorata*) and/or eucalypts (*Eucalyptus coccifera* and *Eucalyptus nitida*) were used, but these species frequently displayed poor ring structure, resulting in problems determining site age. Paper-bark species (*Melaleuca* spp.) were not used since their poor ring structure resulted in an excessive number of individuals being required. Ring counts were made using a dissecting microscope from the lower surface of cross sections cut from just above the ground. These cross sections had been dried and polished with up to 1200 grade sandpaper. A minimum of six individuals were counted at each site. Previous studies (i.e. Marsden-Smedley 1990, 1993a) and extensive cross checking in this project have shown that site age is typically equal to the ring count mode when species are regenerating vegetatively and equal to the ring count mode plus one when species are regenerating from seed.

4.2.3 Fuel data collection

The fuel characteristics at a moorland site (e.g. load, cover, height and species distribution) frequently show considerable levels of spatial variation. Destructive sampling to determine these characteristics to the required precision is very time consuming. Thus a double sampling technique was used to determine site averages of fuel characteristics. This involved the destructive sampling of representative areas for use in the development of regression equations using easily measured predictor variables. This technique has the advantage that the number of destructive samples is small compared to the number of predictions required (see Catchpole and Wheeler 1992). The regression equations developed using these methods can then be used in comparable sites.

Although intuitively it should be possible to predict fuel load using only height and density (typically estimated from the vegetation cover), the structure of the moorland vegetation makes height and cover hard to estimate under field conditions. Most moorland communities are stratified into three distinct layers. These layers normally consist of a lower stratum (5 to 15 cm tall) of moderate cover, overtopped by a second stratum dominated by buttongrass (15 to 50 cm tall) of variable cover. These strata are in turn overtopped by a sparse stratum dominated by emergent shrub species 50 to 200 cm tall.

Fuel height was subjectively estimated by looking across the top of the fuel array, and recording the height below which most of the fuel occurred (typically the height of the second stratum). This method was used to prevent the typically taller tea-tree (*Leptospermum* spp.) and paper-bark (*Melaleuca* spp.) species from positively skewing the height data. These species were frequently over twice as tall as the majority of the vegetation, but normally comprise only a minor component of the fuel load. Similar problems have been documented in some other fuel arrays. For example, big sagebrush in the southwestern USA, which is dominated by monocots with emergent shrubs (see Anderson 1982; Brown 1982).

However, plot cover is relatively straightforward to estimate. Plot cover was estimated using the foliage projective cover method (McDonald et al. 1990). In each plot, the identity, cover (Braun-Blanquet scale, see Mueller-Dombois and Ellenberg 1974) and height of individual vascular plant species was also recorded. When plot cover is estimated, the values obtained by different observers frequently vary considerably. As a result, cover is an unreliable predictor unless calibration is used.

Previous studies of fuel array heterogeneity in buttongrass moorlands has shown that reasonable estimates of fuel load can be made using 2 m by 2 m plots (J. M. Balmer personal communication). Therefore, 2 m by 2 m plots were used in this study, with plots being sampled along transects at two metre intervals. Transects were either 18 m or 38 m long depending on the number of plots being sampled (see Table 4.2). The start and orientation of the transects were randomly located. At each plot all above ground biomass was cut and removed for analysis. The material was then oven dried at 80°C until a constant weight was obtained (minimum 48 hours). Fuel load is the total above ground biomass expressed as the oven dry weight in tonnes per hectare.

In Tasmanian blanket and sedgy buttongrass moorlands, the average fuel particle diameter is about 1.5 mm with typically greater than 90% of the above ground biomass having a diameter of less than six millimetres. As a result, the total fuel load can be used as a reasonable estimate of the fine fuel load.

At each site the dead fuel load was determined by dividing all of the fuel from five 50 by 50 cm plots into its live and dead components, and then oven drying the components at 80 °C for 48 hours so that the dry weight could be calculated. The dead fuel plots were located immediately adjacent to the main fuel analysis plots. The determination of the percentage of dead fuel at Melaleuca and Navarre Plains was done two years after the main fuel sampling took place.

Site slope and aspect were measured using a clinometer and compass. Altitude and geology were obtained from the relevant Tasmap and geology maps. Average soil depth down to the bed rock or gravel was estimated using a probe.

4.3 Results

4.3.1 Fuel load models

In buttongrass moorlands, the height, cover, fuel load and percentage of dead fuel all tend to increase with site age (site averages in Table 4.3). In addition, Table 4.3 shows that at comparable ages, the Franklin-Collingwood and Navarre sites have higher covers and fuel loads than the Melaleuca and Gordon River Road sites. Table 4.4 shows the linear correlation coefficients between the experimental variables (calculated from the raw plot data). As age, cover and height are highly correlated (Table 4.4) the analysis of the fuel load data is complicated due to the lack of independence between different predictor variables. Cover is seen to be most strongly correlated with fuel load ($r = 0.79$, $p < 0.001$).

In a preliminary analysis using the raw data, age times cover appeared to be a good predictor of fuel load. Figure 4.3 suggests that the data fall naturally into two regional groups: Gordon River Road and Melaleuca regions, versus Franklin-Collingwood and Navarre Plains regions. Figure 4.3 also shows that the data fall into site groups within the regions, that is the intra-site variation is less than the inter-site variation. This means that an ordinary analysis of variance on the raw data would not be valid as the assumption of independence of the observations would be violated.

Exploratory data analysis also showed that the variation in fuel load increased with the mean fuel load indicating that a transformation was necessary to produce a homogeneous error variance. A logarithmic transformation produced a reasonably homogeneous error variance. Analyses were carried out on the logarithmically transformed site fuel load data to determine the main sources of variation in the data. Variation in region had a significant effect on fuel load after allowing for the effects of cover and age ($p = 0.04$). There were no significant differences between the Gordon River Road and Melaleuca regions or between the Franklin-Collingwood and Navarre regions ($p > 0.3$ in both cases). As a result, the data from the Gordon River Road and Melaleuca regions were combined to make up the low productivity Southwest group, and the Franklin-Collingwood and Navarre Plains regions were combined to make up the medium productivity Lyell Highway group.

Table 4.3. Site soil depth, age, average height, cover and loads

Site number and name		Soil cm	Age years	Cover %	Height cm	Fuel load t ha^{-1}	Dead %
1	Airstrip Rd @	29.7	3	29	28	2.6	15.4
2	Island Rd	56.5	5	40	29	3.9	10.4
3	Sandfly Cr.	54.6	9	89	32	9.5	17.1
4	McPartlan Pass	17.2	19	66	33	9.7	56.5
5	Edgar	33.0	41	86	38	11.8	64.0
6	Melaleuca 3	>95 *	5	38	21	5.8	8.6 #
7	Melaleuca 4	51.6	12	29	19	5.9	27.7 #
8	Melaleuca 2	>95 *	18	99	36	15.3	50.6 #
9	Melaleuca 5	92.5	20	50	23	11.3	55.7 #
10	Melaleuca 1	45.2	21	59	21	6.2	41.0 #
11	P1	22.2	2	11	13	1.9	4.6
12	P10	33.8	5	52	24	6.9	22.9
13	P4	27.3	6	72	32	11.7	28.3
14	P9	34.6	10	82	29	15.3	57.0
15	Stonehaven Cr	13.4	20	87	29	20.5	63.9
16	King William Saddle 2	29.0	1	13	17	2.4	14.4 #
17	Coates Creek	35.0	5	78	21	4.9	17.0 #
18	King William Creek	63.0	8	100	21	17.5	44.8 #
19	King William Saddle 1	81.0	17	98	27	26.5	54.6 #

Note: @ = unusual site containing dead shrubs unburnt in the previous fire (removed from the data set when developing the dead fuel load prediction equations); * = deeper than the 95 cm probe; # measured 2 years later, so corresponding age is 2 years greater than that shown

Table 4.4. Linear correlation coefficients (r) between the fuel load modelling variables.

	Soil	Age	Cover	Height	Fuel load	% dead
Soil	1.00					
Age	-0.03	1.00				
Cover	0.16	0.47	1.00			
Height	-0.02	0.46	0.59	1.00		
Fuel load	0.23	0.41	0.79	0.42	1.00	
% dead	0.06	0.75	0.56	0.39	0.66	1.00

The lack of significant difference between the two medium productivity regions and the two low productivity regions indicates that altitude (see Table 4.2) has little effect on the relationship of fuel load versus age and cover in the moorlands. In addition, soil depth was found to have no significant effect on the relationship. Differences in slope between the sites were negligible and so the effect of slope is unknown. Observational evidence suggests that slope has only minor, if any, effect on fuel load.

The best fitting model included site productivity (low or medium productivity), cover and age. This model accounted for 87% of the variation in the transformed fuel load data. A simpler model using age times cover without site productivity accounted for 74% of the observed variation. As a result, it is probable that the majority of the variation due to differences in site productivity is accounted for in the variation in cover (see Table 4.3).

An attempt was made to model the variation in fuel load in the raw data using a variance component model of the form:

$$\log(\text{LOAD}) = a_i + b_i \log(\text{AGE} * \text{COVER}) + Vs + Ve \qquad (4.1)$$

where a_i and b_i are constants depending on site productivity (i=1 for low productivity and i = 2 for medium productivity), Vs is the inter-site (within region) sampling variation, and Ve is the intra-site (or error) variation. The model was fitted using the package S-PLUS (Statistical Sciences 1993) and the various available minimisation techniques such as maximum likelihood and residual maximum likelihood (e.g. see Searle et al. 1992). The variance component method was found to be unsatisfactory. The parameter estimates for a_i and b_i varied considerably depending on the minimisation method used. In addition, the 95% confidence limits for the true regression curve were extremely large (Figure 4.3), but this is principally the result of basing estimation on single plot estimates. The values of the parameters in Equation 4.1 are given in Table 4.5.

All further analyses were carried out on the site average data shown in Table 4.3. In any case a prediction equation for average site fuel load from average site characteristics is more relevant for most situations for which the fuel model would be needed. Models were fitted using a weighted analysis with weights equal to the number of observations at each site.

Equations to predict fuel load were originally determined by linear regression using a logarithmic transformation of fuel load. However, inspection of the predicted equations and the prediction limits for new observations at high fuel loads suggested that a less powerful transformation would be better, so a square root transformation was used together with weighted non-linear regression fitting. The square root transformation was applied to both sides of the regression equation (see Carroll and Ruppert 1988). Maximum likelihood analysis showed that the square root transformation was almost as good as the more natural logarithmic transformation (see Carroll and Ruppert 1988 for maximum likelihood analysis methodology). The remaining analyses of the fuel load data were done using square root transformations.

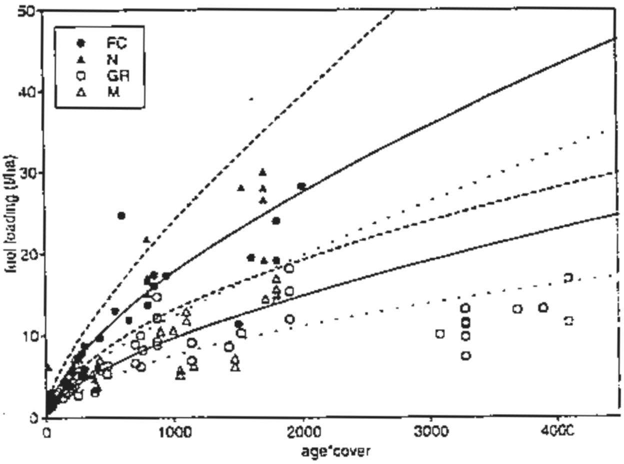


Figure 4.3. Age times cover versus fuel load in the different regions.
Note: FC = Franklin-Collingwood sites; N = Navarre sites; GR = Gordon River Road sites; M = Melaleuca sites; fitted curves from Equation 4.1: semi-solid line = predicted Southwest fuel loads, solid line = predicted Lyell Highway fuel loads; 95% confidence limits: dotted lines = Southwest sites; dashed lines = Lyell Highway sites.

The following equation was fitted to the data, and can be used to predict site mean fuel load from age and site mean cover:

$$\text{FUEL LOAD} = a_i * (\text{AGE} * \text{COVER})^{b_i}, \qquad (4.2)$$

where a_i and b_i are constants whose value depends on site productivity ($i = 1$ for low productivity, and $i = 2$ for medium productivity). The model is shown fitted to the data in Figure 4.4. The estimates for a_i and b_i are given in Table 4.5. Equation 4.2 was fitted using non-linear least squares fitting. The distribution of the parameter estimators for models that have non-linear parameters depends on the data used to fit the model as well as the form of the model (Ratkowsky 1990). For large samples the estimators are close to unbiased, normally distributed minimum variance estimators, as in the case of a linear model. For small samples the estimators may be biased, but the bias in the estimation of the regression curve will be small compared to the variability in the data. The equation will provide a reasonable prediction of average site fuel load provided it is used within the range of the original data. Asymptotic standard errors for a_i and b_i are given in Table 4.5 (see Myers 1989 for methodology). Prediction intervals for fuel load for a new site are dominated by the error variance rather than the uncertainty in the fitted regression curve, so that the prediction intervals for the present data will be close to the asymptotic prediction intervals shown in Figure 4.4.

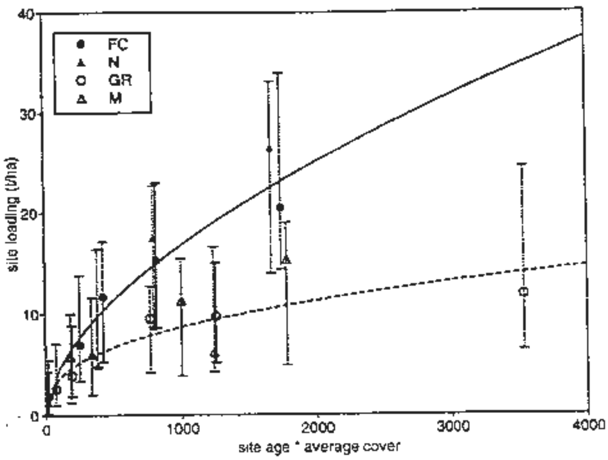


Figure 4.4. Site mean fuel load versus site age times average cover.
Note: FC = Franklin-Collingwood sites; N = Navarre sites; GR = Gordon River Road sites; M = Melaleuca sites; fitted regression curves from Equation 4.2: semi-solid line = predicted Southwest fuel loads, solid line = predicted Lyell Highway fuel loads; 95% prediction intervals for new observations also shown.

Due to problems with the estimation of cover, which have already been discussed, a model without cover was desirable. Within each of the two regions (i.e. Southwest and Lyell Highway) age was found to be a good predictor of fuel load. Plots of fuel load versus age showed that the regional differences in cover are masking the relationship between fuel load and age in the full data set. In addition, the relationship between fuel load and age is non-linear as discussed below, and is not reflected fully in the linear correlation coefficient r.

Plots showed that in the low productivity sites fuel load increased steeply at first with age, and then tended to slow down and become constant with age in the older sites. In the medium productivity sites there were not enough data to confirm this pattern, but it seems reasonable from a ecological viewpoint. The data for older medium productivity sites are hard to obtain as most accessible medium productivity moorlands are burned by accident or design before they are 20 years old.

The following equation was fitted to data:

$$\text{FUEL LOAD} = a_i * (1 - \exp(-b_i * \text{AGE})) \qquad (4.3)$$

where a_i and b_i are constants depending on site productivity ($i = 1$ for low productivity, and $i = 2$ for medium productivity). Similar models have been fitted previously to biomass accumulation data (for example see: Olson 1963; Fox et al. 1979; Birk and Simpson 1980; Walker 1981; Hutson 1985; Fensham 1992; Conroy 1993). The model is shown fitted to the data in Figure 4.5 along with the asymptotic prediction intervals. The estimates of a_i and b_i with their asymptotic standard errors are given in Table 4.5.

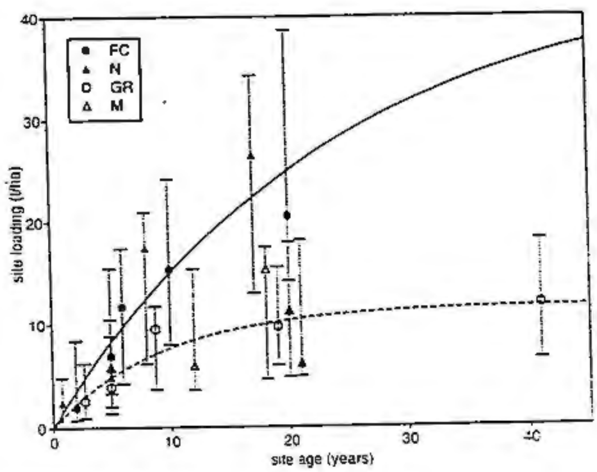


Figure 4.5. Site mean fuel load versus age.
Note: FC = Franklin-Collingwood sites; N = Navarre sites; GR = Gordon River Road sites: M = Melaleuca sites; fitted regression curves from Equation 4.3: semi-solid line = predicted Southwest fuel loads, solid line = predicted Lyell Highway fuel loads; 95% prediction intervals for new observations also shown.

4.3.2 Models for dead fuel load

The total fuel loads were not re-sampled at the time the proportion of dead fuel was assessed for the Melaleuca and Navarre regions. To obtain a model for dead fuel load, the fuel loads for these regions were first re-estimated from the fuel load two years previously using using the growth rate in Equation 4.3. The dead fuel load was then plotted against the total fuel load (Figure 4.6). The dead fuel load is seen to increase with the total fuel load, and this increase tends to linearity for large values of fuel load (or equivalently, for older sites). The relationship between dead fuel load and total fuel load appears to be independent of site productivity. Figure 4.6 shows that the effects of fuel load and dead to live fuel proportions on fire behaviour will be very difficult to separate in buttongrass moorland fire behaviour data.

An equation was fitted to the data in Figure 4.6 which can be used to predict the dead fuel load from the total fuel load if known. The equation is of the form:

$$\text{DEAD FUEL LOAD} = a\sqrt{(\text{LOAD}^2 + (b/a)^2)} - b \qquad (4.4)$$

This represents a function that tends to linearity for large values of the fuel load. The equation was fitted using a 'transform both sides' approach, with a square root transformation and non-linear weighted least squares. The estimated values of a and b and their asymptotic standard errors are given in Table 4.5.

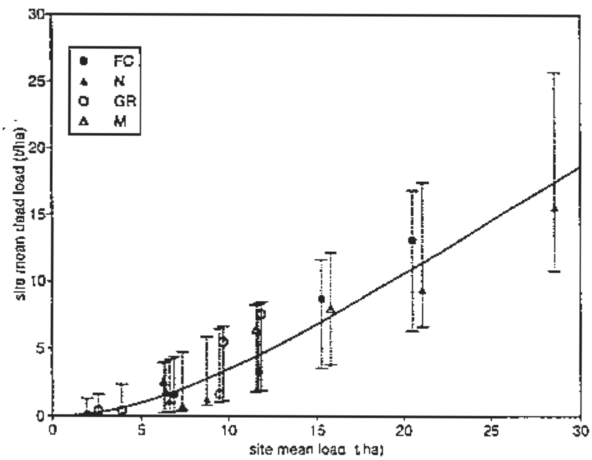


Figure 4.6. Site mean dead fuel load versus total fuel load.
Note: FC = Franklin-Collingwood sites; N = Navarre sites; GR = Gordon River Road sites; M = Melaleuca sites; fitted regression curve from Equation 4.4; 95% prediction intervals for new observations also shown.

If the total fuel load is unknown, and has to be estimated from the fuel age or age times cover, considerably more error will be present in the estimation than is shown by the prediction intervals in Figure 4.6. For this situation an equation directly predicting the fraction of dead fuel from the site age was fitted to the data (Figure 4.7), in the form below:

$$\text{FRACTION DEAD} = a_i * (1 - \exp(-b_i * \text{AGE})) \qquad (4.5)$$

This equation was fitted using an arc sine transformation (Snedecor and Cochrane 1980) to stabilise the variance for proportional data, and the 'transform both sides' methodology was again used. Estimates of the parameters are given in Table 4.5.

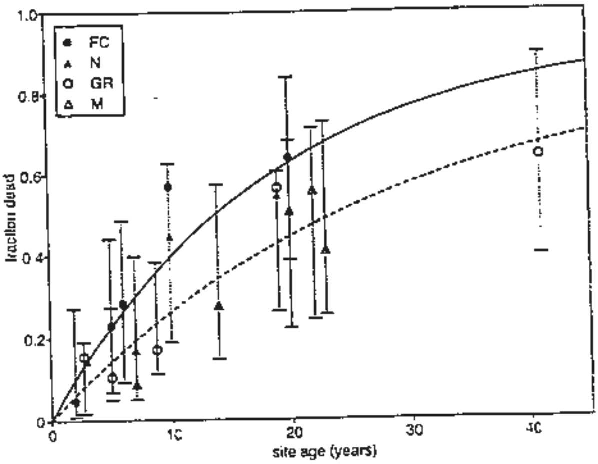


Figure 4.7. Site fraction dead fuel load versus age.
Note: FC = Franklin-Collingwood sites; N = Navarre sites; GR = Gordon River Road sites; M = Melaleuca sites; fitted regression curves from Equation 4.5: semi-solid line = predicted Southwest fuel loads, solid line = predicted Lyell Highway fuel loads; 95% prediction intervals for new observations also shown.

Table 4.5. Estimated values for the parameters in equations 4.1 to 4.5

	Equation 4.1 Fuel load		Equation 4.2 Fuel load		Equation 4.3 Fuel load		Equation 4.4 Dead fuel load		Equation 4.5 Fraction dead	
Parameter	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error
a_1	-2.03	0.451	0.629	0.333	11.73	2.01	0.883	0.255	0.873	0.255
a_2	-1.55	0.404	0.305	0.192	44.61	31.77			0.950	0.484
b_1	0.622	0.068	0.380	0.076	0.106	0.040	9.46	7.32	0.036	0.016
b_2	0.640	0.068	0.580	0.093	0.041	0.038			0.054	0.040

Note: Estimate = equation parameter estimate; Error = standard error; a_1 = first parameter, low productivity sites; a_2 = first parameter, medium productivity sites; b_1 = second parameter, low productivity sites; b_2 = second parameter, medium productivity sites; in the case of Equation 4.4 estimates and standard errors are not site productivity sensitive.

4.4 Discussion

This chapter has discussed the development of models to predict buttongrass moorland fuel loads primarily in terms of site productivity and age. A more accurate model to predict total fuel load in terms of age, vegetation cover and site productivity is also presented. The problems associated with using vegetation cover as a predictor have also been discussed. These issues have been discussed in a research paper (Marsden-Smedley and Catchpole 1995b, see also Appendix 7).

The division of buttongrass moorlands into only two categories (i.e. low versus medium productivity) was subjective. The difference between low and medium productivity sites in western and southwestern Tasmania is probably the result of different geologies. All of the Southwest sites are located on Precambrian quartzite, in contrast to the Lyell Highway sites, which are located on fluvioglacial outwash containing Jurassic dolerite. Sites underlain by quartzite are considered to be low productivity sites, in contrast to sites underlain by fluvioglacial ontwash containing dolerite, which are considered to be medium productivity sites. This may also be reflected in the different community types present in each of the regions.

The situation as regards site productivity may be different in highland areas of western and southwestern Tasmania and in northern and eastern Tasmania, where much higher fuel accumulation rates have been observed. For example, in these areas, fuel accumulation rates approximately double those measured in the Lyell Highway sites have been observed on quartzitic substrates. These high fuel accumulation rates may be the result of the generally warmer climate in northern and eastern Tasmania (Marsden-Smedley and Williams 1993), or slower fuel decomposition rates in the highland areas of southwestern and western Tasmania. Hence the models presented here should at present only be used in lowland areas of western and southwestern Tasmania. More work is needed to test the models in other regions, and if necessary to develop additional fuel models.

The lack of correlation between soil depth and fuel load was expected, since previous studies have shown buttongrass moorland growth rates to be very poorly correlated with soil depth, whilst growth rates are frequently well correlated with soil type (e.g. Marsden-Smedley 1990; see also Pemberton 1988, 1989; Jarman et al. 1988b). A different situation may occur in sites with skeletal soils, where the thin (typically less than ten centimetres deep), gravelly soils are normally associated with discontinuous vegetation covers and low fuel loads. In this situation the fuel load prediction model using age alone badly over-predicts fuel load, while the age times cover model (Equation 4.2) provides good estimates and should be used in preference.

Since the maximum value of age used to develop the medium productivity fuel load and dead fuel models was 20 years, the equations should be used with caution in older medium productivity sites.

The models presented in this chapter predict fuel loads in low and medium productivity buttongrass moorlands. These models can be used in association with the fuel moisture models (Chapter 5) as inputs for the fire behaviour and fire danger models (Chapter 6) and hence will form part of the buttongrass moorland fire behaviour prediction system (Chapter 7). The wider implications of this research will be discussed further in Chapter 8.

5. Fuel moisture

5.1 Background

Fuel moisture content has a major effect on fire behaviour through its influence on ignition probability (Wilson 1985) and fuel combustion. As fuel moisture content increases, more energy is required to dry the fuel prior to combustion, slowing the fuel consumption rate (Rothermel 1972). In addition, moisture driven off the fuel reduces the rate of radiant energy transfer from flames to adjacent fuel particles (Viney 1992).

In order to manage fires under operational conditions, it is necessary to be able to determine fuel moistures over the range of conditions within which fires occur. Several classes of methods have been developed for determining fuel moistures: gravimetric calculation, electrical capacitance, chemical determination, modelling using secondary characteristics, modelling using environmental parameters and the use of surrogates.

Gravimetric calculation is the traditional method of calculating fuel moisture. It involves oven-drying fuel samples at between 80° and 105°C in order to determine the difference between their field and dry weights. This method is accurate but impractical under operational conditions due to the 24 to 48 hour time lag between sample collection and fuel moisture calculation. Methods have been developed which have the potential to reduce this time lag (e.g. rapid drying of samples using heat, low pressure and/or microwaves; L. McCaw personal communication).

In the past, fuel moistures have been calcnlated using chemical determination, typically involving measurement of pressure changes resulting from the oxidation of calcium carbide when introduced to finely ground fuel particles inside a sealed chamber (e.g. the Speedy moisture meter; Dexter and Williams 1976). This method has the advantage of providing rapid measnrements of fuel moisture in the field, but has the disadvantage that the way in which the fuel type responds in the test chamber at different moisture contents needs to be determined. In order to get accurate measurements of fuel moisture, the fuel needs to be carefully prepared and the amount of fuel and calcium carbide carefully measured. As a result of these problems, this system for determining fuel moisture has fallen into disuse.

The recently developed electrical capacitance meter (Chatto and Tolhurst 1997) which relates a fuel sample's electrical capacitance to its moisture content appears to have the potential to provide a robust methodology for determining fuel moistures. However, in order to use this system the relationship between the fuel type being measured and its electrical capacitance needs to be determined, which has not been performed for buttongrass moorland fuel.

Secondary characteristics of a fuel particle may also be used to estimate fuel moisture. These methods normally involve determining either the angle at which a fuel particle will just support flaming combustion or the angle at which it snaps. This angle is then related to the fuel particle moisture using predetermined relationships (e.g. see Burrows 1984, 1991). This system has the advantage of providing rapid estimates of fuel moisture in the field but has the disadvantage that the relationship between the fuel moisture and the angle of combustion or snapping is species-specific and possibly site-specific (Burrows 1991). As a result, this system is not widely utilised.

Hazard sticks are arrays of wood (typically *Pinus radiata* in Australia) which have a known dry weight. Fuel moisture can be estimated from the difference in the dry and field weight of the sticks (Eron 1991). The advantage of using hazard sticks is that as well as being located within the fuel array (and hence being subjected to the same conditions as the fuel array particles) they integrate both the current conditions and the conditions prevailing in the recent past. This is particularly important as regards precipitation, where the fuel moisture may lag considerably behind what would be expected based on the current weather conditions. The main disadvantages of hazard sticks are that the relationship between stick moisture and fuel moisture is species-specific, the sticks require considerable standardisation time in the field prior to estimates of fuel moisture being made (typically 10 to 14 days) and stick degradation is relatively rapid under field conditions (stick life is less than 12 weeks; see Eron 1991).

Since all of the methods discussed so far require field samples in order to determine fuel moistures, their utility is limited, especially under wildfire conditions when estimates of fuel moisture often need to be made at sites remote from the fire. Therefore, to supplement field measurements of fuel moisture, methods of estimating fuel moisture from secondary and/or environmental parameters are required.

Equilibrium moisture models predict fuel moisture content from the humidity and temperature of the actual fuel particle. Relative humidity is normally used as a measure of atmospheric humidity, but dew point temperature could equally be used. In order to use equilibrium moisture models under operational conditions, additional relationships are needed to predict the fuel particle temperature and humidity from parameters such as the screen-level temperature, relative humidity, dew point temperature, solar radiation and wind speed (e.g. Byram and Jemison 1943; van Wagner 1969). Vapour exchange models predict the moisture content of the fuel array on the basis of atmospheric humidity and temperature measured at screen-level, which is typically about 1.5 to 2 m above the ground surface (see Viney 1991, 1992). Vapour exchange models assume implicitly that the measurements of humidity and temperature at screen-level are proportional to those at the fuel particle level, and ignore the direct effects of solar radiation and wind speed on the temperature and humidity of the fuel particle.

The North American 'bookkeeping' models such as the Canadian Fine Fuel Moisture Code (van Wagner and Pickett 1985) and its United States modification (Rothermel et al. 1986) predict fuel moisture content on the basis of the previous day's moisture in association with the weather conditions over the intervening period. These models are based on equilibrium moisture content models, but their predictions also depend on time lag functions based on the temperature, relative humidity and wind speed. The United States equilibrium moisture model (Rothermel et al. 1986) uses fuel particle temperature and relative humidity predicted using the relationships of Byram and Jemison (1943).

Different models available for predicting fuel moisture have been extensively reviewed by Hatton and Viney (1988) and Viney (1991).

Current research (e.g. Gould 1993) indicates the dominant fuel stratum in regard to fire spread rate is probably the near-surface fuel stratum. For most fuel types the near-surface fuel stratum is the well aerated fuel within about 10 to 100 cm above the ground (Cheney et al. 1990; Gould 1993; see also Marsden-Smedley and Catchpole 1995a, 1995b for a discussion of buttongrass moorland fuel characteristics). This contrasts with earlier beliefs that the dominant fuel stratum was the litter stratum (e.g. Luke and McArthur 1978). This suggests that for operational fire management, fuel moisture predictions are required for the near-surface fuel stratum.

In Tasmanian buttongrass moorlands, fuel moisture predictions need to be made over the range of dead fuel moistures within which fires will sustain (i.e. 5 to 70%; see Chapter 6). A predictive model is therefore required which is capable of utilising factors either measured in the field or from weather forecasts. Such factors include screen-level temperature, dew point temperature, relative humidity, wind speed and/or recent precipitation history.

Under operational conditions a general dead fuel moisture model applicable under both absorption and desorption conditions is preferable for simplicity. Such a model ignores the effects of hysteresis which is typically a difference of about two percent moisture content depending on whether adsorption or desorption conditions are prevalent (Viney 1991). In any event, the effect of hysteresis is minor compared to the effect of other factors.

Previous research in Tasmanian buttongrass moorlands has shown fire behaviour to be highly correlated with dead fuel moisture and uncorrelated with live fuel moisture (see Marsden-Smedley and Catchpole 1995b). In addition, buttongrass moorland live fuel moistures have been shown to vary between about 75 and 145% independent of season and locally prevailing weather conditions (Appendix 6; Marsden-Smedley unpublished data).

The main aim of this chapter is to examine the dynamics of dead fuel moisture in Tasmanian buttongrass moorlands. Models were developed to provide real-time predictions of dead fuel moisture using easily measured environmental variables. No attempt was made to model live fuel moistures.

5.2 Methods

5.2.1 Fuel moisture data collection

Fuel moisture data were collected from two sources: the buttongrass moorland fire behaviour modelling project and a program specifically examining fuel moistures in a 15 year old buttongrass moorland at Condominium Creek in Southwest Tasmania. In common with the sites used for fuel characteristics and fire behaviour modelling, the site was flat (i.e. slope less than 1°). The Condominium Creek site is about half way between the Sandfly Creek and Edgar fuel load modelling sites (see Marsden-Smedley and Catchpole 1995a; Marsden-Smedley 1993a).

Fuel moistures were measured gravimetrically by collecting samples from the near-surface fuel stratum (i.e the second fuel stratum, see Section 4.2.3 for a description of buttongrass moorland fuel strata). Attempts were made to sample dead fuel moistures in proportion to each species occurrence in the moorland (see Table 4.1). In buttongrass moorlands most of the dead fuel in the near-surface fuel stratum consists of small bundles of clumped fuel particles about 10 to 30 cm above the ground surface. These bundles typically contain about 10 to 20 fuel particles in the form of strands similar in appearance to grass stems. Little litter fuel occurs in buttongrass moorlands.

Fuel moistures were measured on a total of five runs at Condominium Creek. These runs were designed to target the conditions in spring and autumn within which prescribed burning is performed (one run each) and the conditions in summer in which wildfires occur (one run in each of moderate, high and extreme levels of fire danger). Each run started as soon as possible following the end of a significant wet period (minimum 20 mm of rain in the preceding 48 hours) and continued until the onset of the next wet period. This resulted in data collection runs lasting between three and six days. Samples were collected at two hour intervals from just after dawn until just before dusk. Each dead fuel moisture measurement consisted of the average of five sub-samples. The variability between the five sub-samples was normally of the order of four percent. Immediately following collection, the dead fuel moisture samples were sealed in two litre paint tins for drying at 80°C for 48 hours. Fuel moistures were calculated as the percentage weight of water to the dry weight of fuel.

During each of the runs performed at Condominium Creek, dead fuel and hazard stick moisture data were collected from three densities of moorland (low, medium and high density; see Table 5.1). The low and medium density sites consisted of lowland blanket moorland while the high density site consisted of layered blanket moorland. The height, cover and fuel loads of the Condominium Creek site were estimated using the methods described in Marsden-Smedley and Catchpole (1995a), Marsden-Smedley (1993a) and Chapter 4.

Regression modelling was used to develop equations to predict dead fuel moisture. Prior to being used, the dead fuel moisture data were log transformed in order to stabilise the variance in the data. In addition, several published dead fuel moisture models were tested for their ability to predict dead fuel moistures in Tasmanian buttongrass moorlands to see whether they could provide better predictions than the regression models.

Table 5.1. Heights, covers and fuel loads of sites sampled for measuring dead fuel moistures at Condominium Creek.

Density	Community type	Height m	Cover %	Fuel load t ha^{-1}
low	blanket moorland	0.3	30	6
medium	blanket moorland	0.4	60	8
high	layered blanket moorland	1.0	100	20

Note: community types follow Jarman et al. (1988).

5.2.2 Weather data collection

Screen-level dry bulb temperatures, relative humidities and surface wind speeds (measured at 1.7 m; see Marsden-Smedley and Catchpole 1995b; Marsden-Smedley 1993a) were recorded at five minute intervals throughout each of the sampling runs using an automatic weather station. Dew point temperature was estimated from the relative humidity and temperature. Solar radiation was predicted using the model of Nunez (1983). This solar radiation prediction model utilises cloud cover at three levels (low, medium and high altitude), slope, aspect, latitude, longitude, time of day and day of the year to predict the radiation expected at ground level. At each of the times in which samples were collected, wet and dry bulb temperatures were also measured at screen level using a hand-held whirling psychrometer, and fuel particle temperatures were estimated using a Barnes 14-220-1 infra-red thermometer.

5.2.3 Hazard stick data collection

Preliminary testing had shown that buttongrass moorland dead fuel moistures had much faster response times than the standard hazard stick arrays utilised in Tasmanian eucalypt forests (i.e. arrays containing three 12.5 mm sticks with a total dry weight of 100 g; see Eron 1991). Shade cloth bags containing 100 g of either *Pinus radiata* veneer or dead buttongrass leaves were also tested for use as potential surrogates. Each bag was about 30 by 40 by 1 cm in size and was made up using shade cloth which had a ratiug of 50%. These bags, however, greatly reduced the absorption of overnight dew and during the day, absorbed large amounts solar radiation. This resulted in moisture contents that did not reflect those in the surrounding buttongrass moorland. Thus hazard stick arrays were constructed specifically for use in buttongrass moorlands.

Each buttongrass moorland hazard stick array was made up using five sticks of *Pinus radiata* each 6 mm in cross section by about 400 mm long. The dry weight of wood in each hazard stick array was 50 g. In the field, each hazard stick array was suspended on a wire rack about 100 mm above the ground surface.

At each of the time periods and in each of the moorland densities in which samples were collected at Condominium Creek, the weights of five hazard stick arrays were also recorded.

5.2.4 Effect of variation in aspect on dead fuel moisture

The dead fuel moistures on sites with different aspects (i.e. northwest, northeast, southwest and southeast) were measured on a small steep-sided hill (average slope 29°) about 500 metres north of the Condominium Creek site. Samples were collected in sites with different aspects once per day at 13:00 hours except during the third summer run when the different aspects were not sampled. The fuel array characteristics of the sites used to assess the effects of aspect were equivalent to the low density site at Condominium Creek.

5.2.5 Dead fuel moisture model test data.

The dead fuel moisture models developed from the run data were tested using data from the fire behaviour section of this project. This data consisted of single observations rather than run data but the fuel moistures were collected using the same methods outlined in this thesis (Marsden-Smedley and Catchpole 1995b; Marsden-Smedley 1993a). The measurements of fuel moisture were made immediately prior to the fire behaviour measurements.

5.3 Results

5.3.1 Data summary

Preliminary analysis of the data indicated that fuel moistures collected within six hours of greater than 1.5 mm of rain or within two hours of dawn (i.e. affected by overnight dew fall) had poor correlations with temperature and humidity. This rain and/or dew affected data normally had dead fuel moistures of greater than

35% (i.e. greater than the fibre saturation point; see Viney 1991). A decision was made to exclude all of these data from the preliminary regression modelling utilising weather parameters and from the testing of the published dead fuel moisture prediction models. An attempt was also made to generate a dead fuel moisture model from the hazard stick data. Since the hazard stick model was intended to incorporate the effects of recent rain and/or dew fall, all of the data (i.e. including dead fuel moistures of greater than 35%) were used for this purpose.

Minor but not significant ($p = 0.319$) variation in dead fuel moisture was observed between the different densities of moorland sampled (Figure 5.1; Table 5.1). As a result, the data collected from different densities of moorland were averaged to give a single dead fuel moisture value for each time period.

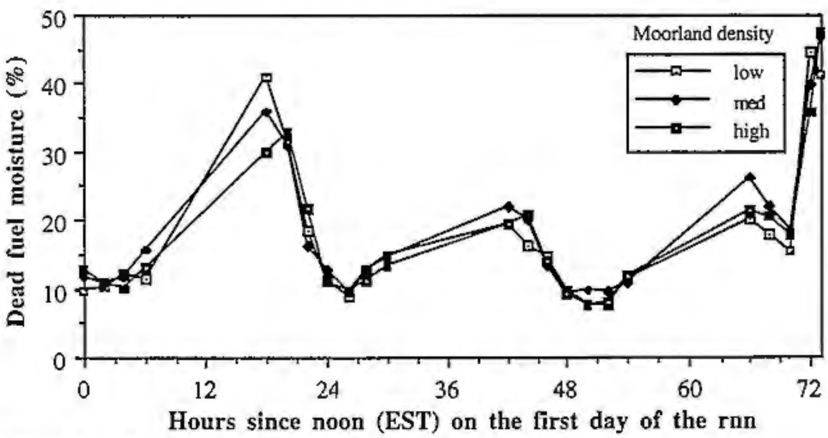


Figure 5.1. Effect of moorland density on dead fuel moisture.
Note: data for the second summer run shown; 0.4 mm of rain fell in the last 2 hours of the run; see Table 5.1 for the community types, heights, covers and fuel loads associated with the different moorland densities.

Table 5.2 shows the range of the dead fuel moisture modelling data. The linear correlation coefficients for the non-rain and/or dew affected data collected at Condominium Creek are shown in Table 5.3. The data used for modelling dead fuel moistures in buttongrass moorlands are in Appendix 1.

The effect of aspect on the non-rain and/or dew affected dead fuel moisture data collected at Condominium Creek was not significant ($p = 0.401$). This lack of significance may be due to the high solar angles during the measurement period (i.e. 13:00 hours eastern Australian standard time). Minor variation of about 2% was, however, observed between the different aspects.

Table 5.2. Dead fuel moisture data range.

	Condominium Creek data										Fire behaviour data			
	All data					Non-rain/dew affected					Non-rain/dew affected			
	Temp °C	RH %	Dew °C	Mf %	Stick %	Temp °C	RH %	Dew °C	Mf %	Stick %	Temp °C	RH %	Dew °C	Mf %
average	16.9	70.9	10.8	31.2	11.4	20.7	60.8	12.2	15.0	7.5	15.1	62.4	8.3	18.4
min	6.1	24.6	4.1	6.3	2.5	10.3	24.6	4.1	6.3	2.5	4.3	32.0	4.0	8.2
max	34.4	100.0	19.1	176.3	37.5	34.4	99.0	19.1	31.7	19.5	27.5	94.0	13.8	34.3

Note: RH = relative humidity; Dew = dew point temperature; Mf = dead fuel moisture; Stick = hazard stick moisture.

Table 5.3. Linear correlation coefficients (R) between the non-rain or dew affected dead fuel moisture modelling variables.

	Temperature	RH	Dew	Radiation	Stick	Mf
Temperature	1.00					
RH	-0.81	1.00				
Dew	0.54	0.10	1.00			
Radiation	0.39	-0.40	0.22	1.00		
Stick	-0.77	0.55	-0.52	-0.17	1.00	
Mf	-0.77	0.80	-0.28	-0.40	0.86	1.00

Note: Data collected at Condominium Creek; Temperature = dry bulb temperature; RH = relative humidity; Dew = dew point temperature; Radiation = solar radiation corrected for the effects of cloud cover; Stick = hazard stick moisture; Mf = dead fuel moisture; non-rain and/or dew affected data only.

5.3.2 Dead fuel moisture response times

The response time of dead fuel moisture in buttongrass moorlands has been examined by Catchpole et al. (in press) who found it to be about 1.9 hours. The effect of the fuel's response time is reflected in the slightly improved model fits which are obtained when time lag is added to the model (i.e. when using weather parameters measured prior to the time at which the fuel moisture was sampled). As only minor improvement is obtained when time lag is used (see Catchpole et al. in press) and since the time period between fuel moisture sampling times was greater than the response time, the dead fuel moistures sampled in different time periods were treated as independent data points and analysed using normal analysis of variance techniques.

5.3.3 Dead fuel moisture modelling using weather data

Three model forms were used for examining the effect of variation in weather data on dead fuel moistures. These model forms were a linear regression model, a model of the form given by van Wagner (1972) and a model of the form given by Nelson (1984). The models given by van Wagner (1972) and Nelson (1984) were both equilibrium moisture content models (see also Viney 1991).

In the linear regression modelling the best fit to the data was obtained using relative humidity and dew point temperature. This model had a R^2 of 0.83. The model form was:

$$Mf_{dead} = \exp(a + b * \text{relative humidity} - c * \text{dew point temperature}) \tag{5.1}$$

The data were examined to see whether the effects of absorption versus desorption and the effect of season were significant. Once the effects of relative humidity and dew point temperature had been accounted for, the effect of absorption versus desorption was not significant ($p = 0.733$) while the effect of the season was significant ($p = 0.018$). However, season only accounted for about four percent of the variation in the data. Since for operational fire management the main requirement is for a robust model applicable under a wide range of conditions, it was decided exclude season from the dead fuel moisture model.

The equation in the form of van Wagner's (1972) model utilises relative humidity and temperature and has the advantage that at high relative humidities it predicts similar dead fuel moisture values over a wide range of temperatures. This model was fitted with a log transformation using the transform both sides approach (Carroll and Ruppert 1988). The form of the model is shown below:

$$Mf_{dead} = a * RH^b + c * \exp((RH - 100)/10) + d * (21.1 - \text{temperature}) * (1 - \exp(-0.115 * RH)) \tag{5.2}$$

Nelson's (1984) equilibrium moisture content model is a semi-physical model based on the relationship between Gibbs free energy and the fuel particle's moisture content. This model was originally developed to model fuel moistures over a range of relative humidities at constant temperature and its applicability over a range in temperatures was tested by Anderson (1990). A major problem with Nelson's (1984) model is that at 100% RH (a common situation in Tasmanian buttongrass moorlands) the model predicts infinitely large dead fuel moistures. Therefore, Nelson (1984) must not be used when the RH is above 99%.

For Nelson's (1984) model, fuel-specific parameters were estimated for buttongrass moorland fuels from the data collected at Condominium Creek (Equation 5.3). The model was fitted to the data and the parameters estimated using the equation:

$$Mf_{dead} = a + b * \log \Delta G \tag{5.3}$$

where ΔG is the change in Gibbs function of the absorbed water with changes in temperature and relative humidity. The model was fitted using screen-level temperatures and relative humidities as no reliable estimates of fuel particle temperature and relative humidity were available (see subsequent section regarding fuel particle temperature and relative humidity). This model was also fitted using the transform both sides approach (Carroll and Ruppert 1988). When using Nelson's (1984) model in this way, the parameters a and b are not functions of temperature, but are averages of the parameters that would be obtained as temperature varies. Since the variation in a and b with variation in temperature is small (Anderson 1990), this approach seems reasonable. In Nelson (1984) the estimates for wiregrass desorption at a temperature of 26.7° C (i.e. a = 0.3364 and b = -0.0720) are very similar to the estimates for buttongrass moorland (see Table 5.4).

The parameters and their standard errors for Equations 5.1 to 5.3 are given in Table 5.4 and the observed and predicted values are plotted in Figure 5.2. Equations 5.1 to 5.3 give reasonable predictions when dead fuel moistures are below about 25%, but tend to sligbtly under-predict at higher moisture contents. Equations 5.1 to 5.3 gave reasonable dead fuel moisture predictions for the fire data used to test the models (Figures 5.2a to 5.2c).

5.3.4 Dead fuel moisture modelling using hazard stick data

All of the data collected at Condominium Creek (i.e. including the rain affected data) were used to examine the relationship between hazard stick moisture and dead fuel moisture. In this analysis there were highly significant seasonal effects ($p < 0.001$). The effect of season was, however, ignored due to the requirement of having a model applicable to all seasons for operational fire management.

The form of the model utilising the hazard stick data is shown in Equation 5.4. The parameters of the hazard stick model are in Table 5.4.

$$Mf_{dead} = a * (Mf_{stick})^b \tag{5.4}$$

The hazard stick model had an R^2 of 0.723. The predictions from the hazard stick model are shown in Figure 5.2d. As can be seen, the hazard stick model failed to provide good predictions, especially at higher fuel moistures.

Table 5.4. Parameters of the dead fuel moisture models developed for buttongrass moorlands.

	Equation 5.1 RH and dew point temperature		Equation 5.2 temperature and relative humidity		Equation 5.3 temperature and relative humidity		Equation 5.4 hazard stick, all data	
	Estimate	Std err	Estimate	Std err	Estimate	Std err	Estimate	Std err
a	1.660	0.116	1.796	0.985	0.338	0.0187	2.278	0.353
b	0.0214	0.0014	0.489	0.136	-0.0723	0.00585	1.024	0.0669
c	0.0292	0.0062	17.380	6.955				
d			0.298	0.083				

Note: Estimate = parameter estimate; std er = standard error; temperature = °C; relative humidity = %; dew point temperature = °C; dead fuel moisture = %; hazard stick moisture = %.

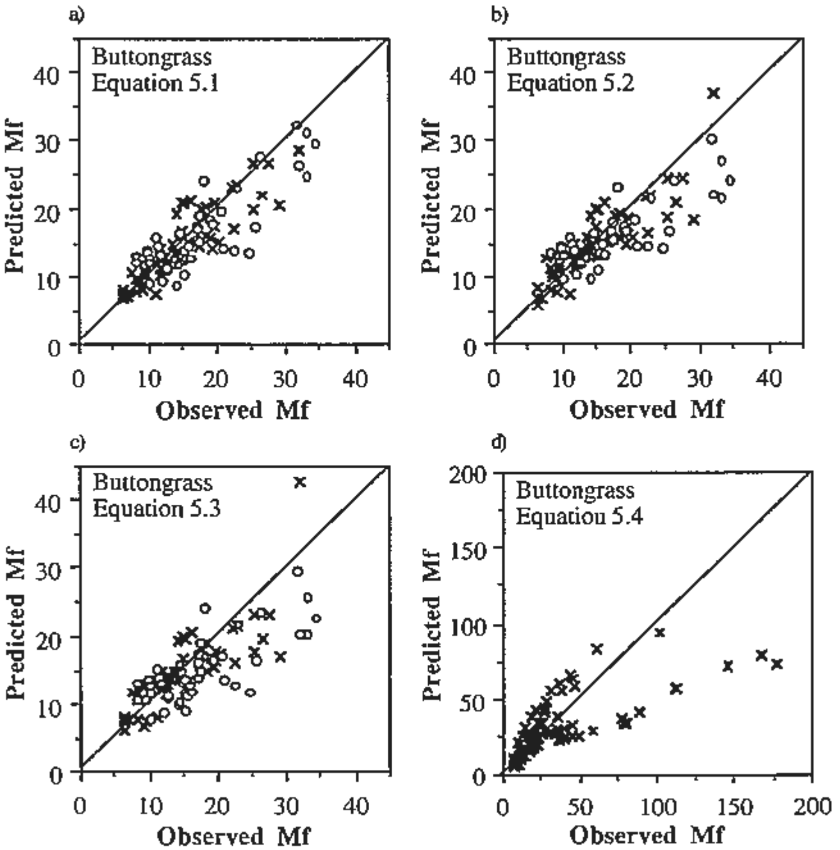


Figure 5.2. Predicted versus observed dead fuel moistures from Equations 5.1 to 5.4. Note: model = model development data; test = model test data, see below; Mf = dead fuel moisture, %.

5.3.5 Published fuel moisture prediction models examined

The fuel moisture data collected from both the buttongrass moorland fire behaviour research project (Marsden-Smedley and Catchpole 1995b) and from Condominium Creek were used to test the published dead fuel moisture models. Eight published models were examined for their potential to predict dead fuel moistures in buttongrass moorlands (Table 5.5). These models included five vapour pressure models and three equilibrium moisture content models. The version of the McArthur (1962) eucalypt litter moisture model modified by Gill et al. (1987) was used. With the exception of the aerial pine fuel model of Pook and Gill (1993), equation parameters for all models were obtained from Viney (1991). Where models had available parameters for more than one fuel type, only the model which gave the best predictions is shown in this thesis. The predictions from the different models examined are in Figure 5.3.

Table 5.5. Published dead fuel moisture models examined.

Reference	Model type	Fuel type
McArthur (1962), Gill et al. (1987)	vapour pressure	eucalypt litter
McArthur (1966)	vapour pressure	grass
McArthur (1967)	vapour pressure	eucalypt litter
Simard (1968)	equilibrium moisture content	wood
van Wagner (1972)	equilibrium moisture content	litter
Anderson et al. (1978)	equilibrium moisture content	pine litter
Pech (1989)	vapour pressure	reindeer lichen
Pook and Gill (1993)	vapour pressure	unthinned aerial pine fuel

The applicability of using fuel particle temperature and relative humidity instead of screen-level conditions in equilibrium moisture content models was tested using the models of Byram and Jemison (1943) and van Wagner (1969) as well as the fuel particle temperatures estimated using the infra-red thermometer. The fuel particle temperature models of Byram and Jemison (1943) and van Wagner (1969) were designed for predicting fuel particle temperature and relative humidity from screen-level conditions (see Viney 1991). The wind speeds at the fuel particle level were estimated from the screen-level wind speeds using the methods of Albini and Baughman (1979). Fuel particle relative humidities were estimated from the temperature recorded by the infra-red thermometer by assnming a constant dew point temperature between the screen and fuel particle levels.

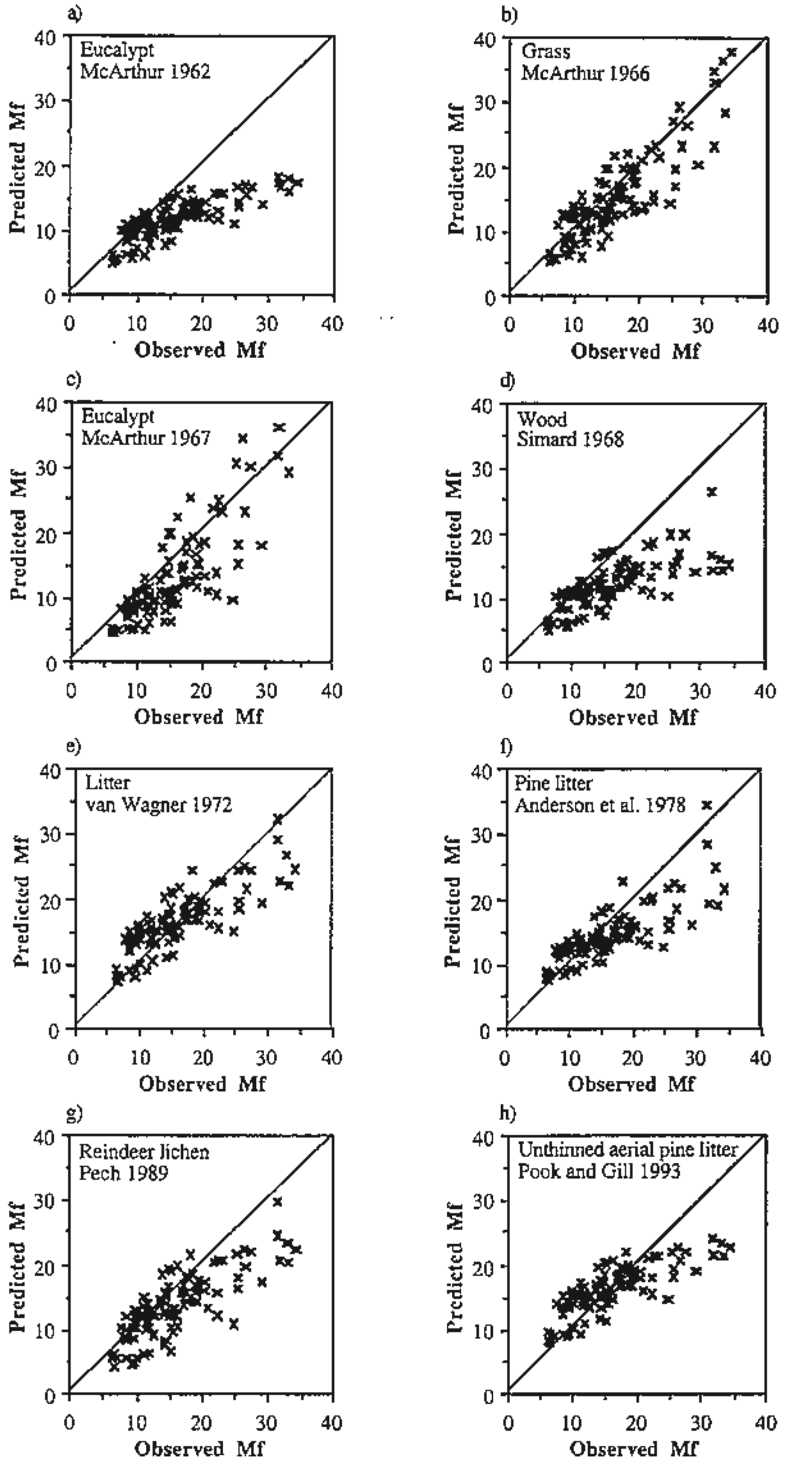


Figure 5.3. Predicted versus observed dead fuel moisture from the different published models examined. Note: Mf = dead fuel moisture, %.

In all cases better predictions of dead fuel moisture were obtained using screen-level temperature and relative humidity than were obtained using the fuel particle temperatures and relative humidities estimated from the infra-red thermometer or predicted from Byram and Jemison (1943). The reason for this is probably related to errors in the fuel particle temperature estimates. These errors may result from inaccuracies in the infra-red thermometer measurements, the applicability of Byram and Jemison (1943) for predicting fuel particle temperature (see Viney 1991) and/or the applicability of Albini and Baughman (1979) for predicting wind speeds at the fuel particle level.

Book-keeping models such as the Canadian Fine Fuel Moisture Code (van Wagner and Pickett 1985) or the Western Australian Forest Fire Behaviour Tables (Sneeuwjagt and Peet 1985) were not tested since the diurnal range in buttongrass moorland dead fuel moisture was consistently greater than the day to day variation. This indicates that this type of model is inappropriate because of the rapid response time in buttongrass moorland fuels (Viney 1991, 1992).

5.3.6 Dead fuel moisture model evaluation

The dead fuel moisture models examined in this work were evaluated by comparing scatter plots of predicted versus observed dead fuel moistures, along with each model's normalised root-mean-square errors and bias. The formula for calculating the root-mean-square errors was obtained from Janssen and Heuberger (1995; see also Viney 1992). The root-mean-square error was normalised by dividing by the standard deviation of the observed values. This gives a more stable estimate than normalisation by the average of the observations, as in Janssen and Heuberger (1995). The error measurements described in Janssen and Heuberger (1995) give estimates of the overall error but do not indicate whether bias is present. In order to overcome this problem a smoothing spline was fitted to the predicted moisture contents, and the square root of the sum of squares of the differences between the spline and the line of perfect fit divided by the number of observations calculated (see Catchpole and Catchpole in prep.). The bias estimate was normalised by dividing by the standard deviation of the observed moisture content. The smoothing parameter for the spline was fixed at 0.001, which generally gave a smoother spline for all models than using cross-validation to estimate the smoothing parameter (see Silverman 1986). The normalised root-mean-square errors and bias estimates are given in Table 5.6.

Table 5.6. Dead fuel moisture model performance.

Model	NRMSE	Bias
buttongrass moorland, Equation 5.1, model development data	0.45	0.22
buttongrass moorland, Equation 5.2, model development data	0.51	0.33
buttongrass moorland, Equation 5.3, model development data	0.54	0.37
buttongrass moorland, hazard stick, Equation 5.4	0.68	0.59
buttongrass moorland, Equation 5.1, model test data	0.57	0.38
buttongrass moorland, Equation 5.2, model test data	0.65	0.54
buttongrass moorland, Equation 5.3, model test data	0.76	0.63
buttongrass moorland, Equation 5.1, all data	0.51	0.28
buttongrass moorland, Equation 5.2, all data	0.58	0.41
buttongrass moorland, Equation 5.3, all data	0.66	0.48
McArthur (1962), eucalypt litter	0.93	0.89
McArthur (1966), grass	0.53	0.25
McArthur (1967), eucalypt litter	0.81	0.49
Simard (1968), wood	0.94	0.87
van Wagner (1972), litter	0.59	0.44
Anderson et al. (1978), pine litter	0.67	0.55
Pech (1989), reindeer lichen	0.69	0.53
Pook and Gill (1993), unthinned aerial pine fuel	0.65	0.56

Note: NRMSE = normalised root-mean-square error; Bias = bias estimate from the smoothing spline.

5.4 Discussion

The two best models for predicting buttongrass moorland fuel moistures were the linear regression model (Equation 5.1) and the McArthur (1966) grassland model. The good performance of these two models was not unexpected since the linear regression model was designed specifically for buttongrass moorland fuels while McArthur (1966) grassland model was designed for a similar fuel type. The linear regression model has the advantage that it utilised relative humidity and dew point temperature which are normally poorly correlated, which is in contrast to McArthur (1966) grassland model which utilised relative humidity and temperature, which are normally highly correlated (e.g. see Table 5.3). The other two models generated using buttongrass moorland data (Equations 5.2 and 5.3) performed similarly to the van Wagner (1972) pine litter model. These models had higher normalised root-mean-square errors and larger bias, reflecting their tendency to under predict at higher fuel moisture contents. The Pook and Gill (1993), Pech (1989) and Anderson et al. (1978) models had higher bias than the models generated specifically for buttongrass moorland fuels (Equations 5.1 to 5.3). The moisture models designed for eucalypt fuels (McArthur 1962, 1967) and the Simard (1968) wood model badly under predicted, especially at higher moisture contents.

As discussed above, rain and/or dew-fall acts to elevate the dead fuel moisture above that expected from the effects of temperature, relative humidity and dew point temperature alone. This effect typically lasts no more than about 24 hours following significant rain events (e.g. greater than about 5 to 10 mm) and only about one to three honrs following dew falls of 0.05 to 0.4 mm. A preliminary model has been developed to predict the effect of recent rain and/or dew fall events. However, as this model is based on a limited data set, it has not been adequately tested and so will not be presented in this thesis (see Marsden-Smedley et al. 1998.).

The empirical buttongrass moorland model (Equation 5.1) should provide adequate predictions for operational fire management provided the temperature is between about 5 and 35°C, the relative humidity is above about 20% and the site is not rain and/or dew affected. Dead fuel moisture predictions will range between abont 6 to 37%. If the site has been rain and/or dew affected the model will under-predict the dead fuel moisture and should therefore be used with cantion.

Overall, the linear regression moisture content model (Equation 5.1) is recommended for predicting fuel moistnres in buttongrass moorlands. This model outperformed both of the models developed from the equilibrium moisture content models of van Wagner (1972) and Nelson (1984; Equations 5.2 and 5.3) and performs equally as well as the McArthur (1966) grassland model. However, since the linear regression model utilises relative humidity and dew point temperature (rather than relative humidity and dry bulb temperature) it should have a wider applicability than the McArthnr (1966) grassland model. The hazard sticks did not provide adequate predictions, especially of the rain and/or dew affected data, and so are not recommended.

The models presented in this chapter predict dead fuel moistures in buttongrass moorlands from easily measured weather variables. These models can be used in association with the outpnts from the fuel characteristics and fire behaviour models (Chapters 4 and 6) in the operational fire behaviour models (Chapter 7). The wider implications of this research will be discussed further in Chapter 8.

6. Fire behaviour

6.1 Background

Wildland fire behaviour is controlled by a very wide range of variables, but the major influences can be attributed to a few critical factors: wind speed, fuel characteristics (e.g. fuel moisture, fuel load and/or fuel dead to live ratio) and topography. Some of these factors may in turn be controlled by other more easily measured variables. For example, in buttongrass moorlands, fuel load is closely related to fuel age, fuel cover and geological type (see Chapter 4), while fuel moisture content is influenced by temperature, humidity and precipitation history (see Chapter 5).

Buttongrass moorland fires frequently have moderate to high rates of spread and intensity even under what are considered to be low to moderate levels of fire danger for most vegetation types. For example, in sites which have not been burnt for 20 years, rates of fire spread in excess of 10 m min^{-1} and flame heights in excess of 5 m have been observed when the temperature, relative humidity and wind speed were 18°, 50% and 12 km hr^{-1} respectively. This situation was particularly marked during the Mulcahy Bay fire of 1986. In this fire over 23 000 ha burned with maximum rates of fire spread in excess of 50 m min^{-1} when the McArthur Forest Fire Danger Meter (McArthur 1973) predicted at most moderate levels of fire danger (Blanks 1991). Most of the area burnt during the Mulcahy Bay fire was buttongrass moorland. At that time, the McArthur Forest Fire Danger Meter was the main fire behaviour prediction system utilised in Tasmania.

In addition, buttongrass moorland fires often expand more rapidly than suppression resources can be applied (Blanks 1991; Tasmanian Fire Review Committee 1994). For example, data from buttongrass moorland fires suggest that a fire burning in flat site with a head fire spread rate of 5 m min^{-1} will have an area of about 1.2 ha and a perimeter of over 0.75 km after just one hour, and an area of nearly 5 ha and a perimeter of over 1.5 km after two hours.

A fire behaviour prediction system for buttongrass moorlands could be developed in one of two ways: by modifying an existing fire behaviour model after correlating observed fire data with the predictions from the existing system, or by developing a fire behaviour prediction system specific to buttongrass moorlands. Major problems are inherent with both methods. Although there are large potential advantages in using a previously developed system, any predictions produced must be treated with a very high degree of caution because the fuel complex used to develop the model is usually different from the vegetation type under consideration. This problem could potentially be overcome by using a physical (or semi-physical) fire behaviour model. However, the performance of the available physical and/or semi-physical fire behaviour models (e.g. the US Forest Service prediction system BEHAVE, Rothermel 1972; Burgan and Rothermel 1984; Andrews 1986; Andrews and Chase 1990) is very limited, which greatly restricts their utility under operational conditions (see Section 1.3.3).

An empirical fire behaviour prediction system has the advantage of ensuring that the predictions will be specific to the locally occurring conditions, but also has the disadvantage that only a limited amount of data can be collected, reducing the degree of confidence that can be placed on the predictions. In addition, an empirical fire behaviour prediction system should be restricted to the fuel type and conditions within which it was developed until extensive verification has been performed. Provided the empirical model has a strong physical basis it should be possible to produce robust, field applicable models using this system (as was discussed in Section 1.3.3).

As a result, the main aims of this chapter are to examine the dynamics of fire behaviour in Tasmanian buttongrass moorlands. The models developed in this chapter will then be used in association with fuel characteristics and dead fuel moisture models (Chapters 4 and 5) in the fire management section (Chapter 7) of this thesis.

6.2 Methods

6.2.1 Site locations

A total of 115 buttongrass moorland head fires from 21 sites were measured. These fire data were obtained from four sources: research burns (40 fires), hazard-reduction burns (35 fires), test fires (35 fires) and wildfires (five fires). Although the data collection concentrated on head fires, where possible data were also collected for flank and back fires. The fire behaviour data are in Appendix 6.

Research burns were lit, measured and extinguished for the sole purpose of obtaining fire behaviour data. Hazard-reduction burns in buttongrass moorlands were prescribed fires lit for the purpose of modifying the fuel array characteristics in order to reduce the intensity of wildfires. Test fires were fires lit under high dead fuel moisture and/or low wind speed conditions in order to determine whether the fire would sustain or not. Wildfires were unplanned fires measured while burning out of control.

6.2.2 Fuel loads

In Tasmanian buttongrass moorlands, the average fuel particle diameter is about 1.5 mm with typically greater than 90% of the vegetation having a diameter of less than six millimetres. The total fuel load thus is a good estimate of the fine fuel load. The fuel load present at a site can be predicted using the site age and vegetation cover or more conveniently (but less precisely) from age alone using Equations 4.2 or 4.3.

For all of the fire research burns, and the hazard-reduction burns located in the Lyell Highway blocks P4 and P9, fuel loads and percentages of dead fuel were measured prior to the burn. For all of the other fires fuel loads and percentages of dead fuel were estimated using Equation 4.2. In sites where fuel loads were measured, data were collected from either five or ten 2 by 2 metre plots located on randomly oriented transects. All the material collected was dried at 80°C until constant weights were obtained. See section 4.2.3 for the full fuel data collection methodology.

6.2.3 Fuel moisture

Fuel moisture contents were calculated from two live fuel and five dead fuel samples collected from random locations within the area to be burnt immediately prior to the fire. The fuel samples were sealed into two litre tins in the field and were dried at 80°C for a minimum of 48 hours. Live and dead fuel moisture contents were estimated as percentages of the dry weights.

6.2.4 Fuel heat content

Fuel heat content is required to estimate fire intensity. This was calculated using the methods given in Alexander (1982) by modifying the heat content for the losses due to evaporating the fuel moisture (see Equation 6.2). Heat contents for moorland species are given in Marsden-Smedley (1993a) and Marsden-Smedley and Catchpole (1995b).

6.2.5 Meteorological data

During fire research burns data for temperature, relative humidity, wind direction and wind speed (10 m and surface) were collected using an automatic weather station. The weather station was located within 250 m, and either parallel to or upwind of the block being burnt. Weather data were averaged over a one minute period for all fires except for McPartlan Pass research block 16 where the weather data were averaged over a three minute period. For all of the fire research burns weather data were collected for a minimum of two hours prior to the fire being measured.

The surface wind speed was the wind measured at 1.7 m above the ground. The height 1.7 m above the ground surface was used because this height is the one most applicable to operational fire management, where wind speeds are normally measured using hand held sensors. When hand held sensors are used the most common methodology used is to hold the sensor at arm's length, which for most practitioners approximates 1.7 m above the ground surface.

During hazard-reduction burns and wildfires, data for temperature, relative humidity, wind direction and surface wind speed at 1.7 m were collected using hand-held sensors.

6.2.6 Burning block design, fire ignition and control

For research burns, all blocks were flat, square and either 0.25 or 1 ha (i.e. 50 or 100 m fireline lengths). All of the hazard-reduction burns had fireline lengths in excess of 100 m while all of the wildfires had fireline lengths in excess of 500 m.

The research burn blocks were delineated by slashing strips approximately two metres wide (e.g. see Figure 6.1). These strips were ineffective in controlling moderate intensity fires (i.e. when the rates of fire spread were greater than 5 m min^{-1}), and for these fires a strip approximately 10 m wide was burnt along the downwind edge of the block. Hose lines were set up around each block and four to seven people were used to extinguish the fires once they reached the control strips.

Figure 6.1. McPartlan Pass fire research burning site. Photograph taken from the Sentinel Range, looking north in January 1992, about half way through the research burning program at this site.

Drip-torches were used to light a line of fire along the whole of the upwind edge of the block starting at the block corners. Collection of fire behaviour data started when the whole of the upwind edge of the block was burning (approximately 30 seconds from the start of the ignition period).

6.2.7 Rates of fire spread and flame heights

Due to containment concerns the fires measured in this project were burned under a limited range of weather conditions and had correspondingly limited levels of fire behaviour. Data were also available from two high intensity wildfires, the Birchs Inlet fire of 1985 and the Mulcahy Bay fire of 1986, which burned at much higher wind speeds and had much higher rates of fire spread (see Blanks 1991).

Two methods were used for determining rates of fire spread. On research burns, rates of spread were determined by timing when the fire front reached predetermined reference points. On all other fires, the location of the fire front was recorded at different times and the distance the fire front had travelled in each time interval was measured. Rates of fire spread for high intensity wildfires were measured over a fire run of greater than nine kilometres.

On all fires the head fire data were used only if meteorological conditions were constant (e.g. if there were no significant changes in wind direction and speed) and after the fire had reached its quasi-steady state. The quasi-steady state was normally reached one to three minutes after the start of the ignition period.

On all of the fire research burns measurements of fire behaviour were made by averaging the results of two observers, one on each side of the fire. For each fire, five to 15 data points were collected over a five to 60 minute period (depending on rate of spread and block size). On all of the fires measured, very little variation occurred between the data collected by different observers. On all other fires, a single observer was used. The variation in spread rate at different times within a fire was typically less than 20%. Notes were also made about the shape of the fireline. Average rates of fire spread were calculated for all fires by dividing the distance the fire front had travelled in the time of quasi-steady state conditions. Only the average spread rate was used in the analysis of the fire data, since it was not possible to get good correlations between the fire behaviour in each time interval and the wind speed measured at the meteorological station.

The characteristics of the flaming zone were measured using the methods advocated by Alexander (1982; see also Gill and Knight 1988). Ocular estimates were made of the height from the ground surface to the top of the flaming zone, the angle of an imaginary line from the flame tip to the ground at the mid point of the flaming zone, and the horizontal depth of the flaming zone. The flame height was the vertical height of the flaming zone above the top of the fuel array, the flame length was the distance between the flame tip and the top of the vegetation at the mid point of the flames, and the flame depth was the distance along the ground surface of the flaming zone. Estimates were made to the nearest half metre for flames up to four metres high and/or deep, beyond which estimates were made to the nearest metre. Angles were estimated to the nearest 15°, with vertical flames being recorded as 90°. The flame height, flame length and angle data were checked whenever possible using photographs and videos (Figures 6.2 and 6.3).

6.2.8 Fuel consumption

For all fires, estimates were made of the amount of fuel left unburnt throughout the block.

Figure 6.2. Measuring low intensity fire behaviour on fire KgrRb1.

Figure 6.3. Measuring the rate of fire spread on fire RbyWf1.4.

6.3 Results

6.3.1 Published fire behaviour models

Seven models were examined for their potential to predict rate of fire spread, and four models for their potential to predict flame dimensions (Table 6.1).

Table 6.1. Fire behaviour models examined.

Model	Reference
Rate of fire spread models	
McArthur Forest Fire Danger Meter Mark 5	McArthur (1973), see Noble et al. (1980)
McArthur Grassland Fire Danger Meter Mark 3	McArthur (1966), see Noble et al. (1980)
McArthur Grassland Fire Danger Meter Mark 5	McArthur (1977), see Noble et al. (1980)
Rothermel fire behaviour model	Rothermel (1972), Wilson (1990)
Thomas' heather and gorse rate of spread model	Thomas (1970, 1971)
Guidelines for prescribed burning	Forestry Commission (1977, updated)
Prescriptions for burning buttongrass moorlands	Gellie (1980)
Flame dimension models	
McArthur Forest Fire Danger Meter Mk 5	McArthur (1973), see Noble et al. (1980)
Albini's flame height model	Albini (1981), Nelson and Adkins (1986)
Byram's flame length model	Byram (1959)
Thomas' flame length model	Thomas (1963)

Note: see Section 6.3.1 for a discussion on the different fire behaviour models

The 'guidelines for prescribed burning' (Forestry Commission 1977) and the 'prescriptions for burning buttongrass moorlands' (Gellie 1980) were developed by Forestry Tasmania to indicate the range of weather conditions suitable for conducting prescribed burning. The 'guidelines for prescribed burning' were subsequently informally updated by reducing the allowable wind speed for prescribed burning from 15 to 10 km hr^{-1}. In order to avoid confusion, the modified guidelines for prescribed burning in Tasmanian buttongrass moorlands are referred to as Forestry Commission (1977, updated).

The McArthur Forest Fire Danger Meter was originally developed for litter fuels in dry sclerophyll forest on the southern tablelands of New South Wales and the Australian Capital Territory, and is widely used in both wet and dry sclerophyll forest in Tasmania. The McArthur Grassland Fire Danger Meters are not generally used in Tasmania, but since buttongrass has a structure comparable to grassland it was thought worthwhile to compare the predictions from the grassland meters with the observed spread rates. The equations for rate of spread and flame length for the McArthur Fire Danger Meters were obtained from Noble et al. (1980).

The inputs for the McArthur Grassland Mark 3 and 5 meters are wind speed (10 m), temperature, relative humidity, curing (i.e. percentage of dead fuel), and in the Mark 5 meter only, fuel load. The McArthur forest meter requires as inputs wind speed (10 m), temperature, relative humidity, fuel load, slope, and a drought factor derived from the Keetch-Byram drought index (Keetch and Byram 1968) along with the recent rainfall history.

The Rothermel Fire Behaviour Model (Rothermel 1972) is a hybrid physical-empirical model intended for use in all fuel types. The inputs required are thus generally quite complex, but simplify for vegetation such as buttongrass moorland that consists mainly of fine fuel. The environmental variables needed are the wind speed at half-flame height, slope and live and dead fuel moisture content. The fuel array is described by depth, load, percentage of dead fuel, moisture of extinction, heat content, surface area to volume ratio, mineral content, silica content and particle density. With the exception of moisture of extinction, fuel array values applicable to buttongrass moorlands are in Chapter 4 and/or in Marsden-Smedley (1993a) and Marsden-Smedley and Catchpole (1995b). The moisture of extinction was determined from the non-sustaining research burns and test fires. The equations for the Rothermel Fire Behaviour Model were obtained from Wilson (1980) while the limatitions of the Rothermel Fire Behaviour Model were discussed in Section 1.3.3.

The heather and gorse fire spread and flame length models were developed in England by Thomas (1963, 1970, 1971) to enable fire management to be performed in heather and gorse moorlands adjacent to production forests. Since the structure of some English and Tasmanian moorlands is superficially similar, it seemed reasonable to test these fire behaviour models. Thomas (1971) was constructed for very homogeneous fuels and predicts rate of spread in terms of the bulk density of the fuel consumed and the wind speed. An earlier version (Thomas 1970) incorporated the average moisture content of the entire fuel array, but the later version assumed the average moisture content of the live fuel was 100%.

Byram's flame length model (Byram 1959) was developed to predict flame lengths in southern USA conifer forests, but it has been extensively used in other situations, for example, BEHAVE (Andrews 1986). Like Thomas' flame length model it predicts flame length as a function of Byram's intensity (Byram 1959; Thomas 1963).

Albini's flame height model (Albini 1981) is a theoretical model based on conservation of mass and energy principles, and potentially could apply to any free-burning fire in medium to high wind speeds. This model was used in its approximate form (see Nelson and Adkins 1986) where flame length is predicted as a function of Byram's intensity and surface wind speed.

McArthur's flame height model (McArthur 1973) is an empirical model predicting flame height as a function of spread rate and fuel load.

Most models for flame dimensions require an estimate of Byram's intensity I_B (Equation 6.1; Byram 1959), which can be calculated as:

$$I_B = (h_{corr} * w_a * R)/600 \qquad (6.1)$$

where h_{corr} is the heat yield (the heat content adjusted for losses), w_a is the available fuel, and R is the rate of spread (Brown and Davis 1973). The heat content was corrected using Equation 6.2 which follows the formula given in Alexander (1982):

$$h_{corr} = h - 1263 - (24 * Mf_{dead}) \qquad (6.2)$$

where h is the heat content (taken as 19 900 kJ/kg for buttongrass moorland fuel; see Marsden-Smedley 1993a). The units and parameters for Equations 6.1 and 6.2 are given in Table 6.4. No corrections were made for radiation losses on the grounds that radiation losses can not properly be estimated without instrumentation.

As most of the fuel in buttongrass moorlands is fine fuel, the total fuel load from either Equation 4.2 or 4.3 along with the percentage of the fuel load consumed in the fire can be used to estimate w_a in Equation 6.1.

All of the fire data with the exception of the test fires (see Appendix 6) were used to examine the fit of the models in Table 6.1. For prediction and modelling purposes the spread rates for the two fires that were on slopes were adjusted using the slope factor in the McArthur Forest Meter (see Noble et al. 1980).

The McArthur Forest Fire Danger Meter and the McArthur Grassland Fire Danger Meter Mark 3 badly under-predicted fire behaviour in buttongrass moorlands (see Figures 6.4a and 6.4b). The McArthur Grassland Fire Danger Meter Mark 5 predicted zero spread rates under all conditions since the percentage of dead fuel (used to estimate 'curing') was less than 50% in all cases.

Thomas' gorse and heather model did not predict spread rates very well. Although the low to medium intensity predictions were of the right order, there was considerable scatter between the observed and predicted values. The high intensity fires were predicted very poorly (see Figure 6.4c).

In the Rothermel model, the moisture of extinction was set to 70%, which was the value above which the fires would not propagate in buttongrass moorlands (see Figure 6.5). Even so, the model predicted that the live fuel would not burn in a third of fires. This is not consistent with the fire data, where in all but the most marginal fires (i.e. fires 19, 20, 23 and 24, see Appendix 6) the live fuel burned in the fire front. Although the observed and predicted data were correlated (see Figure 6.4d), the Rothermel model under-predicted by about 20% on average.

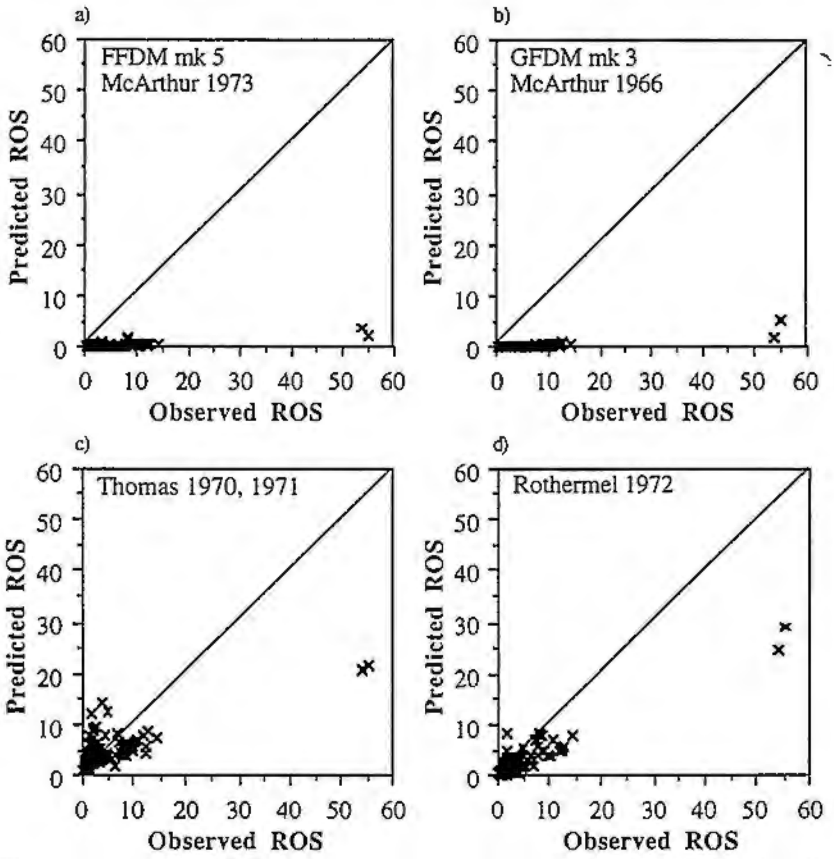


Figure 6.4. Predicted versus observed rates of fire spread from the fire behaviour models tested. Note: ROS = rate of fire spread, m min^{-1}; observed fire behaviour data in Appendix 6.

While it is probable that adjustment of the fuel parameters along the lines suggested by Burgan and Rothermel (1984) could result in better predictions, this was not attempted since the model has been shown to be over-sensitive to changes in fuel depth in grasslands (Gould 1991), and because of problems in predicting when live fuel will burn. In addition, by their nature, such 'adjustments' to a model's parameters are going to be highly subjective and will almost certainly influence other aspects of the model's relationships. As a result extreme caution should be taken when performing adjustments to a model's parameters and should only be performed in association with extensive model testing and re-evaluation (see also Section 1.3.3).

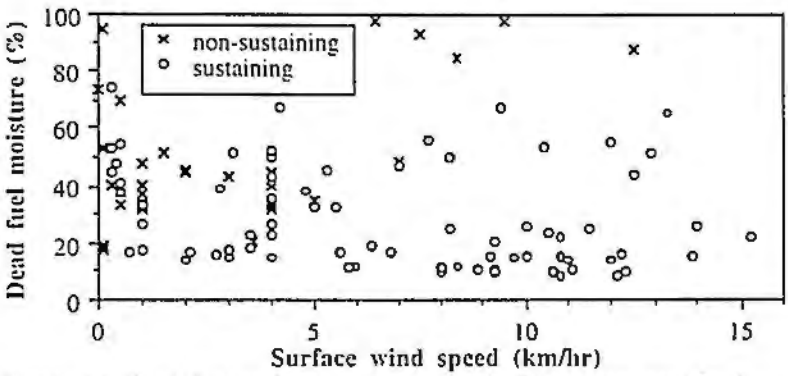


Figure 6.5. Dead fuel moisture of extinction in buttongrass moorlands.

The McArthur Forest Fire Danger Meter under-predicted flame heights badly (Figure 6.6a). An attempt was made to improve the flame height predictions by using the observed rates of fire spread instead of the rates of spread predicted by the model, but in this situation the flame height model under-predicted the flame heights for low intensity fires and over-predicted the flame heights for the higher intensity fires.

Albini's flame height model provided predictions of the right order, but there was considerable scatter between the observed and predicted values (Figure 6.6b).

Byram's flame length model under-predicted, although there were strong correlations between the observed and fitted values (Figure 6.6c). Thomas' flame length model gave good predictions, with the exception of the three highest intensity fires (Figure 6.6d).

The previously published prescriptions (Forestry Commission 1977, updated; Gellie 1980) for burning buttongrass moorlands worked well for the young moorlands (i.e. eight years or less since the last fire) but poorly in older moorlands. In young moorlands all of the fires which were burnt under conditions which were within the published prescriptions had rates of fire spread and flame heights which were within the limits for prescribed burning. That is, when the moorland age was eight years or less, the wind speed was below 10 km hr^{-1}, temperature was below 20° C and relative humidity was between 40 and 60%, the rate of fire spread was less than 2 m min^{-1} and flame height was less than 3 m. In contrast under the same weather conditions, about 70% of the fires in moorlands older than eight years since the previous fire had levels of fire behaviour higher than those recommended for prescribed burning (Table 6.2).

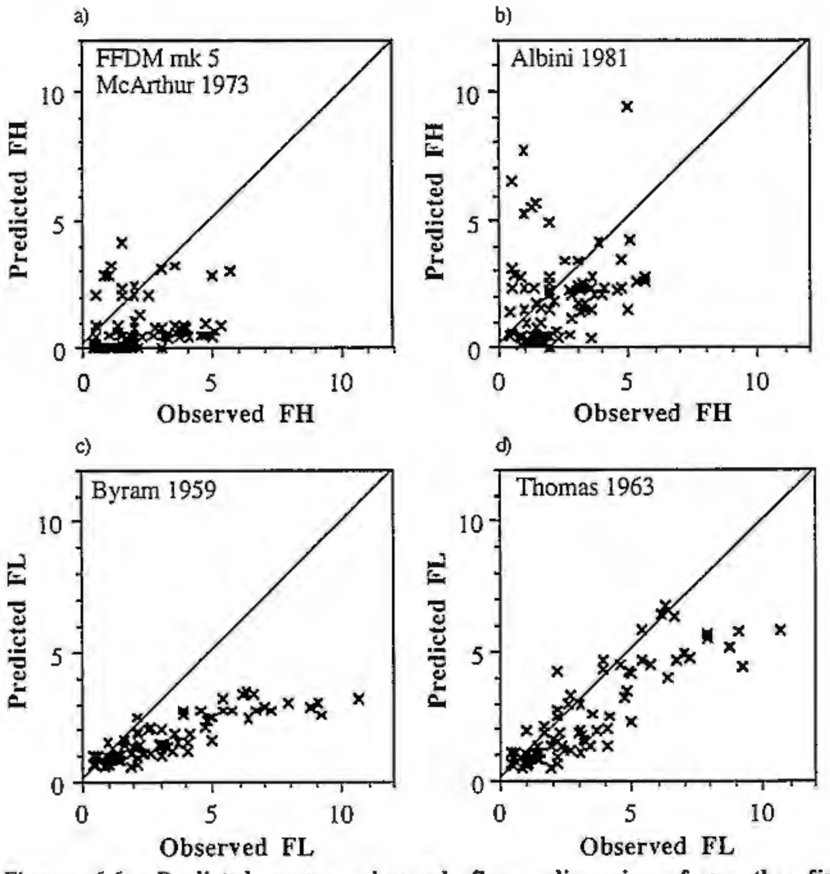


Figure 6.6. Predicted versus observed flame dimension from the fire behaviour models tested. Note: FH = flame height (F_H), m; FL = flame length (F_L), m.

The failure of the prescriptions for burning older buttongrass moorlands is probably because the prescriptions were developed in younger moorlands.

Forestry Tasmania formulated the prescriptions as part of their fuel reduction burning program, in which burns are normally performed at five to eight year intervals, and the prescriptions best reflect fire behaviour under these conditions.

Table 6.2. Rates of fire spread and flame heights of buttongrass moorland fires which were burnt within the prescriptions of Forestry Commission (1977, updated) and Gellie (1980).

	All sites				≤8 year old sites				>8 year old sites			
	n	Mean	Min	Max	n	Mean	Min	Max	n	Mean	Min	Max
ROS	28	3.3	0.5	12.4	9	1.7	0.8	3.1	19	4.1	0.5	12.4
F_H	28	2.2	0.5	5.0	9	1.1	0.5	2.7	19	2.8	1.1	5.0

Note: n = number of fires; ROS = rate of spread, m min^{-1}; F_H = flame height, m; recommended prescriptions are wind speed below 10 km hr^{-1}, temperature below 20° C and relative humidity between 40 and 60%.

With the exception of Thomas' (1963) flame length model, none of the pre-existing flame models gave satisfactory predictions in buttongrass moorlands (Figure 6.6). For operational fire management flame dimension models give a good indication of fire suppression difficulty, with flame height being a more relevant estimate than flame length. This is mainly because field staff can more easily understand and utilise estimates of flame height than flame length.

As a result of the poor performance of the published fire spread and flame height models in buttongrass moorlands, specific models for predicting fire behaviour in Tasmanian buttongrass moorland were developed.

6.3.2 Buttongrass moorland rate of fire spread model

All of the fire behaviour data for sustaining fires and fires for which there was head fire data were used for model development and testing. A total of 45 sustaining head fires were used for model development. This data consisted of all of the data from the fire research burns, the Lyell P4 and Lyell P9 hazard-reduction burns and two high intensity wildfires (see Appendix 6). The remaining 35 sustaining head fires were used to test the fire behaviour models. The fire behaviour modelling data range is shown in Table 6.3.

The data were also available for an additional 35 fires which did not sustain. These fires were used to determine the dead fuel moisture of extinction and the conditions under which fires will self-extinguish.

Table 6.3. Fire behaviour modelling data range.

	Fuel load t ha^{-1}	Dead load t ha^{-1}	Site age years	Mf_{dead} %	RH %	Temperature dry bulb °C	Temperature dew °C	Wind speed km hr^{-1}	ROS m min^{-1}	F_H m
average	9.8	3.6	15.9	32.1	58.2	15.8	5.8	9.6	6.6	2.4
min	4.3	1.0	4	8.2	30.0	7.1	-3.3	0.7	0.0	0.1
max	15.1	7.2	25	97.9	96.0	27.5	14.4	36.0	55.0	5.6

Note: Mf_{dead} = dead fuel moisture; RH = relative humidity; ROS = rate of fire spread; F_H = flame height.

A reasonable assumption for fire behaviour data is that variation in spread rate increases with the mean spread rate, suggesting the use of a logarithmic transformation in the analysis. The experimental and low intensity wildfire data were initially analysed using a logarithmic transformation in order to determine the principal variables affecting spread rate. The high intensity wildfire data were not included in this initial analysis due to the large influence they had on the estimated effect of wind speed on spread rate. About 73% of the variation in fire spread could be explained by wind speed, age and dead fuel moisture content. After the effects of these variables had been accounted for, there was no significant variation in spread rate that could be attributed to differences in fireline length ($p = 0.26$) and thus this variable was not used in the analysis. Whether there is any effect of fireline length at the magnitude reached by the high intensity wildfires is a matter of conjecture.

Live fuel moisture content had no significant effect on spread rate. The lack of any correlation between live fuel moisture and rate of fire spread was not unexpected since live fuel moisture content has been shown to be uncorrelated with weather conditions in western and southwestern Tasmania (Chapter 5; Appendix 6; Marsden-Smedley unpublished data).

Within the fire behaviour modelling data it was not possible to differentiate between the effects of fuel load and the percentage of dead fuel on the fire spread rate. This was due to the high correlation in the data between the fuel load and the percentage of dead fuel ($r = 0.725$, $p < 0.001$). The fuel load and the percentage of dead fuel were also highly correlated with the age ($r = 0.616$ and 0.986 respectively, $p < 0.001$ in both cases). Since the age is easy to determine in buttongrass moorlands (see Section 4.2.2) and has a similar effect on the fire spread rate as has the fuel load and the percentage of dead fuel, age was used as the predictor of fuel characteristics in the fire behaviour model.

When a logarithmic transformation of the spread rate was used, the resulting model gave poor predictions for the high intensity wildfire data. While it is acknowledged that there is some uncertainty in wildfire weather data (wind speed in particular), it is of greater concern that there are large differences between observed and predicted fire spread rates. There were, however, no intermediate spread rates between the high intensity wildfires and the experimental burns (because the highest intensity experimental burns were at the limit of safe containment and the other wildfires were below the maximum intensity of the experimental fires, see fires 61 to 63 in Appendix 6). This meant that the form of the relationship of spread rate and wind speed was not well determined.

As a consequence non-linear regression modelling with no transformation was used to develop the fire spread model. This produced a model that gave good predictions for the wildfires, with no apparent reduction in the quality of the predictions for fires in the intensity range of the experimental fires for which prescriptions for fire management were sought.

In addition, using a non-linear model allowed for the use of a more natural surrogate for the fuel characteristics to be used by utilising an asymptotic function of age. This asymptotic age function was of the same form as used in the prediction models for fuel load and fraction of dead fuel (Equations 4.3 and 4.5).

The resulting buttongrass moorland rate of spread model for flat terrain is given by:

$$ROS = a * U^b * \exp(-c * Mf_{dead}) * (1 - \exp(-d * AGE)) \qquad (6.3)$$

where ROS is the rate of fire spread, U is the surface wind speed, Mf_{dead} is the elevated dead fuel moisture content, and AGE is the time since the last fire. The parameters and units used in Equation 6.3 are given in Table 6.4. There was very little correlation between the explanatory variables, so the coefficients in the regression equation genuinely reflect the effect of these variables.

The estimates and asymptotic standard errors for the constants a, b, c, and d for fitting this non-linear regression model are also given in Table 6.4 (see Myers 1989 for techniques). With the exception of the high intensity wildfire data, the observed values of spread rate versus predictions from this model are shown in Figure 6.7. The high intensity wildfire data has not been plotted in Figure 6.7

due to the magnitude of the difference between these fires and the rest of the fire data. The spread rate model did give good (although slightly under) predictions for the high intensity wildfire data, with the observed and predicted fire rate of spread data being 54 versus 59 m min^{-1} for the Mulchay Bay fire, and 55 versus 66 m min^{-1} for the Birchs Inlet fire.

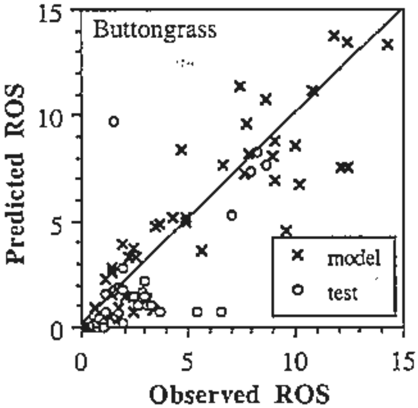


Figure 6.7. Observed versus predicted rate of fire spread using Equation 6.3. Note: model = model development data; test = model test data; ROS = fire spread rate, m min^{-1}.

For logistic reasons, the fires used to develop the model were mainly on low productivity sites, but the validation data collected from medium productivity sites fitted the model equally well, justifying the development of a single rate of spread model. This also suggests that the percentage of dead fuel, which is much less dependent on site productivity, is more important in determining spread rate than is the gross fuel load.

In Figure 6.8 the relative effects of variation in wind speed, dead fuel moisture content and age on the rate of spread as predicted by the model (Equation 6.3) are shown.

Since a power function was used to model wind speed, the model predicts a zero spread rate at zero wind speed, but this is of minor practical importance. An exponential function of wind speed was considered, but it did not fit the data as well as a power function.

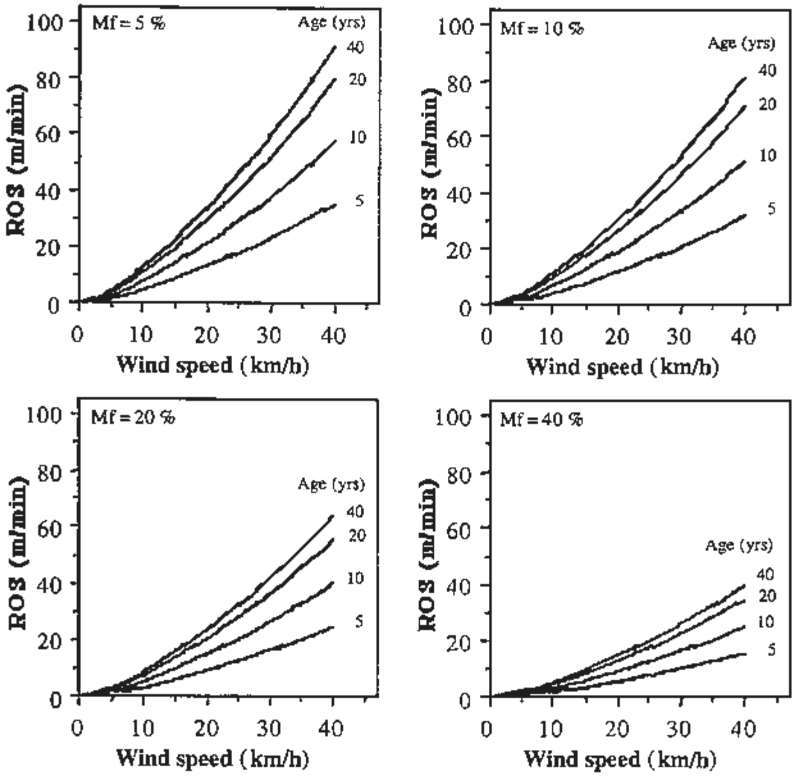


Figure 6.8. Effects of variation in wind speed, dead fuel moisture content and age on the predicted rate of fire spread. Note: wind speeds measured at 1.7 m.

6.3.3 Buttongrass moorland flame height model

A model for flame height rather than flame length was developed because flame height gives a better indication of suppression potential and can be more easily estimated by field staff. The form of the flame height model was based on a power function of Byram's intensity:

$$F_H = p * I_B^q \qquad (6.4)$$

where F_H is the flame height. Estimates and standard errors for p and q are given in Table 6.4. The r^2 value for the fit of the model was 0.76. I_B was estimated by Equation 6.1 using the fuel load, rate of fire spread and fuel heat content corrected for dead fuel moisture content (Equation 6.2).

The observed versus predicted flame heights are given in Figure 6.9. Overlaid on these are the observed and predicted flame heights from the validation data.

Table 6.4. Values for the equation parameters.

	Equation 6.3 Rate of spread		Equation 6.4 Flame height	
Parameter	Estimate	Standard error	Estimate	Standard error
a	0.678	0.168		
b	1.312	0.055		
c	0.0243	0.005		
d	0.116	0.030		
p			0.148	0.038
q			0.403	0.035

Equation units:

age	years;	surface wind speed	km hr^{-1};
dead fuel moisture	%;	fuel heat content	kJ kg^{-1};
fuel load	t ha^{-1};	rate of fire spread	m min^{-1};
Byram's intensity	kW m^{-1};	flame height	metres.

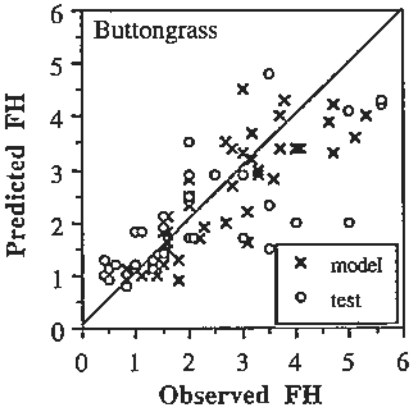


Figure 6.9. Observed versus predicted flame height using Equation 6.4. Note: model = model development data; test = model test data; FH = flame height (F_H), m.

In order to determine I_B under operational conditions, the fuel load would have to be predicted using either Equation 4.2 or 4.3 and corrected for the percentage of fuel consumption. The spread rate would be predicted from Equation 6.3. Reasonable estimates of fuel consumption are 100% if dead fuel moistures are less than 30%, and 75% if dead fuel moistures are between 30 and 70%. These issues will be discussed further in Chapter 7.

6.3.4 Buttongrass moorland flank and back fire predictions

Data were also collected where possible on flank and back fire rates of spread and intensity. Flank and back fire rates of spread were found to be approximately 40% and 10% respectively of the head fire rates of spread. Flank and back fire flame heights were approximately 60% and 50% respectively of the head fire flame heights (see Appendix 6).

6.3.5 Fire behaviour model evaluation

In common with the dead fuel moisture model evaluation (Section 5.3.6) the different models observed versus predicted rates of fire spread and flame dimension scatter plots, normalised root-mean-square errors and bias were compared (Figures 6.4, 6.6, 6.7 and 6.9; Table 6.5). The formulas for calculating root-mean-square errors were obtained from Janssen and Heuberger (1995; see also Viney 1992). The model bias was calculated using the methods of Catchpole and Catchpole (in prep.). When the normalised root-mean-square errors and bias were calculated, the two high intensity wildfires were deleted due to the large effect these fires had on the error estimates compared to the other data points.

Table 6.5. Rate of fire spread and flame dimension model performance.

Model	NRMSE	Bias
Rate of fire spread		
Buttongrass moorland, Equation 6.3, model development data	0.33	0.77
Buttongrass moorland, Equation 6.3, model test data	0.90	1.59
Buttongrass moorland, Equation 6.3, all data	1.12	0.93
McArthur Forest Fire Danger Meter mark 5 (1973)	9.75	2.68
McArthur Grassland Fire Danger Meter mark 3 (1966)	1.49	2.71
Rothermel (1972)	3.81	1.84
Thomas (1970, 1971)	0.86	1.77
Flame height		
Buttongrass moorland, Equation 6.4, model development data	0.94	0.96
Buttongrass moorland, Equation 6.4, model test data	0.64	1.29
Buttongrass moorland, Equation 6.4, all data	0.79	1.18
McArthur Forest Fire Danger Meter mark 5 (1973)	8.85	2.30
Albini (1981)	2.07	1.76
Flame length		
Byram's intensity (1959)	5.99	2.36
Thomas (1963)	3.04	1.72

Note: NRMSE = normalised root-mean-square error; Bias = bias estimate.

6.4 Discussion

The issues raised in this Chapter have also been discussed in a research paper (Marsden-Smedley and Catchpole 1995c, see also Appendix 7).

6.4.1 Fire behaviour model performance

None of the published fire behaviour models provided adequate predictions of fire behaviour in buttongrass moorlands. This poor performance is clearly shown by the poor observed versus predicted plots (Figures 6.4 and 6.6), and their large root-mean-square errors and bias (Table 6.5). These results suggest that only the models developed in this chapter (i.e. Equations 6.3 and 6.4) should be used to predict fire behaviour in Tasmanian buttongrass moorlands.

6.4.2 Factors influencing buttongrass moorland fire behaviour

The dominant factor influencing buttongrass moorland fire spread was wind speed, accounting for about 40% of the observed variation in the rate of fire spread. Age and dead fuel moisture each accounted for about 15 to 20% of the observed variation in the rate of fire spread.

The rate of fire spread was the dominant factor influencing flame height, accounting for about three quarters of the observed variation. Wind speed affects flame height through its strong influence on spread rate. Age (through its influence on fuel loads) had a much larger effect on flame height than did dead fuel moisture.

Wind speed

The dominance of the fire behaviour by wind speed wonld be due to the low open (i.e. non-forested) nature of buttongrass moorlands, and was reflected in the very rapid changes in fire spread rate following changes in wind speed.

The wind speed index b in Equation 6.3 has a higher value than the one reported in Equation 6 of Cheney et al. (1993) for grassland, even though both of these models are for low open vegetation types. The higher value for b in Equation 6.3 is a result of including the two high intensity wildfires in the buttongrass moorland fire behaviour model. If these fires are removed from the analysis, the value for b is reduced to 0.879, which is close to the value of 0.951 given for b in Cheney et al. (1993) who did not have any high wind speeds in their data. The value for b in Equation 6.3 is much less than the wind speed index of 2 that McArthur (1966) suggested for grassland. It is closer to the value of B (estimated to be 1.12) which is obtained when the Rothermel wind factor $Ø_w = A\ U^B$ is applied to buttongrass moorland fuel.

Age

The influence of age on fire behaviour could relate to changes in the fuel load or to the percentage of dead fuel, but within the available data it was not possible to differentiate statistically between these two factors. Site productivity, however, has major influences on fuel load but only minor influences on the percentage of dead fuel (Chapter 4). Since the rate of fire spread was found to be independent of site productivity, it is most likely that the major fuel factor is the percentage of dead fuel and/or the dead fuel load.

Fuel moisture

The range of dead fuel moisture contents over which buttongrass moorlands were observed to burn was much wider than that reported for eucalypt and pine litter. The dead fuel moisture of extinction in eucalypt litter is between 16 and 20%, while for pine needles it is about 30% (Luke and McArthur 1978). In contrast, the dead fuel moisture of extinction in buttongrass moorlands is about 70% (see Figure 6.5). A similar situation has been reported in UK gorse and heather fuels where fires burned with dead fuel moisture contents of about 60% (Hobbs and Gimingham 1984).

Since these high dead fuel moisture levels are above the fibre saturation point (about 35% for wood, Viney 1991) some of this moisture was probably surface water. This is supported by the observation that when these dead fuel samples were collected the fuel felt wet to touch, particularly when the fuel particles were clumped together, which is common in buttongrass moorlands.

Assuming there were no breaks in the fuel array continuity and the wind speeds were below about 20 km hr^{-1}, fires would not sustain when the age was less than about three years (i.e. when the percentage of dead fuel was less than about 10%). However, provided fuel moistures were below about 35% and the age was more than three years, fires sustained even with low wind speeds (less than 2 km hr^{-1}). This situation occurred even over standing water, at very low temperatures and/or at high relative humidities (i.e. below 2° C and at 100 % RH, Appendix 6).

From the data that is available, there is strong evidence to suggest that the dead fuel moisture of extinction is wind dependent (see Figure 6.5). At low wind speeds (i.e. less than about 2 km hr^{-1}), fires would only sustain when the dead fuel moisture was below about 35%. When dead fuel moistures were between about 35 and 70%, however, fires sustained with constant levels of fire behaviour when the wind speed was above about 2 km hr^{-1}, and then self-extinguished very quickly when the wind speed dropped below about 2 km hr^{-1}. This is in contrast to the earlier analyses, where it was suggested that the dead fuel moisture of extinction in buttongrass moorlands was not wind dependent (see Marsden-Smedley and Catchpole 1995c).

Live fuel moisture content was found not to be correlated with spread rate. The range in live fuel moisture content was 75 to 145% independent of season. A marked spring growth flush does not occur in buttongrass moorlands. It is probable that live fuel moisture content is not a factor in buttongrass moorland fire spread rate, except when the moorlands are under extreme levels of drought stress.

Fire behaviour in Tasmanian buttongrass moorlands can be easily predicted using the models developed in this chapter. These models utilise site age, wind speed, dead fuel moisture content and available fuel. The utility of these fire behaviour models will be discussed further and operational fire behaviour models developed in the fire management chapter, while some of the wider implications of this research will be discussed in Chapter 8.

7. Fire management in buttongrass moorlands

7.1 Background

In the past six chapters of this thesis, various aspects of buttongrass moorland fire regimes, fuel characteristics, fuel moistures and fire behaviour have been discussed. In this chapter some of these issues will be re-visited and then placed into a operational fire management context.

By producing a comprehensive assessment of the interactions between different aspects of buttongrass moorland fires, this thesis will provide the basis for much improved fire management in Tasmanian buttongrass moorlands. Using the operational fire behaviour models developed in this chapter in association with the information on fire regimes, it will be possible to objectively target fire management in these moorlands in order to achieve specific outcomes. These outcomes will include:

- targeted operational fire management which addresses the fire needs of fire-adapted vegetation whilst minimising potential impacts to fire-sensitive vegetation;
- improved hazard-reduction burning which will maximise the potential for reducing fuels whilst minimising the risk of fire escapes;
- better targeted habitat-management burns which provide the maximum benefit to target species whilst minimising adverse impacts to other values;
- improved fire management planning and fire risk assessments; and
- enhanced and safer wildfire management over a wider range of conditions.

7.2 Changes in fire regime in southwest Tasmania

Over the past about 170 years there have been major changes in the fire regime of southwest Tasmania. The fire regime has probably gone from an Aboriginal regime of frequent low intensity buttongrass moorland fires with few other fires, to the early European fire regime of frequent high intensity fires in all vegetation types, to a regime of low to medium intensity moorland fires, to the current fire regime of very few fires.

These changes in fire regime have profound implications for the fire management of southwest Tasmania. At present, about 75% of the area of lowland non-forest vegetation in southwest Tasmania would be classified as old-growth, while only about 12% would be classified as each of regrowth or mature. As regards wet eucalypt forests, less than 20% of the area would be classified as old-growth, while about 75% would be classified as mature and less than 4% as regrowth. With rainforests, about 25% would be classified as regrowth, with up to about 60 to 75% classified as either mature or old-growth. In highland areas of southwest Tasmania, about 55% would be classified as regrowth, and up to about 45% of would be classified as either mature or old-growth (see Tables 3.5, 3.12 and 3.13).

It should also be noted that over the past 170 years in southwest Tasmania, there have been three landscape scale fires, each of which was preceded by a period of few fires. Each of these low fire periods was about 30 to 50 years long, while each of the landscape scale fires burned between about 630 000 ha and 1 000 000 ha in southwest Tasmania. These landscape scale fires also burnt very extensive areas in other parts of Tasmania.

This pattern of a period of few fires followed a massive fire may not be the result of chance. The probability of getting a large scale, fast moving fire would be greatly enhanced by extensive areas of old-growth vegetation. This would be mainly due to the interactions between fuel array characteristics and the time since the last fire (see Section 1.2). In old-growth vegetation the fuel array characteristics are such that there are normally high fuel loads, high dead to live fuel ratios and highly continuous fuels. This means that when fires occur, the fires normally have higher rates of fire spread and intensities than is normal. Such fires would also have a high probability of transgressing natural boundaries and hence burning other vegetation types.

In southwest Tasmania, where about 75% of the non-forest vegetation is old-growth, the potential for such a landscape scale fire would be high. In addition, it is highly probable that across extensive areas, there has been, or will be in the near future, the shading out of the light and/or open space demanding species, with resultant impacts on community biodiversity.

A major finding of this thesis is that an increase in burning in southwest Tasmanian lowland buttongrass moorlands would be ecologically beneficial. Since southwest Tasmanian rainforests, and subalpine and alpine vegetation types would be classified as fire-sensitive, all fires would cause adverse impacts and so should be avoided.

7.3 Interactions between different aspects of buttongrass moorland fuel characteristics

The time since the previous fire and the site productivity have major influences on buttongrass moorland fuel characteristics. Long unburnt buttongrass moorland sites tend to have high fuel loads, high dead to live fuel ratios and highly continuous fuels. In most sites, good estimates of the fuel load and ratio of dead to live fuel can be made from the age and site productivity. Alternatively, some sites only have thin skeletal soils and much slower fuel accumulation rates. These sites also tend to have low fuel covers, and so the fuel characteristics can be predicted from the age and fuel cover.

If fires burn under marginal conditions, particularly when fuel moistures are high, only the upper parts of the fuel array may burn, leaving extensive mats of unburnt fuel (thatch). This thatch typically persists for about one to five years. This thatch load is primarily dependent on the characteristics of the previous fire and not the site characteristics and so can not be predicted using the fuel characteristics models developed in this thesis.

The only other project to examine buttongrass moorland fuel accumulation rates (Gellie 1980) examined fuel accumulation in what would be considered to be low productivity sites in southwest Tasmania. The fuel accumulation rates measured by Gellic (1980) were very similar to those predicted by the low productivity fuel load model.

Heathlands and woodlands in the Sydney region of New South Wales (see Conroy 1993) are reported to have have fuel accumulation rates approximately midway between low and medium productivity buttongrass moorlands. Mallee-broombrush near the Dark Island Soak in South Australia (see Specht 1966) has similar fine fuel accumulation rates to low productivity buttongrass moorlands for the first 12 years following fire, but more data are needed to see whether this trend is continued over longer time periods. In contrast, heathlands near Dark Island (see Specht 1966) had slower fuel accumulation rates than low productivity buttongrass moorlands in the first nine years following fire, after which marked increases in fuel accumulation rate were observed.

Southern Californian chamise (see Rothermel and Philpot 1973) has similar fuel accumulation rates to medium productivity buttongrass moorlands while mixed chaparral has fuel accumulation rates approximately double those of medium productivity buttongrass moorlands. It should also be noted that the fuel accumulation rates and fuel array structures in mixed chaparral (Rothermel and Philpot 1973) are similar to those observed in high productivity buttongrass moorlands. In South African fynbos (see van Wilgen 1982) fine fuel accumulation rates were of the order of one third of those modelled for low productivity buttongrass moorlands.

7.4 Buttongrass moorland dead fuel moisture

Buttongrass moorland fuel is a good example of a fine fuel which responds rapidly to changes in environmental conditions. In these fuels, the effects of significant precipitation events only appear to affect the dead fuel moisture content for up to about 24 hours while overnight dew fall only appears to influence dead fuel moistures for up to about three hours after dawn. As a result, buttongrass moorland dead fuel moistures will fall to levels below the dead fuel moisture of extinction in short time periods following precipitation events.

Due to the rapid response of the fuels to changes in environmental conditions, dead fuel moistures in buttongrass moorlands can be modelled using easily measured weather parameters. The dead fuel moisture content model recommended in this thesis (Equation 5.1) utilises dry bulb temperature and dew point temperature, both of which are easy to obtain under operational conditions.

7.5 Buttongrass moorland fire behaviour

The dominant factors influencing buttongrass moorland fire spread rate are wind speed, dead fuel moisture and fuel characteristics. As regards flame heights, the dominant factors were fire spread rate, age (through its influence on fuel loads) and dead fuel moisture.

Of these factors, wind speed is the most important, probably due to the low open nature of buttongrass moorlands. It was not possible to determine which were the most important fuel characteristics factor(s) influencing fire spread rate. Both of the major fuel characteristics factors (i.e. fuel load and ratio of dead to live fuel) were highly correlated with spread rate and with the time since the last fire. As a result, age was used as a predictor in the fire spread rate model. Since the flame height model is based on a function of Byram's Intensity, fuel load is used as the fuel characteristics variable.

Buttongrass moorland fires were observed to burn over a much wider range of dead fuel moistures than are reported for most other fuel types. The moisture of extinction in moorlands was of the order of about 70%, which is over three times the moisture content at which eucalypt fires and over double the moisture content at which pine fires extinguish. This ability to burn at such high moisture contents is probably a reflection of the high bulk density of very fine dead fuel. It should also be noted that the moisture of extinction was highly wind dependant.

It is also worth noting that for vegetation assemblages, such as buttongrass moorlands, which grow in wet environments and rely on fire to maintain their competitive advantage over other vegetation assemblages, the ability to carry fire with high fuel moistures would be a major adaptive advantage (in line with the theory of Mutch 1970). In western and southwestern Tasmania, extensive rain-free periods are rare, and 14 days without significant rain (i.e. greater than 5 to 10 mm) would be 'an extended dry spell'. In this region, a minimum of 50 mm of precipitation occurs in the driest month.

7.6 Buttongrass moorland operational fire management

7.6.1 Aims of buttongrass moorland operational fire management

As was discussed in Section 1.3.7, buttongrass moorlands are managed for two main purposes: conservation and asset protection. In conservation, the primary aims are to maintain high levels of species diversity, structural diversity, and/or in selected areas, the maintenance and/or promotion of selected species. In the management for asset protection, frequent hazard-reduction burning is normally performed. The primary aims of hazard-reduction burning are to reduce the intensity and spread rate of subsequent wildfires, broaden the conditions within which fire management is possible and increase the probability that fires will not sustain.

These differences in the aims and outcomes between conservation management and hazard-reduction burning frequently cause conflicts in management. For example, the frequent fires required for asset protection will almost certainly severely disadvantage species which require old moorlands with a high vegetation cover. In contrast, management of moorlands for species which require high covers will result in the fire control window being much reduced (see Section 1.3.7). Due to these opposing values, the relative balances between the different types of buttongrass moorland fire management will need to be carefully planned.

In some areas, frequent low intensity hazard-reduction burns in spring and autumn may be a lesser threat to the ecological values of a site than high intensity and/or dry peat wildfires in summer. This will particularly be the case in areas with a high risk of arson fires. A good example of this type of problem occurs along the Lyell Highway in western Tasmania. This area has a long term history of arson fires in all seasons (Blanks 1991) which are reported to have caused damage to the area's peat soils (M. Pemberton personal communication). In this area, the risk of fires spreading from the highway and causing damage to other more sensitive vegetation types is considered greater than the risk to the moorland communities (Blanks 1991; Parks, Wildlife and Heritage 1992; Kendall 1995).

The research outlined in this thesis is intended to aid the fire management of buttongrass moorlands in Tasmania. From information on past fire regimes (Chapter 3), how often different sites have been burnt, their age (i.e. time since the last fire), average fire size and fire frequency can be obtained. This information can then be used in association with information on the fuel characteristics of a site (Chapter 4), its fuel moisture (Chapter 5) and fire behaviour (Chapter 6) to perform operational fire management in buttongrass moorlands. In addition, by providing reliable predictions of fire behaviour over a wider range of conditions, it will be possible to perform enhanced wildfire control operations. These wildfire control operations will also be safer to perform and have a greater potential for the successful control of wildfires.

7.6.2 Buttongrass moorland operational fire behaviour model parameters

In order to use the buttongrass moorland fire behaviour models developed in Chapter 6 under operational conditions, some of the data inputs need to be modified to those available under field conditions. For example, in the rate of fire spread model (Equation 6.3) the measured dead fuel moisture needs to be replaced by the estimated dead fuel moisture (Equation 5.1). The inputs for Equation 5.1 have also be modified using a function from Stull (1995) which uses dry bulb temperature and relative humidity to predict dew point temperature. In the flame height model (Equation 6.4) the measured fuel load needs to be replaced by the estimated fuel load (Equation 4.2 or 4.3).

If fires are burning in sites with significant slopes, adjustments need to be made to the fire spread rate. At present only limited data are available from buttongrass moorland fires burning on slopes. Until more data become available the slope correction factor developed by McArthur (1967; see also Luke and McArthur 1978; Noble et al. 1980) is recommended (Equation 7.1):

$$R_{slope} = R_{flat} * \exp(0.0693 * slope) \tag{7.1}$$

where R_{slope} is the slope corrected rate of fire spread, R_{flat} is rate of fire spread on flat ground and the slope is the the site slope in degrees. Where fires are burning downhill the slope needs to be applied in Equation 7.1 as a negative value.

To date, the dynamics of the effect of recent rainfall events on dead fuel moistures have not yet been adequately studied. If fire behaviour predictions are being made within 24 hours of significant rain events (e.g. greater than about 5 to 10 mm) or within about about three hours of dawn, then the dead fuel moisture model may under-predict (see Chapter 5).

The time since the previous fire is required for both the rate of spread and flame height models. This can be estimated in the field from ring and/or node counts (Section 4.2.2) or from fire history maps. If no data are available from either field surveys or fire history records, then in all probability the site has not been burnt recently, and a reasonable estimate (for the purpose of fire behaviour prediction) of the age is 20 years. This is because the asymptotic nature of the age relationship in Equations 4.3 and 6.3 means that once the age reaches about 15 years the rate of change with increases in age greatly decreases, resulting in only minor variation in the effect of age for values of greater than about 20 years.

The productivity of the site where the fire is burning is also required due to its effect on fuel accumulation rates, and hence the predicted flame height. Sites underlain by quartzite are considered to be low productivity sites, while sites underlain by fluvioglacial outwash containing dolerite are considered to be medium productivity sites (Chapter 4).

All of the meteorological inputs (i.e. wind speed, relative humidity and temperature) used in the operational fire behaviour models should be measured at 1.7 metres above the ground surface. If the meteorological inputs are being obtained from weather forecasts (e.g. the Bureau of Meteorology fire weather forecast) then the wind speed will need to be adjusted from the ten metre wind speed to the surface wind speed by multiplying by 0.67 (i.e. two thirds of the ten metre value).

7.6.3 Buttongrass moorland operational fire behaviour model equations

Using the parameters detailed in Section 7.6.2, buttongrass moorland operational fire behaviour model equations have been developed. These models are shown in Equations 7.2 to 7.4. Due to the multiplicative nature of Equations 7.2 to 7.4, with the exception of slope, all of the data inputs (i.e. the wind speed, temperature, relative humidity and age) must be greater than zero (see Section 6.3.2).

Buttongrass moorland operational rate of fire spread model:

$$\begin{aligned}ROS = {} & 0.678 * wind^{1.312} * \exp(-0.0243 * \exp(1.66 + 0.0214 * RH - 0.0292 * \\ & (((1 / 273.16 - 0.000184 * \ln(((0.611 * \exp((17.2694 * \\ & ((temperature + 273.16) - 273.16)) / ((temperature + 273.16) - 35.86))) * \\ & (RH / 100)) / 0.611))^{-1}) - 273.16))) * (1 - \exp(-0.116 * AGE)) * \\ & \exp(0.0693 * slope)\end{aligned} \tag{7.2}$$

Buttongrass moorland operational flame height model, low productivity sites:

$$\begin{aligned}F_{H\,low} = {} & 0.148 * ((18637 - (24 * \exp(1.66 + 0.0214 * RH - 0.0292 * \\ & (((1 / 273.16 - 0.000184 * \ln(((0.611 * \exp((17.2694 * \\ & ((temperature + 273.16) - 273.16)) / ((temperature + 273.16) - 35.86))) * \\ & (RH / 100)) / 0.611))^{-1}) - 273.16))) * (11.73 * (1 - \exp(-0.106 * AGE))) * \\ & ROS) / 600)^{0.403}\end{aligned} \tag{7.3}$$

Buttongrass moorland operational flame height model, medium productivity sites:

$$\begin{aligned}F_{H\,med} = {} & 0.148 * ((18637 - (24 * \exp(1.66 + 0.0214 * RH - 0.0292 * \\ & (((1 / 273.16 - 0.000184 * \ln(((0.611 * \exp((17.2694 * \\ & ((temperature + 273.16) - 273.16)) / ((temperature + 273.16) - 35.86))) * \\ & (RH / 100)) / 0.611))^{-1}) - 273.16))) * (44.61 * (1 - \exp(-0.041 * AGE))) * \\ & ROS) / 600)^{0.403}\end{aligned} \tag{7.4}$$

where ROS is the fire spread rate (m min^{-1}), wind is the surface wind speed measured at 1.7 m (km hr^{-1}), temperature is the dry bulb temperature in degrees Celsius, RH is the relative humidity in percent, age is the time since the last fire (years), slope is the site slope (degrees), $F_{H\,low}$ is the flame height in low productivity sites (metres) and $F_{H\,med}$ is the flame height in medium productivity sites (metres).

The relationships between different levels of fire behaviour and their corresponding fire control options are shown in Table 7.1. These relationships have been developed from observations by the author of fire behaviour during this project.

Table 7.1. Relationships between buttongrass moorland fire characteristics and fire control options.

Fire spread rate m min^{-1}	Flame height m	Fire characteristics
0 to 1.5	0 to 3	- level of fire behaviour may be too low for effective hazard-reduction burning due to fires of this level of fire behaviour frequently leaving large amounts of fuel unburnt; - suitable conditions for habitat-management burning; - fire easy to control using handtools.
1.5 to 4.5	1 to 5	- suitable fire behaviour for hazard-reduction and habitat-management burns; - handtools (knapsacks and beaters) effective on head and flank and back fires; - 5 m wide control lines should hold if supported by hand tools.
4.5 to 7.5	2 to 6	- if suitable fire control boundaries exist (e.g. scrub or forest that is too wet to burn, well defined tracks or roads), fire behaviour may be acceptable for hazard-reduction burning; - level of fire behaviour may be too high for effective habitat-management burning due to fires of this level of fire behaviour frequently leaving few areas unburnt; - head fire too intense for hand tools, but hand tools effective on flank and back fires; - pumps required to control fire if control lines up to 5 m wide are being used; - short distance (up to about 5 m) spotting expected.
7.5 to 15	2 to 8	- fire hard to control; - fire behaviour too intense for prescribed burning; - control lines less than 5 m wide unlikely to control head fires, but may hold flank and back fires; - 10 to 25 m wide fire breaks required to control head fires; - spot fires 30 m plus ahead of the main front expected.
15 to 36	3 to 12	- head fire control very difficult, with 25 to 50 m wide fire breaks required; - 10 m wide control lines may hold flank and back fires if supported; - high risk of fire spotting across fire breaks; - personnel positioned down wind and to the flanks of the fire should be made aware of the high risk of the fire jumping fire breaks.
36 to 70	5 to 17	- direct attack on fire not possible; - >100 m fire breaks required to control head fires, and >10 m wide fire breaks required to control flank and back fires; - very high risk of fire spotting across fire breaks; - essential no personnel be positioned down wind or to the flank of the fire unless they have safe low fuel zones to retreat into.
>70	>8	- fire control not possible until the level of fire behaviour reduces; - essential no personnel be positioned down wind or to the flank of the fire.

7.6.4 Prescriptions for conducting buttongrass moorland burning

From the operational buttongrass moorland fire behaviour models (Section 7.6.3; Equations 7.2 to 7.4), new prescriptions for conducting prescribed burning have been developed.

The actual prescriptions used for a burn will be determined by its required outcomes. For example, with hazard-reduction burning the major aim is to change the fuel characteristics such that if a fire occurs, either it will not sustain itself, or if it does sustain, the fire intensity and rate of spread will be low enough to allow fire suppression under a wide range of weather and site conditions.

Habitat-management burns in contrast, aim to advantage one species and/or community type. Since there is no requirement for habitat-management burns to burn 70% of the fuels over 70% of the site (see Section 1.3.7) broader prescriptions may be used for habitat-management burns than for hazard-reduction burns. With habitat-management burns a patchy burn that burns about 50 to 90% of the area of a site will normally be superior to a fire which burns the all of the site. The rationale for this is that patchy burns should allow for the faster and more effective recolonisation by many species (e.g. small mammals, see Section 1.3.8).

Until more information becomes available and a requirement for fire is demonstrated, habitat-management burning should not be performed in subalpine buttongrass moorlands due to these moorlands normally containing fire-sensitive species (see Section 7.7.2). The altitude above which subalpine buttongrass moorlands occur at can determined from floristic surveys and/or using the methods outlined in Section 3.3.2 (i.e. at altitudes above 100 m below the local treeline).

In order to be manageable by fire crews prescribed fires must be performed at relatively low levels of fire behaviour. In most circumstances, the aim will be to keep the rate of fire spread and flame height below about 7.5 m min^{-1} and 6 m respectively (see Table 7.1).

Variation in fire frequency may also occur between hazard-reduction and habitat-management burns. Since with hazard-reduction burns the critical requirement is to modify the fuel characteristics, burns are normally performed at the maximum frequency that will sustain fires under the conditions used (see Section 1.3.5).

This normally results in burns being performed at five to eight year intervals. With habitat-management burns it is advantageous to perform the burns on a variable regime, so that any one species or group of species is not unduly advantaged or disadvantaged (see Section 1.3.6). The prescriptions for conducting prescribed burns in Tasmanian buttongrass moorlands are outlined in Table 7.2. An analysis of the occurrence of suitable weather for conducting prescribed burning in buttongrass moorlands was performed in Marsden-Smedley et al. (1988). This analysis found that suitable conditions for burning occurred on a reliable basis in western and southwestern Tasmania.

Table 7.2 Prescriptions for buttongrass moorland prescribed burning.

	Hazard-reduction burning			Habitat-management burning		
Season						
autumn	April to early May			April to June		
spring	September to early October			August to early October		
	Optimum	Min	Max	Optimum	Min	Max
Fire frequency, years				variable, between 5 and 30 years, dependent on the species and/or community type being managed		
low productivity sites	7 to 10	5	15			
medium productivity sites	5 to 8	5	10			
Weather conditions						
days since rain	2	1	-	2	1	-
temperature, ° C	14 to 16	10	20	12 to 16	5	20
relative humidity, %	50 to 60	45	75	50 to 75	45	95
surface wind speed, km hr^{-1}	6	3	10	4 to 6	0	10

Note: habitat-management burning should not be performed in subalpine buttongrass moorlands due to these moorlands normally containing fire-sensitive species.

Regardless of why a burn is being performed, the possibility that the conditions will be unsuitable on the planned burning day must be included in the planning and budgeting process. The situation where a burn proceeds just because that was when it was planned for, and the budget will not allow it to be postponed to a later date, must be avoided at all costs.

7.7 Further fire research required in buttongrass moorlands

Some further fire research is required in Tasmanian buttongrass moorlands. This research can be divided into five main areas. These are: Aboriginal fire regimes, fire regimes in other parts of western Tasmania, effect of variation in fire regime on buttongrass moorland species' composition and structure, fuel characteristics in high productivity and high altitude buttongrass moorlands, effect of precipitation on dead fuel moistures and refinement of the prescriptions for conducting prescribed burning.

7.7.1 Further fire regime research required in buttongrass moorlands

From the information gained in Chapter 3, the characteristics of the likely fire regime utilised by the Tasmanian Aborigines have been deduced. Additional information on this regime, both within buttongrass moorlands and in other vegetation types, is required. Probably the only feasible method of determining these regimes in western and southwestern Tasmania will be to examine fire scars and tree rings in large fire-resistant trees such as *Eucalyptus* spp. and/or *Leptospermum* spp. in association with work on selected fire-sensitive trees such as celery-top pine. Similar work has been performed in some other parts of the world, with a very high degree of success.

In common with the area studied in Chapter 3, there is considerable anecdotal evidence of past fires in other parts of western Tasmania. Therefore, in order to adequately manage the natural values of these areas (e.g. the northern half of the World Heritage Area, Tarkine in northwestern Tasmania), information is required on past fire regimes.

7.7.2 Further fire ecology research required in buttongrass moorlands

Further information is required on the effects of variation in fire regime on the species composition and structure of buttongrass moorlands. For example, observational evidence suggests that the fire regime practised by Forestry Tasmania in their moorlands (i.e. hazard reduction burning using low intensity fires on a five to eight year rotation) results in an increase in the dominance of sedge species and a marked decrease in the cover and dominance of heath species. Alternatively, the low fire frequencies utilised by the Parks and Wildlife Service across much of the World Heritage Area probably has adverse impacts on light demanding sedge, forb and grass species. Therefore, if we are going to manage these moorlands for different values, then we need to have a comprehensive understanding of how variation in fire frequency, intensity and season affects buttongrass moorland ecology.

In addition, the fire ecology of subalpine buttongrass moorlands is very poorly understood. Subalpine buttongrass moorlands are floristically diverse and contain fire-sensitive species such as pencil pine, King Billy pine and/or celery-top pine along with a range of subalpine heath species (including in some cases, coniferous heaths). Extensive areas of these moorlands occur above 900 m in altitude in the northern part of the Cradle Mountain–Lake St Clair National Park, many of which have not been burnt since the 1890s (probably 1896, see Innes 1897). Smaller areas of subalpine buttongrass moorland also occur in southwest Tasmania, many of which have not been burnt since 1933/34 (Section 3.4.2; Figures 3.7 to 3.14). Very low fire frequencies are probably required to maintain these moorlands. In these moorlands the major disturbance factors are probably climatic (e.g. frost, wind and/or ice glazing), with fire only playing a secondary role. Fire probably acts in these moorlands to reduce the cover and dominance of fire-sensitive species, allowing the more fire-tolerant species to maintain their competitive edge. The ecological requirements of these moorlands needs to be determined so that they can be adequately managed.

7.7.3 Further fuel characteristics research required in buttongrass moorlands

The fuel characteristics models developed in this thesis are intended for use in low and medium productivity moorlands in lowland areas of western and southwestern Tasmania. Observational evidence, however, suggests that there are higher fuel accumulation rates in northern and eastern Tasmania and in highland areas of western and southwestern Tasmania.

If fires are going to be managed in these areas, then fuel accumulation models will be required in order to predict flame heights. These models would be developed using the same techniques utilised in Chapter 4.

7.7.4 Further fuel moisture research required in buttongrass moorlands

In the operational fire behaviour model, there is no function to relate recent precipitation events to changes in dead fuel moisture. As was discussed in Chapter 5, precipitation in about the preceding 24 hours can act to elevate dead fuel moistures above those predicted by the dead fuel moisture model developed in this thesis (i.e. Equation 5.1). A preliminary rain and/or dew fall model has been developed, but since this model is still undergoing development and testing, it has not been presented in this thesis. As a result, additional work is required in this area to test the utility of the rain and/or dew fall model and if necessary extend its range. This function will be particularly important for conducting prescribed burning, where fires are often conducted short time periods after significant rain events. This dead fuel moisture-precipitation function should be finalised within about the next six to 12 months (see Marsden-Smedley et al. 1998).

7.7.5 Further fire behaviour research required in buttongrass moorlands

Additional information is required on when buttongrass moorland fires will self-extinguish. This information will aid in the development of prescriptions for the burning of buttongrass moorlands in sites where either only part of the moorland is to be burnt and/or there are no secure boundaries. This work is currently being performed by the author and should be completed within about the next six months.

Finally, when prescribed fires are being conducted and/or wildfires occur, fire behaviour data should be collected in order to ensure the models developed in this thesis are performing adequately. In this way, if there is a problem with the models produced, either within the buttongrass moorlands studied to produce the models or in related vegetation types, the problem can be identified and new models and/or prescriptions developed.

7.8 Outcomes of the buttongrass moorland fire behaviour models

The outcomes of this research can be divided into two main areas: formulation of new fire behaviour models and the elucidation of a better understanding of fire behaviour. Both of these developments will have important implications for future fire behaviour research and fire management.

The operational buttongrass moorland fire behaviour models developed in this thesis (Equations 7.2 to 7.4) provide an easy and robust methodology for predicting buttongrass moorland fire behaviour. These models are being extensively utilised in fire training courses and operational fire management throughout Tasmania. These techniques have met with wide acceptance by fire management staff (D. Kendall personal communication; D. Chuter personal communication; M. Chladil personal communication).

The models have also been used to refine the prescriptions for conducting prescribed burning (both for hazard-reduction and habitat-management), improve the techniques used for wildfire control and develop fire risk assessment systems (e.g. Kendall 1995).

The models could also provide the techniques for reintroducing fire into the buttongrass moorlands in southwestern and western Tasmania. These techniques could be applied to both the hand (e.g. using drip torches) and aerial (e.g. using a aerial incendiary machine, see Forestry Tasmania, Parks and Wildlife Service, Tasmania Fire Service 1996). Using these techniques, burns could be targeted in order to maximise the potential for achieving specific outcomes, such as burning areas on specific rotations and/or containing fires to selected areas.

The work reported on in this thesis has also led to a better understanding of some the factors influencing fuel characteristics and fire behaviour, particularly in the areas of wind speed and fuel moisture. Some of the problems associated with extending the utilisation of fire behaviour prediction systems beyond the fuel arrays for which they were developed have also been identified. It should be noted that only a small subset of the potential range of explanatory variables has been utilised in this work. A good example of the type of changes that can occur between related fuel types is the effect of variation in fuel height on fire spread rate in heathlands versus buttongrass moorlands. In heathlands, variation in fuel height has a major influence on fire spread rate (W. R. Catchpole personal communication), while in buttongrass moorlands, fuel height is not correlated with fire spread rate. Therefore, although these models work well in Tasmanian buttongrass moorlands, they should not be utilised in other fuel types without extensive verification. This is mainly due to the high probability that there will be differences in the characteristics of the fuel array.

The use of a non-linear function for wind speed is strongly supported by the data collected in this thesis. In this work, a power function of wind speed was used which was in accord with Catchpole et al. (1995) and gave a good fit to the data. The alternative proposal that the wind speed - rate of fire spread relationship is instead a step function (as proposed by Beer 1991, 1993) can not be discounted. Over the range of available data, however, both power and step functions are going to give very similar outputs, with their inherent errors being minor compared to errors in other parts of the fire behaviour model.

Another major finding of this research relates to the ability of buttongrass moorland fires to burn with very high fuel moisture contents. This higher than expected dead fuel moisture of extinction is probably a reflection of the large amount of fine elevated dead fuel with a high bulk density in buttongrass moorlands. A parallel situation probably occurs in UK gorse and heather fuels (Chapter 6; see also Hobbs and Gimingham 1984).

The techniques and relationships developed for buttongrass moorlands may also have utility in other, related vegetation types. It may also be possible to utilise the data collected in this project for developing other fire behaviour prediction systems. For example, the fire behaviour data from the older buttongrass moorland fires (i.e. ages greater than 15 years) appears to be very similar to that observed in heathland fires (W. R. Catchpole personal communication). Leading on from this observation, a project was initiated to collate data from the published literature and fire researchers in Australia and New Zealand. This database currently contains over 190 fires (including 53 fires in buttongrass moorlands). From these data several heathland rate of fire spread models have been developed which utilise a range of input parameters (Catchpole et al. unpublished). These models range from very simple relationships utilising wind speed alone through to more complex models utilising wind speed, fuel height and fuel moisture. To date these models have not been comprehensively tested under Tasmanian conditions. For the data that is available, however, the model utilising wind speed, fuel height and fuel moisture gives good rate of spread predictions in Tasmanian heathlands.

Fire behaviour in Tasmanian buttongrass moorlands can be predicted using factors easily measured under operational conditions. These models should provide adequate predictions over the majority of conditions prevailing in western and southwestern Tasmania. The implications of the different options for managing fires in buttongrass moorland and other wildland vegetation types will be discussed further in Chapter 8.

8. Fire in wildland vegetation

Recurrent fire is a characteristic part of many wildland environments. In natural vegetation types the impact of fire ranges from short term, low level impacts through to long term, deleterious changes. Buttongrass moorlands are an extreme example of this variation in fire effects, in that they are a fire-dependent and fire-promoting vegetation assemblage, with fire normally only having short term ecological effects.

The plant species found in buttongrass moorlands have a wide range of adaptations which promote their survival and/or regeneration following fire. Many of these adaptions also promote the spread of fires. These adaptations in moorland species include the production of large amounts of elevated fine dead fuel with a high bulk density and vegetative regeneration following fire. In addition, buttongrass moorland fires are capable of sustaining with very high fuel moisture content. Such fire-promoting characteristics would be essential for the maintenance of the moorland communities. These characteristics would interact with the increased fire frequencies resulting from human activities to allow the moorland to expand into many of the habitats that would otherwise be occupied by more fire-sensitive vegetation.

Through their ability to carry fires over a wide range of conditions, buttongrass moorlands have also probably resulted in increases in the distribution of other fire-adapted vegetation types in southwest Tasmania (e.g. wet scrub and wet eucalypt forest). Therefore, there has probably been a positive feedback situation occurring, where widespread burning by Aborigines (see Section 3.4.1) resulted in a fundamental shift in the vegetation patterns of the region. This shift has been away from fire-sensitive rainforest community types to fire-adapted buttongrass moorland, wet scrub and wet eucalypt vegetation types. Hence the dominant ecological influence has probably gone from being variation in soil type and climate to being variation in fire regime.

The Aboriginal fire regime was probably one of mainly frequent low intensity buttongrass moorland fires, and would have probably caused relatively low levels of floristic and structural diversity in this vegetation type. This in itself is not surprising since the aim of the Aboriginal fire regime would have been to maximise the potential of the environment to provide resources (e.g. for hunting and access), and not to maximise biodiversity.

In the period of early European utilisation of southwest Tasmania there was probably an increase the intensity and frequency of burning (Section 3.4.2). It should also be noted that this increase in both the fire intensity and frequency of fire was almost certainly unsustainable. This European fire regime probably resulted in not only the removal of much of the region's accumulated soil nutrient capital (along the lines proposed by Harwood and Jackson 1975; Jackson 1977), but also resulted in long term catastrophic impacts to the ecology of the region (e.g. see Brown 1988; Peterson 1990; Robertson and Duncan 1991).

The current utilisation of southwest Tasmania for recreation and natural values (especially wilderness) is in marked contrast to the fire management practices of the early Europeans. This management regime has resulted in the majority of the region's buttongrass moorland being classified as old-growth (Sections 3.4.5 and 3.5).

Southwest Tasmania is an area of very high cultural and ecological value, as evidenced by its World Heritage Status. Therefore, the management of the region must be targeted to maximise the positive aspects of the management regime whilst minimising the negative impacts. The Tasmanian Wilderness World Heritage Area Draft Management Plan (Parks and Wildlife Service 1997) states that the overall main management objectives are:

> To identify, protect, conserve, present and, where appropriate, rehabilitate the natural and cultural values of the World Heritage Area, and to transmit that heritage to future generations in as good or better a condition than at present (Parks and Wildlife Service 1997).

A regime of natural (i.e. lightning) fires is not going to meet these goals. This is because the slow rates of vegetation succession in southwestern Tasmania result in very long fire free periods being required in order to transform the vegetation to the less flammable rainforest community types (see Section 3.5). Infrequent fire would also result in the fire-adapted vegetation of the region being classified as old-growth with the attendant problems of high fuel loads, high dead to live fuel ratios and highly continuous fuels. Under a regime of infrequent fires, when the inevitable summer fire occurred in fire-adapted vegetation, the characteristics of the fuel array would ensure that the fire had higher rates of fire spread and intensities than is normal. Such fires would also have a high probability of burning peat soils and transgressing natural boundaries and therefore burning fire-sensitive vegetation.

This proposal is strongly supported by the historical data. Between about the 1830s and 1851 and between 1897/98 and 1933/34 (and also probably between 1851 and 1897/98) the fire regime across the majority of southwest Tasmania would have been dominated by lightning fires. Each of these periods of low fire frequency would have allowed for the development of very extensive areas of old-growth fire-adapted vegetation which in each case was followed by a massive landscape scale fire (see Sections 3.4.2 and 3.5). At present, since the majority of southwest Tasmania has not been burnt for over 60 years, the potential for another landscape scale fire is probably high. This, when added to the problems associated with the requirement of moorland species for open, high light conditions, indicates that there is a high probability that a ecological collapse (along the lines proposed by Brown 1996) could occur in the foreseeable future. Therefore, if we are going to maintain the ecological values of our wildland vegetation, we are going to have to re-introduce fire back into the ecological processes in southwestern Tasmania.

The fire regime required to maintain these ecological values will vary between different vegetation types. For example, in buttongrass moorlands, fire age only appears to have limited effect on species diversity for fire ages of up to about 50 to 75 years of age, with species diversity only being reduced in older moorlands than this (e.g. see Brown and Podger 1982a; Jarman et al. 1988a, 1988b; Marsden-Smedley 1990, 1993b). In the other vegetation types of the region much less information is available. From what is known however, it appears that long unburnt wet scrub (i.e. greater than 150 years since the last fire) will be transformed into rainforest, primarily by the invasion of bird dispersed species (Marsden-Smedley 1990). A similar situation also occurs in long unburnt wet eucalypt forests.

In buttongrass moorlands, a variable frequency and low intensity spring and autumn fire regime probably has the highest probability of achieving the aims of maximising biodiversity whilst minimising the risk of fires spreading to fire-sensitive vegetation. Such a fire regime should allow for the perpetuation of all of the species present in buttongrass moorlands and minimise the probability of damage to the peat soils. The rationale for applying burning on a variable frequency is that such a regime should minimise the probability that any one species or group of species will be disadvantaged.

As a result, if we are to maintain and enhance the biodiversity of the wildlands of western and southwestern Tasmania, we are going to have to reintroduce fire into many of the areas which currently have a low fire frequency. However, when fire is reintroduced to these areas, it is absolutely essential that the fire regime implemented is in keeping with the the ecological requirements of the vegetation being burnt. Such a reintroduction of fire could be easily implemented using modern technology. For example, using the prescriptions outlined in Section 7.6.3 in association with a helicopter equipped with a aerial incendiary machine, extensive areas could be ignited when the meteorological and fuel array conditions are suitable.

This does not mean that we should necessarily be reintroducing a Aboriginal style fire regime. The main aims of the Aboriginal fire regime would probably have been the maintenance of suitable hunting areas and access routes, with such a regime being unlikely to maximise the level of floristic and structural diversity. What is required instead is a regime with a variable fire frequency and intensity. Such a regime should result in some areas being burnt frequently, some areas with a moderate frequency and other areas with a low frequency. The exact mix of fire regimes utilised will need to be dynamic and flexible so that it can be tailored to the specific needs of different areas and modified as additional information becomes available.

At present, only limited quantitative information is available on the fire regime which will maximise species and structural diversity in buttongrass moorlands. From the information that is available (e.g. Brown and Podger 1982a; Jarman et al. 1988a, 1988b; Marsden-Smedley 1990; Marsden-Smedley and Williams 1993) and other related vegetation types (e.g. heathlands, see Keith and Bradstock 1994; van Wilgen et al. 1994; Bradstock et al. 1995a, 1995b; Gill and Bradstock 1995; Keith 1996; Morrison et al. 1996), reasonable estimates can be made of the most appropriate regimes. The most appropriate fire regime for southwest Tasmanian buttongrass moorlands will be a mixture of spring and autumn fires with a variable fire frequency of between about six and 50 years. In addition, due to the number of ignition sources present in buttongrass moorlands (especially arson, Table 3.1), there will be occasional arson fires in summer.

The alternative policy of not performing prescribed burning and allowing natural fires to burn (i.e. similar to the policy applying in some of the USA wilderness parks, see Leopold et al. 1963; Kilgore 1985; Schullery 1989) is unlikely to be effective in southwest Tasmania. Such a policy of benign neglect (see Brown 1996) will not provide an adequate number of fires to maintain fire-adapted vegetation types whilst protecting fire-sensitive vegetation types. Such a policy will also require a high degree of fatalism (see Blanks 1991) since it almost certainly lead to a repeat of the situation that occurred during the 1851, 1897/98 and 1933/34 summers when very extensive areas of fire-sensitive vegetation were burnt.

The situation where there is a requirement for the reintroduction of fire into fire-adapted vegetation is not unique to western and southwestern Tasmania. Many other parts of the world have similar ecological problems. In northern America, over the past decade there has been an increasing push for the restoration of wildland vegetation, often using fire (e.g. Parsons et al. 1986; Schullery 1989; Brennan and Hermann 1994; Mutch 1994). These strategies have both ecological and economic advantages.

In order to achieve these aims we will need to conduct adequate research so that we have a reasonable assessment of what are the current best practices and then be pro-active and dynamic in our management. If we follow such guidelines, then we have a reasonable chance of being able to maximise our gains whilst minimising our impacts. Not to do so, is almost certainly to degrade our wildland environment, whilst incurring increased economic costs.

9. References

Abel G. No date. Against the grain: with the Huon pine loggers of the West Coast of Tasmania. The Printing Press.

Albini F. A. 1981. A model for the wind-blown flame from a line fire. Combustion and Flame 43: 155-174.

Albini F. A. 1993. Dynamics and modelling of vegetation fires: observations. In: P. J. Crutzen and J. G. Goldammer. Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. Report of the Dahlem Workshop, Berlin 15-20 March 1992. John Wiley and Sons. Chichester, England.

Albini F. A. and Baughman R. G. 1979. Estimating wind speeds for predicting wildland fire behaviour. USDA Forest Service Research Paper INT-221, Intermountain Research Station, Ogden, Utah, USA.

Alexander M. E. 1982. Calculating and interpreting forest fire intensities. Canadian Journal of Botany 60: 349-357.

Anderson H. E. 1982. Aids to determining fuel models for estimating fire behaviour. USDA Forest Service General Technical Report INT-122. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Anderson H. E. 1990. Predicting equilibrium moisture content of some foliar forest litter in the northern Rocky Mountains. USDA Forest Service Research Paper INT-429, Intermountain Research Station, Ogden, Utah, USA.

Anderson H. E., Schuette R. D. and Mutch R. W. 1978. Timelag and equilibrium moisture content of Ponderosa pine needles. USDA Forest Service Research Paper INT-202, Intermountain Research Station, Ogden, Utah, USA.

Andrews P. L. 1986. BEHAVE: fire behaviour prediction and fuel modelling system - BURN subsystem, part 1. USDA Forest Service General Technical Report INT-194. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Andrews P. L. and Chase C. H. 1989. BEHAVE: fire behaviour prediction and fuel modelling system - BURN subsystem, part 2. USDA Forest Service General Technical Report INT-260. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Arkell B. 1995. Small mammal secondary succession in buttongrass moorlands. Unpublished MSc thesis, Department of Geography and Environmental Studies, University of Tasmania, Hobart, Tasmania.

Balmer J. M. 1990. Two moorland boundaries. TasForests 2: 133-141.

Barker M. J. 1991. The effect of fire on west coast lowland rainforest. Technical Report Tasmania NRCP 7. Forestry Commission, Hobart, Tasmania and DASETT, Canberra, ACT.

Beattie A. J. 1995. Why conserve biodiversity? In: R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney and D. P. Sivertsen (eds). Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, NSW, Australia.

Beer T. 1991. The interaction of wind and fire. Boundary-Layer Meteorology 54: 287-308.

Beer T. 1993. The speed of a fire front and its dependence on wind speed. International Journal of Wildland Fire 3: 193-202.

Bell A. 1983. Fire and rainforest in Tasmania. Ecos 37: 3-8.

Binks C. J. 1980. Explorers of Western Tasmania. Mary Fisher Bookshop, Launceston, Tasmania.

Birk E. M. and Simpson R. W. 1980. Steady state and the continuous input model of litter accumulation and decomposition in Australian eucalypt forests. Ecology 61: 481-485.

Blainey G. 1993. Peaks of Lyell. Fifth edition. St Davids Park Publishing, Hobart, Tasmania.

Blanks T. 1991. Fatalism: a cost effective approach to fire management in Southwest Tasmania. In: Fifth Regional Seminar on National Parks and Wildlife Management Tasmania, 1991. Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

Bond W. J. and van Wilgen B. W. 1996. Fire and plants. Chapman and Hall, London, England.

Bowman D. M. J. S. 1980. Fire, vegetation and nutrient interactions in the Southwest of Tasmania. Unpublished honours thesis, University of Tasmania.

Bowman D. M. J. S. 1995. Why the skillful use of fire is critical for the management of biodiversity in Northern Australia. In: D. B. Rose. Country in flames. Proceedings of the 1994 symposium on biodiversity and fire in North Australia. Biodiversity Series, Paper No. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, The Australian National University, Canberra, Australia.

Bowman D. M. J. S. and Jackson W. D. 1981. Vegetation succession in Southwest Tasmania. Search 12: 358-362.

Bowman D. M. J. S., Maclean A. R. and Crowden R. K. 1986. Vegetation-soil relations in the lowlands of south-west Tasmania. Australian Journal of Ecology 11: 141-153.

Bradstock R. A. 1990. Demography of woody plants in relation to fire: *Banksia serrata* Lf. and *Isopogon anemonifolius* (Salisb.) Knight. Australian Journal of Ecology 15: 117-132.

Bradstock R. A., Bedward M. and Scott J. 1995a. Plant species diversity in fire-prone heathlands: a spatially explicit model incorporating competitive effects. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Bradstock R. A., Keith D. A. and Auld T. D. 1995b. Fire and conservation: imperatives and constraints on managing for diversity. In: R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney and D. P. Sivertsen (eds). Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, NSW, Australia.

Braithwaite R. W. 1995. A healthy savanna, endangered mammals and Aboriginal burning. In: D. B. Rose. Country in flames. Proceedings of the 1994 symposium on biodiversity and fire in North Australia. Biodiversity Series, Paper No. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, The Australian National University, Canberra, Australia.

Brennan L. A. and Hermann S. M. 1994. Prescribed fire and forest pests: solutions for today and tomorrow. Journal of Forestry 92: 34-37.

Bridle K. L. and Kirkpatrick J. B. 1997. Local environmental correlates of variability in the organic soils of moorland and alpine vegetation, Mt Sprent, Tasmania. Australian Journal of Ecology 22: 196-205.

Brown A. A. and Davis K. P. 1973. Forest fire: control and use. McGraw-Hill Inc., 2nd edition.

Brown J. K. 1982. Fuel and fire behaviour prediction in big sagebrush. USDA Forest Service General Research Paper INT-290. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Brown M. J. 1988. Distribution and conservation of King Billy pine. Forestry Commission, Hobart, Tasmania.

Brown M. J. 1993. Buttongrass moorland ecosystems. In: S. J. Smith and M. R. Banks (eds). Tasmanian wilderness – world heritage values. Royal Society of Tasmania, Hobart, Tasmania.

Brown M. J. 1996. Benign neglect and active management in Tasmania's forests: a dynamic balance or ecological collapse? Forest Ecology and Management 85: 279-289.

Brown M. J. and Podger F. D. 1982a. Floristics and fire regimes of a vegetation sequence from sedgeland heath to rain forest at Bathurst Harbour, Tasmania. Australian Journal of Botany 30: 659-676.

Brown M. J. and Podger F. D. 1982b. Short note. On the apparent anomaly between observed and predicted percentages of vegetation types in south-west Tasmania. Australian Journal of Ecology 7: 203-205.

Brown P. B. and Wilson R. I. 1984. The orange-bellied parrot recovery plan. National Parks and Wildlife Service, Tasmania.

Brown P. M. and Sieg C. H. 1996. Fire history in the interior Ponderosa pine commnnities of the Black Hills, South Dakota, USA. International Journal of Wildland Fire 6: 97-105.

Bryant S. L. 1991. The ground parrot *Pezoporus wallicus* in Tasmania. Distribution, density and conservation status. Scientific Report 91/1. Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

Buchanan A. M. 1995. A census of the vascular plants of Tasmania and index to the Students Flora of Tasmania. Tasmanian Herbarium Occasional Publication Number 5. Tasmanian Herbarium, Hobart, Tasmania.

Burbidge A. A. and Wallace K. J. 1995. Practical methods for conserving biodiversity. In: R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney and D. P. Sivertsen (eds). Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, NSW, Australia.

Burgan R. E. and Rothermel R. C. 1984. BEHAVE: Fire behaviour prediction and fuel modelling system - fuel subsystem. USDA Forest Service General Technical Report INT-167. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Burn D. 1842. Narrative of the overland journey of Sir John and Lady Franklin and party from Hobart Town to Macquarie Harbour. In: G. Mackaness (ed.) Australian Historical Monographs XVI (new series), published 1977.

Burrows N. D. 1984. Describing forest fires in Western Australia. Forests Department of Western Australia, Perth, Western Australia.

Burrows N. D. 1991. Rapid estimation of the moisture content of dead *Pinus pinaster* needle litter in the field. Australian Forestry 54: 116-119.

Byram G. M. 1959. Combustion of Forest Fuels. In: Davis K. P. (ed.), Forest Fire Control and Use. McGraw-Hill, New York.

Byram G. M. and Jemison G. M. 1943. Solar radiation and forest fuel moisture. Journal of Agricultural Research. 67: 149-176.

Calder J. E. 1847. Letter discussing the existence of natives in unexplored parts of Tasmania in 1847. CSO24/24/575. Archives Office of Tasmania.

Calder J. E. 1849. Some account of the country lying between Lake St Clair and Macquarie Harbour. Tasmanian Journal of Natural Science, Agriculture, Statistics, & 3: 415-429.

Calder J. E. 1860a. Topographical sketches of Tasmania. Number 3. Mercury Newspaper, 27 January 1860.

Calder J. E. 1860b. Topographical sketches of Tasmania. Number 5. Mercury Newspaper, 6 March 1860.

Calder J. E. 1860c. Exploration. Some account of the country between Hamilton and Lake Pedder. Mercury Newspaper, 13 April 1860.

Carroll R. J. and Ruppert D. 1988. Transformation and weighting in regression. Chapman and Hall. New York.

Catchpole E. A., Catchpole W. R. and Rothermel R. C. 1995. A new semi-physical model for laboratory fire behaviour. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Catchpole W. R. and Wheeler C. J. 1992. Estimating plant biomass, a review of techniques. Australian Journal of Ecology 17: 121-131.

Catchpole W. R., Catchpole E. A. in prep. A note on estimating bias in prediction models.

Catchpole W. R., Catchpole E. A. and Viney N. R. 1996. Methods for estimating fuel moisture response times in the field. Paper presented at the 13th Conference on fire and forest meteorology. October 27-31, 1996. Lorne, Victoria, Australia.

Catchpole W. R., Catchpole E. A., Viney N. R., McCaw W. L. and Marsden-Smedley J. B. In prep. Modelling fuel moisture response times and equilibrium moisture content from field data.

Catchpole W. R., Bradstock R. A., Choate J., Foggarty L., Gellie N. Gellie N. J. H., Marsden-Smedley J. B., McCarthy G., McCaw L. and Pearce G. Unpublished. Report of the heathland fire behaviour modelling group meeting held at the 13th Conference on fire and forest meteorology. October 30, 1996. Lorne, Victoria, Australia.

Chatto K. and Tolhurst K. 1997. Development and testing of the Wiltronics T-H moisture meter. Research Report 46. Fire Management Branch, Department of Natural Resources and Environment, Victoria, Australia.

Cheney N. P. 1996. The Effectiveness of fuel reduction burning for fire management. In: J. R. Merrick. Proceedings of the Fire and Biodiversity: the effects and effectiveness of fire management conference, 8 - 9 October 1994. Footscray, Melbourne, Victoria, Australia.

Cheney N. P. and Gould J. S. 1997. Letter: fire growth and acceleration. International Journal of Wildland Fire 7: 1-5.

Cheney N. P., Gould J. S. and Catchpole W. R. 1993. The influence of fuel, weather and fire shape variables on fire-spread in grasslands. International Journal of Wildland Fire 3: 31-44.

Cheney N. P., Gould J. S. and Hutchings P. T. 1990. Management of eucalypt regrowth in East Gippsland: sampling available fuel and damage to trees retained after thinning and burning. Technical Report 12, Department of Conservation and Environment, Victoria.

Christensen N. L. 1993. Fire regimes and ecosystem dynamics. In: P. J. Crutzen and J. G. Goldammer. Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. Report of the Dahlem Workshop, Berlin 15-20 March 1992. John Wiley and Sons. Chichester, England.

Christensen N. L., Agee J. K., Brussard P. F., Hughes J., Knight D. H., Minshall G. W., Peek J. M., Pyne S. J., Swanson F. J., Thomas J. W., Wells S., Williams S. E. and Wright H. A. 1989. Interpreting the Yellowstone fires of 1988. BioScience 39: 678-685.

Condor H. 1915. The wild west. Port Davey to Macquarie Harbour. One hundred miles of track. Mercury Newspaper, 31 March 1915.

Conroy B. 1993. Fuel management strategies for the Sydney Region. In: J. Ross (ed.). The burning question: fire management in NSW. University of New England, Armidale, NSW.

Cook E. R., Bird T., Peterson M., Barbetti M., Buckley B., D'Arrigo R. and Francey R. 1992. Climatic change over the last three millennium in Tasmania reconstructed from tree-rings. The Holocene 2: 205-217.

Cook E. R., Buckley B. and D'Arrigo R. 1996. Inter-decadal climate oscillations in the Tasmanian sector of the Southern Hemisphere: evidence from tree rings over the last three millennia. In: P. D. Jones, R. S. Bradley and J. Jouzel (eds). Climate variations and forcing mechanisms of the last 2000 years. NATO ASI volume 141.

Cook G. D. and Williams R. J. 1995. Is fire protection a greater risk to tree survival than controlled burning? The effects of a single fire in a fire-protected savanna at Kapalga, Kakadu National Park. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Cosgrove R., Allen J. and Marshall B. 1994. Late Pleistocene human occupation in Tasmania: reply to Thomas. Australian Archaeology 38: 28-35.

Cotton H. 1850. Unpublished report on access routes and pasture land in southwest Tasmania. CSO 24/130/4347/368-372, Archives Office of Tasmania.

Cotton H. 1851. Government Notice No. 38. General report on the progress of operations west of the Derwent. Hobart Town Gazette, 8 April 1851.

Counsel E. A. 1898. Timber industry in Tasmania. Parliament of Tasmania Journal, 1898, report 48.

Crutzen P. J. and Goldammer J. G. 1993. Fire in the environment. The ecological, atmospheric, and climatic importance of vegetation fires. John Wiley and Sons. Chichester, England.

Davies J. B. 1983. Huon pine survey. Wildlife Division Technical Report 83/2. National Parks and Wildlife Service, Tasmania.

Davies R. H. 1846. On the Aborigines of Van Diemans Land. Tasmanian Journal of Natural Science, Agriculture, Statistics, & 2: 409-420.

Davis C. 1940. Preliminary survey of the vegetation near New Harbour, Southwest Tasmania. Papers and Proceeding of the Royal Society of Tasmania 40: 1-10.

Department of Mines Tasmania. 1960. South West Tasmania. 1:158 400 sketch map.

Dexter B. D. and Williams D. F. 1976. Direct field measurement of fine fuel moisture content. Australian Forestry 2: 140-144.

Driessen M. M. and Comfort M. D. 1991. Small mammal trapping in sedgeland at McPartlan Pass: a new location for *Mastacomys fuscus*. Tasmanian Naturalist 107: 1-5.

Dupuy J. L. 1995. Slope and fuel load effects on fire behaviour: laboratory experiments in pine needles fuel beds. International Journal of Wildland Fire 5: 153-164.

Eron Z. 1991. Using fuel moisture sticks for high-intensity planned burns. Forestry Commission, Hobart, Tasmania.

Fensham R. J. 1992. The management implications of fine fuel dynamics in bushlands surrounding Hobart, Tasmania. Journal of Environmental Management 36: 301-320.

Flanagan R. 1985. A terrible beauty. History of the Gordon River country. Greenhouse Publications Pty Ltd. Melbourne, Victoria.

Forestry Commission. 1977. Guidelines for prescribed burning. Forestry Commission, Hobart, Tasmania.

Forestry Tasmania, Parks and Wildlife Service, Tasmania Fire Service. 1996. Fuel reduction burning: course notes. Hobart, Tasmania.

Fox B. J., Fox M. D. and McKay G. M. 1979. Litter accumulation after fire in a eucalypt forest. Australian Journal of Botany 27: 157-165.

Fox M. D. and Fox B. J. 1987. The role of fire in the scleromorphic forests and shrublands of Eastern Australia. In: L. Trabaud (ed.) The role of fire in ecological systems. SPB Academic Publishing. The Hague, Netherlands.

Frankland G. 1835. Account of a trip to the middle Gordon and Huon River plains. Hobart Town Courier, 27 March 1835.

Frankland G. 1836. Account of tracks to Lake St Clair and the Huon River. Hobart Town Courier, 15 July 1836.

Franks S. M. 1958. Land exploration in Tasmania, 1824-1842 with special reference to the Van Diemen's Land Company. Unpublished Master of Arts Thesis, University of Tasmania.

Gellie N. J. H. 1980. Fire ecology of buttongrass moorlands. Bulletin 6. Forestry Commission, Tasmania.

Gibson N. 1986. Conservation and management of Huon pine in Tasmania. Wildlife Division Technical Report 86/3. National Parks and Wildlife Service, Hobart, Tasmania.

Gilbert J. M. 1959. Forest succession in the Florentine Valley, Tasmania. Papers and Proceedings of the Royal Society of Tasmania 93: 129-151.

Gilbert J. M. 1978. Notes on forest classification and fire occurrence. Lower Gordon Environmental Investigation. Unpublished report to the Hydro Electric Commission, Hobart, Tasmania.

Gilbert J. M. 1979. Fires in the Tasmanian bush. The Tasmanian Tramp 23: 118-122. Hobart Walking Club, Hobart, Tasmania.

Gill A. M. and Bradstock R. A. 1995. Extinction of biota by fires. In: R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney and D. P. Sivertsen (eds). Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, NSW, Australia.

Gill A. M., Christian K. R., Moore P. H. R. and Forester R. I. 1987. Bushfire incidence, fire hazard and fuel reduction burning. Australian Journal of Ecology 12: 299-306.

Gill A. M., Groves R. H. and Noble I. R. 1981. Fire and the Australian biota. Australian Academy of Science, Canberra, Australia.

Gill A. M. and Knight I. K. 1988. Fire measurement. In: N. P. Cheney and A. M. Gill (eds). Proceedings of the Conference on Bushfire Modelling and Fire Danger Rating Systems. Canberra, 11-12 July 1988. CSIRO Division of Forestry, Canberra, ACT, Australia.

Givnish T. J. 1981. Serotiny, geography and fire in the pine barrens of New Jersey. Evolution 35:101-123.

Gledhill J. 1993. Hazard reduction burning. The Tasmanian experience. In: J. Ross (ed.) The burning question: fire management in NSW. University of New England, Armidale, NSW.

Goldammer J. G. and Crutzen P. J. 1993. Fire in the environment: scientific rationale and summary of results of the Dahlem Workshop. In: P. J. Crutzen and J. G. Goldammer. Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. Report of the Dahlem Workshop, Berlin 15-20 March 1992. John Wiley and Sons. Chichester, England.

Goodwin J. 1828. Goodwin's statement. CSO 1/276/6658, Archives Office of Tasmania.

Gore A. P. J. 1983. Introduction. In: Gore A. P. J. (ed.). Mires: swamp, bog, fen and moor. Ecosystems of the world, 4A. Elsevier, Amsterdam.

Gould C. 1862a. Macquarie Harbour. Mr. Gould's report. Legislative Council Journal volume VII, report 20, Hobart, Tasmania.

Gould C. 1862b. Safety of Mr. Gould's party. Discovery of a gold field and valuable mineral country. Mercury Newspaper, 14 May 1860.

Gould J. E. 1991. Validation of the Rothermel fire-spread and related fuel parameters. In: N. P. Cheney and A. M. Gill (eds). Proceedings of the Conference on Bushfire Modelling and Fire Danger Rating. Commonwealth Scientific and Industrial Research Organisation, Canberra.

Gould J. S. 1993. Prescribed burning in coastal regrowth *E. sieberi* forest. In: J. Ross (editor). The burning question: fire management in New South Wales. University of New England, Armidale, New South Wales.

Gowlland R. and Gowlland K. 1976. Trampled wilderness. The history of south-west Tasmania. Third edition, 1986. Richmond Printers, Devonport, Tasmania.

Haggstrom D. 1994. Fire and forest management policies on the boreal forest and wildlife of interior Alaska. Wildfire 3: 30-38.

Hales R. C. 1918. Unpublished track report: Exploration of Gordon - Tyenna track. NP 21/14, Archives Office of Tasmania.

Hannan D. G., Banks M. R., Kiernan K., Pemberton M. and Williams E. 1993. Physical environment - geology, geomorphology and soils. In: S. J. Smith and M. R. Banks (eds). Tasmanian wilderness – world heritage values. Royal Society of Tasmania, Hobart, Tasmania.

Harris S. 1991. Coastal vegetation. In: J. B. Kirkpatrick (ed.). Tasmanian native bush: a management handbook. Tasmanian Environment Centre. Hobart, Tasmania.

Harwood C. E. and Jackson W. D. 1975. Atmospheric losses of four plant nutrients during a forest fire.Australian Forestry 38: 92-99.

Hatton T. J. and Viney N. R. 1988. Modelling fine dead, surface fuel moisture. In: N. P. Cheney and A. M. Gill (eds). Proceedings of the Conference on Bushfire Modelling and Fire Danger Rating Systems. Canberra, 11-12 July 1988. Division of Forestry, Commonwealth Scientific and Industrial Research Organisation, Canberra, ACT, Australia.

Hay J. 1871. Exploration trip to the west. Mercury Newspaper, 24 March 1871.

Hill R. S. 1982. Rainforest fire in Western Tasmania. Australian Journal of Botany 30: 583-589.

Hill R. S. and Read J. 1984. Post-fire regeneration of rainforest and mixed forest in western Tasmania. Australian Journal of Botany 32: 481-493.

Hills L. 1914. Geological reconnaissance of the country between Cape Sorell and Point Hibbs. Geological Survey Bulletin 18. Department of Mines, Hobart, Tasmania.

Hobbs R. J. and Gimingham C. H. 1984. Studies on fire in Scottish heathland communities. I. Fire characteristics. Journal of Ecology 72: 223-240.

Howard C. 1927. Notes on the country between Low Rocky Point and Fitzgerald. Report of the Director of Mines. Parliament of Tasmania Journal, 1927, report 4.

Hutson, B. R. 1985. Rates of litterfall and organic matter turnover at three South Australian indigenous forest sites. Australian Journal of Ecology 10: 351-359.

Innes E. G. 1887. The Derwent Valley Track to Linda. The Tasmanian Mail, 29 January 1887.

Innes E. G. 1896. Route to the west coast: Report of Mr. Surveyor Innes upon the country between Mount Humboldt and the head of the navigable water upon the River Gordon. Parliament of Tasmania Journal, 1896, report 74.

Innes E. G. 1897. Route to the west coast: Report of Mr. Surveyor Innes upon the track from Mole Creek to Rosebery, Mt Reid. Parliament of Tasmania Journal, 1897, report 43.

Jackson W. D. 1968. Fire, air, water and earth - an elemental ecology of Tasmania. Proceedings of the Ecological Society of Australia 3: 9-16.

Jackson W. D. 1977. Nutrient cycling in Tasmanian oligotrophic environments. In: Nutrient cycling in indigenous forest ecosystems. Proc. Symposium, Division of Land Resources Management, Commonwealth Scientific and Industrial Research Organisation, Perth, Australia.

Jackson W. D. 1981. The vegetation of Tasmania. Botany Department, University of Tasmania, Tasmania, Australia.

Janssen P. H. M. and Heuberger P. S. C. 1995. Calibration of process-oriented models. Ecological modelling 83: 55-66.

Jarman S. J. and Brown M. J. 1983. A definition of cool temperate rainforest in Tasmania. Search 14: 81-87.

Jarman S. J., Brown M. J. and Kantvilas G. 1984. Rainforest in Tasmania. National Parks and Wildlife Service, Tasmania.

Jarman S. J., Kantvilas G. and Brown M. J. 1988a. A preliminary study of stem ages in buttongrass moorlands. Research Report 3, Tasmanian Forest Research Council Inc., Hobart, Tasmania.

Jarman S. J., Kantvilas G. and Brown M. J. 1988b. Buttongrass moorland in Tasmania. Research Report 2, Tasmanian Forest Research Council Inc., Hobart, Tasmania.

Jarman S. J., Crowden R. K. and Brown M. J. 1982. A descriptive ecology of the vegetation in the lower Gordon River basin, Tasmania. Papers and Proceeding of the Royal Society of Tasmania 116: 165-177.

Johannes C. E. and Brown A. V. 1992. W. C. Piguenit 1836-1914 retrospective. Tasmanian Museum and Art Gallery, Hobart, Tasmania.

Johnson E. A. and Fryer G. I. 1989. Population dynamics in Lodgepole pine - Engelmann spruce forests. Ecology 70: 1335-1345.

Johnson E. A., Fryer G. I. and Heathcott M. J. 1990. The influence of man and climate on frequency of fire in the interior wet belt forest, British Columbia. Journal of Ecology 78: 403-412.

Johnson E. A., Miyanishi K. and Weir J. M. H. 1995. Old-growth, disturbance, and ecosystem management. Canadian Journal of Botany 73: 918-926.

Johnson E. A., Miyanishi K. and Weir J. M. H. 1996. Old-growth, disturbance, and ecosystem management: reply. Canadian Journal of Botany 74: 511.

Johnston B. 1935. To the Jane River. The Tasmanian Tramp 4: 5-12. Hobart Walking Club, Hobart, Tasmania.

Jones D. 1881. Report on track from Macquarie Harbour to upper Huon. Parliament of Tasmania Journal, 1881, report 126.

Jones R. 1969. Fire stick farming. Australian Natural History 16: 224-228.

Jones R. 1993. Discovery of a Pleistocene world. In: S. J. Smith and M. R. Banks (eds). Proceedings of the Tasmanian Wilderness - World Heritage Values symposium 3rd and 4th November 1990. Royal Society of Tasmania, Hobart, Tasmania.

Jones R. 1995. Mindjongork: legacy of the firestick. In: D. B. Rose. Country in flames. Proceedings of the 1994 symposium on biodiversity and fire in North Australia. Biodiversity Series, Paper No. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, The Australian National University, Canberra, Australia.

Keetch J. J. and Byram G. M. 1968. A drought index for forest fire control. USDA Forest Service Research Paper SE-38, Southeast Forest Experimental Station, Asherville, North Carolina, USA.

Keith D. A. 1996. Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. Proc. Linn. Soc. NSW 116: 37-78.

Keith D. A. and Bradstock R. A. 1994. Fire and competition in Australian heath: a conceptual model and field investigations. Journal of Vegetation Science 5: 347-354.

Kelly J. 1816. First discovery of Port Davey and Macquarie Harbour. Papers and Proceedings of the Royal Society of Tasmania 1920.

Kendall D. 1995. A framework for assessing the standard of wildfire protection provided by fuel reduction burning in the Franklin - Gordon Wild Rivers National Park. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Kiernan K., Jones R. and Ranson D. 1983. New evidence from Fraser Cave for glacial age man in south-west Tasmania. Nature 301: 28-32.

Kilgore B. M. 1985. The role of fire in wilderness: a state-of-knowledge review. In: R. C. Lucas (ed.). Proceedings of the National Wilderness Research Conference. USDA Forest Service General Technical Report INT-220. Intermountain Forest and Range Experimental Station, Ogden Utah, USA.

Kirkpatrick J. B. 1977. Native vegetation of the West Coast region of Tasmania. In: M. R. Banks and J. B. Kirkpatrick (eds). Landscape and man. Proceedings of the Symposium of the Royal Society of Tasmania.

Kirkpatrick J. B. 1982. Phytogeographical analysis of Tasmanian alpine floras. Journal of Biogeography 9: 255-271.

Kirkpatrick J. B. 1984a. Altitudinal and successional variation in the vegetation of the northern part of the West Coast Range, Tasmania. Australian Journal of Ecology 9: 81-91.

Kirkpatrick J. B. 1984b. Tasmanian high mountain vegetation II - Rocky Hill and Pyramid Mountain. Papers and Proceedings of the Royal Society of Tasmania. 118: 5-20.

Kirkpatrick J. B. and Brown M. J. 1987. The nature of the transition from sedgeland to alpine vegetation in south-west Tasmania. I altitudinal vegetation change on four mountains. Journal of Biogeography 14: 539-549.

Kirkpatrick J. B. and Brown M. J. 1991. Reservation analysis of Tasmanian forests. Resource Assessment Commission Forest and Timber Inquiry Consultancy Series No. FTC91/16.

Kirkpatrick J. B. and Dickinson K. J. M. 1984a. Impact of fire on Tasmanian alpine vegetation and soils. Australian Journal of Botany 32: 613-629.

Kirkpatrick J. B. and Dickinson K. J. M. 1984b. Vegetation map of Tasmania, 1 : 500 000. Forestry Commission, Hobart, Tasmania.

Kirkpatrick J. B. and Harwood C. E. 1980. Vegetation of an infrequently burned Tasmanian mountain region. Proceedings of the Royal Society of Victoria 91: 79-107.

Kirkpatrick J. B., Hutchinson M. N. and McQuillan P. B. 1993. Alpine ecosystems. In: S. J. Smith and M. R. Banks (eds). Tasmanian wilderness – world heritage values. Royal Society of Tasmania, Hobart, Tasmania.

Kirkpatrick J. B., Nunez M., Bridle K. and Chladil M. A. 1996. Explaining a sharp transition from sedgeland to alpine vegetation on Mt Sprent, southwest Tasmania. Journal of Vegetation Science 7: 763-768.

Kirkpatrick J. B., Peacock R. J., Cullen P. J. and Neyland M. G. 1988. The wet eucalypt forests of Tasmania. Tasmanian Conservation Trust, Hobart, Tasmania.

Kitzberger T., Veblen T. T. and Villalba R. 1997. Climatic influences on fire regimes along a rain forest-to-xeric woodland gradient in northern Patagonia, Argentina. Journal of Biogeography 24: 35-47.

Kohen J. L. 1995. Aboriginal environmental impacts. University of New South Wales Press, Sydney, Australia.

Lands, Parks and Wildlife. 1988a. Southwest National Park fire management plan. Department of Lands, Parks and Wildlife, Hobart, Tasmania.

Lands, Parks and Wildlife. 1988b. Fire management plan Franklin - Lower Gordon Wild Rivers National Park. Department of Lands, Parks and Wildlife, Hobart, Tasmania.

Leach M. K. and Givnish J. T. 1996. Ecological determinants of species loss in remnant prairies. Science 273: 1555-1558.

Legge W. V. 1887. The highlands of Lake St. Clair. Papers and proceedings of the Royal Society of Tasmania, 1887.

Leopold A. S., Cain S. A., Cottam C. M., Gabrielson I. N. and Kimball T. L. 1963. Wildlife management in the national parks. Transactions of the North American Wildland Natural Resources Conference 24: 28-45.

Lewis H. T. and McPartlan F. 1859. Diary of Mr. Henry Tayler Lewis and Mr. F. McPartlan. Mercury Newspaper, 2 June 1859.

Little J. 1833. Account of a journey from Macquarie Harbour to the Huon. Hobart Town Chronicle, 26 March 1833.

Luke R. H. and McArthur A. G. 1978. Bushfires in Australia. Division of Forest Research, CSIRO, Department of Primary Industry, Canberra.

Lunt I. D. 1995. Seed longevity of six native forbs in a closed *Themeda triandra* grassland. Australian Journal of Botany 43: 439-449.

MacLean A. R. 1978. Mineral nutrients in soils and vegetation of sedgeland and heathland communities in Southwest Tasmania. Unpublished honours thesis, University of Tasmania.

Macphail M. K. 1980. Regeneration process in Tasmanian forests. A long term perspective based on pollen analysis. Search 11: 184-190.

Macphail M. K. 1981. A history of fire in the forest. In: Kirkpatrick J. B. (ed.), Fire and forest management in Tasmania. Tasmanian Conservation Trust, Hobart, Tasmania.

Marriott R. 1908. Report on track connecting Webster's Track with Great Western Railway Track. Department of Lands and Surveys: report for the year ended 30th June 1908. Parliament of Tasmania Journal, 1908, report 13.

Marsden E. A. 1898. Unpublished report regarding the construction of the track from Frodshams Pass to Bathurst Harbour. AOT LSD 6/194/849c, Lands and Survey Department, Hobart, Tasmania.

Marsden-Smedley J. B. 1990. The ecology of moorland-copse boundaries in southwest Tasmanian oligotrophic environments. Unpublished Honours Thesis, Department of Plant Science, University of Tasmania.

Marsden-Smedley J. B. 1993a. Fuel characteristics and fire behaviour in Tasmanian buttongrass moorlands. Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

Marsden-Smedley J. B. 1993b. Orange-bellied parrot recovery plan: operational prescriptions for habitat management burns. Unpublished report for the Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

Marsden-Smedley J. B. and Catchpole W. R. 1995a. Fire behaviour modelling in Tasmanian buttongrass moorlands. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Marsden-Smedley J. B. and Catchpole W. R. 1995b. Fire behaviour modelling in Tasmanian buttongrass moorlands. I. Fuel modelling. International Journal of Wildland Fire 5: 203-214.

Marsden-Smedley J. B. and Catchpole W. R. 1995c. Fire behaviour modelling in Tasmanian bnttongrass moorlands. II. Fire behaviour. International Journal of Wildland Fire 5: 215-228.

Marsden-Smedley J. B. and Catchpole W. R. submitted. Fire behaviour modelling in Tasmanian buttongrass moorlands. III. Fuel moisture. International Journal of Wildland Fire.

Marsden-Smedley J. B. and Williams K. J. 1993. Floristics and fire management in West Tamar buttongrass moorlands. Unpublished report for the Forestry Commission, Tasmania.

Marsden-Smedley J. B., Catchpole W. R. and Pyrke A. 1996. Unbounded burning in Tasmanian buttongrass moorlands: Preliminary results. Poster paper presented at the 13th Conference on Fire and Forest Meteorology. Lorne, Victoria, Australia.

Marsden-Smedley J. B., Catchpole W. R. and Pyrke A. 1998. Unbounded burning in Tasmanian buttongrass moorlands. Unpublished report prepared for the Tasmanian Fire Research Fund. Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Marsden-Smedley J. B., Rudman T. and Catchpole W. R. 1993. Fire modelling and fire behaviour in buttongrass moorlands. Poster paper presented at the Landscape Fires '93 conference. Department of Conservation and Land Management, Perth, Western Australia.

McAlpine R. S. 1995. Testing the effect of fuel consumption on fire spread rate. International Journal of Wildland Fire 5: 143-152.

McArthur A. G. 1962. Control burning in eucalypt forests. Department of National Development, Commonwealth of Australia, Forestry and Timber Research Bureau, Canberra, Leaflet 80.

McArthur A. G. 1966. Weather and grassland fire behaviour. Department of National Development, Commonwealth of Australia, Forestry and Timber Research Bureau, Canberra, Leaflet 100.

McArthur A. G. 1967. Fire behaviour in eucalypt forests. Department of National Development, Commonwealth of Australia, Forestry and Timber Research Bureau, Canberra, Leaflet 107.

McArthur A. G. 1973. Forest fire danger meter, mark 5. Forest Research Institute, Forestry and Timber Bureau, Canberra, Australia.

McArthur A. G. 1977. Grassland fire danger meter, mark 5. Country Fire Authority of Victoria, Melbourne. Published as a linear slide rule.

McAulay I. 1939. Tasmania's wild south west. Walkabout 1 August 1939.

McCaw L., Simpson G. and Mair G. 1992. Extreme wildfire behaviour in 3-year-old fuels in a Western Australian mixed *Eucalyptus* forest. Australian Forestry 55: 107-117.

McDonald R. C., Isbell R. F., Speight J. G., Walker J. and Hopkins M. S. 1990. Australian soil and land survey field handbook. Second edition. Inkata Press, Melbourne, Australia.

McGowan A. 1993. Historic heritage. In: S. J. Smith and M. R. Banks (eds). Tasmanian wilderness – world heritage values. Royal Society of Tasmania, Hobart, Tasmania.

McRae M. D. 1960. Port Davey and the South-west. Papers and Proceedings of the Tasmanian Historical Research Association 8: 46-50.

McShane I. 1982. T. B. Moore - a bushman of learning. Unpublished Honours Thesis, University of Tasmania.

Meredith G. C. 1876. Journal of a prospecting trip to western Tasmania. AOT NS718/1.

Meredith G. C. 1898. Journal of a prospecting trip to southwestern Tasmania. AOT NS718/9.

Mercer G. N., Gill A. M. and Weber R. O. 1995. A flexible, non-deterministic, litter accumulation model. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania.

Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Minnich R. A. and Chou Y. H. 1997. Wildland fire patch dynamics in the chaparral of southern California and northern Baja California. International Journal of Wildland Fire 7: 221-248.

Mitchell E. 1898. Bush fires. Letter to the Editor of the Mercury Newspaper, 15 January 1898.

Moore T. B. 1887. Description of a trip to Frenchmans Cap, in February 1887. Archives Office of Tasmania NS 573/1/10. Similar article printed in 1970 in Skyline 20: 5-9.

Morrison D. A., Buckney R. T., Bewick B. J. and Cary G. J. 1996. Conservation conflicts over burning bush in south-eastern Australia. Biological Conservation 76: 167-175.

Mount A. B. 1972. The derivation and testing of a soil dryness index using run-off data. Bulletin 4, Forestry Commission, Hobart, Tasmania.

Mount A. B. 1979. Natural regeneration processes in Tasmanian forests. Search 10: 180-186.

Mueller-Dombois D. and Ellenberg H. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York.

Mutch R. W. 1994. Fighting fire with prescribed fire: a return to ecosystem health. Journal of Forestry 92: 31-33.

Myers R. H. 1989. Classical and modern regression analysis with applications. 2nd edition. PWS-Kent, Mass.

Nelson R. M. 1984. A method for describing equilibrium moisture content of forest fuels. Canadian Journal of Forest Research. 14: 597-600.

Nelson R. M. and Adkins C. W. 1986. Flame characteristics of wind-driven surface fires. Canadian Journal of Forest Research 16: 1293-1300.

Noble I. R., Bary G. A. V. and Gill A. M. 1980. McArthur's fire-danger meters expressed as equations. Australian Journal of Ecology 5: 201-203.

Nunez M. 1978. Climate. In: Gee H. and J. Fenton. (eds.) The Southwest Book. Australian Conservation Foundation, Melbourne, Australia.

Nunez M. 1983. Estimation of solar radiation received on slopes in Tasmania. Papers and Proceedings of the Royal Society of Tasmania 117: 153-159.

Olson J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44: 322-332

Parks and Wildlife Service 1997. Henty-Anthony Fire Management Plan. Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

Parks, Wildlife and Heritage. 1992. Tasmanian Wilderness World Heritage Area Management Plan. Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

Parsons D. J., Graber D. M., Agee J. K. and van Wagtendonk J. W. 1986. Natural fire management in national parks. Environmental Management 10: 21-24.

Pech G. 1989. A model to predict the moisture content of reindeer lichen. Forest Science 35: 1014-1028.

Pedley J., Brown M. J. and Jarman S. J. 1980. A survey of Huon pine in the Pieman River State Reserve and environs. Wildlife Division Technical Report 80/2. National Parks and Wildlife Service, Tasmania.

Pemberton M. 1988. Soil erosion between Birchs Inlet and Elliott Bay, southwestern Tasmauia. Papers and Proceedings of the Royal Society of Tasmania 122: 109-114.

Pemberton M. 1989. Land systems of Tasmania region 7 - Southwest. Department of Agriculture, Hobart, Tasmauia.

Pemberton M. and Cullen P. 1995. Impacts of fire on soils in Tasmania. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Perrin G. S. 1887. Wood and forests of Tasmania: report of the Conservator of Forests, 1886-7. Parliament of Tasmania Journal, 1887, report 59.

Perrin G. S. 1898. Forests of Tasmania: their conservation and future management. Parliament of Tasmania Journal, 1898, report 48.

Peterson M. 1990. Distribution and conservation of Huon Pine. Forestry Commission, Hobart, Tasmania.

Philp J. E. 1937. Unpublished manuscript: Where tracks are made. NS 21/22/1, Archives Office of Tasmania.

Piguenit W. C. 1892. Among the Western Highlands of Tasmania. Report of the Fourth Meeting of the Australasian Association for the Advancement of Science, 1892, Hobart, Tasmania. Transactions of the Australasian Association for the Advancement of Science. Government Printer, Tasmania.

Plomley N. J. B. 1966. Friendly mission: the Tasmanian journals and papers of George Augustus Robinson 1829-1834. Tasmanian Historical Research Association, Hobart, Tasmania.

Plomley N. J. B. 1991. Jorgen Jorgenson and the Aborigines of Van Diemen's Land. Blubberhead Press, Hobart, Tasmania, Australia.

Pook E. W. and Gill A. M. 1993. Variation of live and dead fine fuel moisture in *Pinus radiata* plantations of the Australian Capital Territory. International Journal of Wildland Fire 3: 155-168.

Pyne S. J. 1984. Introduction to Wildland Fire. Fire Management in the United States. Johu Wiley and Sons, New York.

Pyne S. J. 1991. Burning bush: a fire history of Australia. Henery Holt, New York.

Ratkowski D. A. 1990. Handbook of non-linear regression models. Marcel Dekker, New York.

Robertson D. I. and Duncan F. 1991. Distribution and conservation of deciduous beech. Forestry Commission Tasmania and Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

Romme W. H. and Despain D. G. 1989. Historical perspective on the Yellowstone fires of 1988. A reconstruction of prehistoric fire history reveals that comparable fires occurred in the early 1700s. BioScience 39: 695-699.

Roth H. L. 1899. The Aborigines of Tasmania. Fullers Bookshop, Hobart, Tasmania.

Rothermel R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service Research Paper INT-115. Intermountain Forest and Range Experimental Station, Ogden, Utah, USA.

Rothermel R. C. and Philpot C. W. 1973. Predicting changes in chaparral flammability. Journal of Forestry 71: 640-643.

Rothermel R. C., Wilson R. A., Morris G. A. and Sackett S. S. 1986. Modelling moisture content of fine dead wildland fuels: input to the BEHAVE fire prediction system. USDA Forest Service Research Paper INT-359, Intermountain Research Station, Ogden, Utah, USA.

Savage M. 1997. The role of anthropogenic influences in a mixed-conifer forest mortality episode. Journal of Vegetation Science 8: 95-104.

Schullery P. 1989. The fires and fire policy. The drama of the 1988 Yellowstone fires generated a review of national policy. BioScience 39: 686-694.

Scott J. R. 1871. Arthur Plains and Port Davey. Mercury Newspaper, 5 April 1871.

Scott J. R. 1875. Port Davey in 1875. Papers of the Royal Society of Tasmania.

Searle S. R., Casella G. and McCulloch C. E. 1992. Variance components. Wiley, New York.

Sharland W. S. 1861. Rough notes of a journal of expedition to the westward in 1832. Survey Office Reports, Legislative Council Journal volume VI part 1, report 16, Hobart, Tasmania.

Silverman, B.W. 1986. A fast and efficient cross-validation method for smoothing parameter choice in spline regression. Journal of the American Statistical Association 79: 584-589.

Simard A. J. 1968 The moisture content of forest fuels I. A review of the basic concepts. Canadian Department of Forest and Rural Development, Forest Fire Research Institute, Information Report FF-X-14, Ottawa Ontario.

Singh G. and Geissler E. A. 1985. Late Cainozoic history of vegetation, fire, lake levels and climate at Lake George, New South Wales, Australia. Philosophical Transactions, Royal Society of London. 311: 379-447.

Singh G., Kershaw A. P. and Clark R. L. 1981. Quaternary vegetation and fire history in Australia. In: A. M. Gill, R. H. Groves and I. R. Noble. Fire and the Australian biota. Australian Academy of Science, Canberra, Australia.

Snedecor G. W. and Cochrane W. G. 1980. Statistical methods. Seventh edition. Iowa State University Press, Ames, Iowa.

Sneeuwjagt R. J. and Frandsen W. H. 1977. Behaviour of experimental fires vs. predictions based on Rothermel's fire model. Canadian Journal of Forest Research 7: 357-367.

Sneeuwjagt R. J. and Peet G. B. 1985. Forest fire behaviour tables for Western Australia. Western Australian Department of Conservation and Land management, Perth, Western Australia.

Specht R. L. 1966. The growth and distribution of mallee-broombrush (*Eucalyptus incrassata-Melaleuca uncinata* association) and heath vegetation near Dark Island Soak, Ninety-Mile Plain, South Australia. Australian Journal of Botany 14: 361-371.

State Emergency Service. 1990. History of emergency events issue 1. July 1990. State Emergency Service, Hobart, Tasmania.

Statistical Sciences. 1993. S-PLUS for Windows. Reference manual. Volume 1. Version 3.1. Statistical Sciences Inc., Seattle, Washington.

Stephenson L. H. 1991. The Orange-bellied Parrot recovery plan: Management phase. Department of Parks, Wildlife and Heritage, Tasmania.

Stockton J. 1982. Fires by the seaside: historic vegetation changes in northwestern Tasmania. Papers and Proceedings of the Royal Society of Tasmania 116: 53-66.

Stull R. B. 1995. Meteorology today for scientists and engineers. West Publishing Company, Minneapolis/St Paul, USA

Tasmanian Fire Review Committee. 1994. Review of vegetation-based fire in Tasmania. Report. Hobart, Tasmania.

Taylor R. J. and Comfort M. D. 1993. Small terrestrial mammals and bats of Melaleuca and Claytons, Southwestern Tasmania. Papers and Proceedings of the Royal Society of Tasmania 127: 33- 37.

Thirkell R. A. C. 1908. Report on track from Mt Arrowsmith to Gordon River. Department of Lands and Surveys: report for the year ended 30th June 1908. Parliament of Tasmania Journal, 1908, report 13.

Thomas I. 1991. The Holocene archaeology and palaeoecology of Northeastern Tasmania, Australia. Unpublished PhD thesis, University of Tasmania.

Thomas I. 1993a. Late Pleistocene environments and Aboriginal settlement patterns in Tasmania. Australian Archaeology 36: 1-11.

Thomas I. 1993b. The Central Highlands. In: S. J. Smith and M. R. Banks (eds). Proceedings of the Tasmanian Wilderness - World Heritage Values symposium 3rd and 4th November 1990. Royal Society of Tasmania, Hobart, Tasmania.

Thomas I. 1995. Where has all the forest gone: new pollen evidence from Melaleuca Inlet in SW Tasmania. In: G. Dixon and D. Aitkin (eds). Monash University Publications in Geography 45: 295-301.

Thomas I. and Hope G. 1994. An example of Holocene vegetation stability from Camerons Lagoon, a near treeline site on the Central Plateau, Tasmania. Australian Journal of Ecology 19: 150-158.

Thomas P. H. 1963. The size of flames from natural fires. Ninth Symposium on Combustion, The Combustion Institute, Pittsburgh, PA, USA.

Thomas P. H. 1970. The rates of spread of head fires in gorse and heather. FR Note No. 796, Joint Fire Research Organisation, Ministry of Technical and Fire Office's Commission, England.

Thomas P. H. 1971. Rates of spread of some wind-driven fires. Forestry 44: 155-175.

Thwaites J. B. 1934. Frenchman's Cap. The Tasmanian Tramp 3: 5-11. Hobart Walking Club, Hobart, Tasmania.

Tolhurst K. G. 1996. The effects of fuel reduction burning on litter loads in a dry sclerophyll forest. In: J. R. Merrick. Proceedings of the Fire and Biodiversity: the effects and effectiveness of fire management conference, 8 - 9 October 1994, Footscray, Melbourne, Victoria, Australia.

Tully W. A. 1859. The western country. Mercury Newspaper, 26 April 1859.

Twelvetrees W. H. 1906. Unpublished report on the Cox Bight Tin field. AC 19, Archives Office of Tasmania.

Twelvetrees W. H. 1908. Report by Mr. W. H. Twelvetrees, Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1908. Parliament of Tasmania Journal, 1908, report 13.

Twelvetrees W. H. 1909. Western exploration: report on journey to the Gordon River by Mr. W. H. Twelvetrees, Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1909. Parliament of Tasmania Journal, 1909, report 21.

Twelvetrees W. H. 1915. Annual report of the Government Geologist. Department of Mines, Hobart, Tasmania.

Tyler W. H. and Harper W. T. 1906. Cox's Bight. Mercury Newspaper, 19 April 1906.

van Wagner C. E. 1969. Combined effect of sun and wind on surface temperature of litter. Canadian Forestry Service Information Report PS-X-10, Petawawa Forest Experimental Station, Chalk River, Ontario.

van Wagner C. E. 1972. Equilibrium moisture contents of some fine forest fuels in eastern Canada. Canadian Forestry Service Information Report PS-X-36, Petawawa Forest Experimental Station, Chalk River, Ontario.

van Wagner C. E. and Pickett T. L. 1985. Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. Canadian Forestry Service Technical Report 33.

van Wilgen B. W. 1982. Some effects of post-fire age on the above-ground plant biomass of fynbos (macchia) vegetation in South Africa. Journal of Ecology 70:217-225.

van Wilgen B. W., Richardson D. M. and Seydack A. H. W. 1994. Managing fynbos for biodiversity: constraints and options in a fire-prone environment. South African Journal of Science 90: 322-329.

Villalba R. and Veblen T. T. 1997. Regional patterns of tree population structures in northern Patagonia: climatic and disturbance influences. Journal of Ecology 85: 113-124.

Viney N. R. 1991. A review of fine fuel moisture modelling. International Journal of Wildland Fire 1: 215-234.

Viney N. R. 1992. Modelling fine fuel moisture content. Unpublished PhD thesis, Department of Mathematics, University College, University of New South Wales, Canberra, ACT.

Walker J. 1981. Fuel dynamics in Australian forests. In: A. M. Gill, R. H. Groves and I. R. Noble (eds.) Fire and the Australian biota. Australian Academy of Science, Canberra.

Walker J. B. 1887. Walk to the west. In: Stoddart M. (ed.). Journal of a trip to Tasmania's west coast, 17 February to 5 March 1887. Royal Society of Tasmania.

Wallace W. H. 1901. Report of the Secretary for Mines for 1900-1901. Parliament of Tasmania Journal, 1901, report 4.

Ward L. K. 1908. Report by M. L. K. Ward, Assistant Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1908. Parliament of Tasmania Journal, 1908, report 13.

Ward L. K. 1909. Report by M. L. K. Ward, Assistant Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1909. Parliament of Tasmania Journal, 1909, report 21.

Warren R. 1936. Diary of two wretched females on a trip to Frenchman's Cap. The Tasmanian Tramp 5: 44-48. Hobart Walking Club, Hobart, Tasmania.

Wilson R. A. 1980. Reformulation of fire spread equations in SI units. USDA Forest Service Research Note INT-292. Intermountain Forest and Range Experimental Station, Ogden Utah, USA.

Wilson R. A. 1985. Observations of extinction and marginal burning states in free burning porous fuel beds. Combustion Science Technology 44: 179-193.

Appendix 1. Historical references used

Published sources

Author(s)	Location or title	Subject	Source	Date and issue	Notes
Kelly J	Pt Davey and Macquarie Hbr	exploration	journal	1815	Pap. Proc. Roy. Soc. Tasm. 1920:160-181,*
Goodwin J	Macquarie Hbr to Derwent R.	exploration	CSO 1/276/6658, AOT	1828	
Little J	Macquarie Harbour to the Huon	exploration	Hobart Town Chronicle	25 March 1833	
Baylee ?	comment on trip of J. Little 1833	history	The capture of the Frederick	1834	republished by Sullivans Cove Press 1981
Frankland G	middle Gordon to the Huon	exploration	Hobart Town Courier	27 Mar 1835	*
Frankland G	Lk St Clair, Huon R.	exploration	Hobart Town Courier	15 Jul 1836	
Davies RH	Aborigines of Van Diemen's Land	history	Tas. J. of Natural Sci.	1846: II, 409-420	*
Calder JE	Existence of Aborigines	history	Royal Society of Tasmania	RS 19/6, 1847	letter detailing existence of Aborigines, *
Calder JE	Lake St Clair to Macquarie Hbr	track cutting	Tas. J. of Natural Sci.	1849: III, 415-429	*
Cotton H	Pt Davey, Bathurst Hbr, Arthur Pl.	exploration	CSO 24/130/4347/368-372	1850	Survey Office Report, includes map, *
Cotton H	Pt Davey, Bathurst Hbr, Arthur Pl.	exploration	Hobart Town Gazette	8 Apr 1851	*
Tully WA	upper Franklin & Collingwood R.	exploration	Mercury	26 Apr 1859	*
Lewis T and McPartlan F	Davey and Hardwood Rivers	exploration	Mercury	2 Jun 1859	*
Calder JE	Topographical Sketch: I	track cutting	Mercury	21 Jan 1860	notes on Franklin's 1832 trip, *
Calder JE	Topographical Sketch: II	track cutting	Mercury	25 Jan 1860	notes on Franklin's 1832 trip
Calder JE	Topographical Sketch: III	track cutting	Mercury	27 Jan 1860	notes on Franklin's 1832 trip, *
Calder JE	Topographical Sketch: IV	track cutting	Mercury	9 Feb 1860	notes on Franklin's 1832 trip, *
Calder JE	Topographical Sketch: V	track cutting	Mercury	6 Mar 1860	notes on Franklin's 1832 trip, *
Calder JE	Hamilton to Lake Pedder	exploration	Mercury	13 Apr 1860	*
Gunn RC	Hampshire Hills	exploration	Mercury	17 Apr 1860	*
Sharland WS	Bronte to Frenchmans Cap	exploration	Legislative Council J.	1861: 16	Survey Office Report, *
Burgess G	Lake St Clair to King R.	search	Mercury	10 May 1862	
Gould C	Lake St Clair to Macquarie Hbr	exploration	Mercury	14 May 1862	*
Editorial	C. Gould's exploration	comment	Mercury	16 May 1862	*
Gould C	Macquarie Harbour	exploration	House of Assembly J.	1862: 20	*
Fennyfather ?	Lake St Clair to King R.	search	Mercury	3 May 1862	
Sorell HP	Lake St Clair to King R.	search	Mercury	10 May 1862	
Gould C	Macquarie Harbour	exploration	Legislative Council J.	1863: 1A	*
Dumaresq A	Mt Arrowsmith	exploration	Legislative Council J.	1863: 50	
Hay J	Huon to Lake Pedder	exploration	Mercury	24 Mar 1871	*
Scott JR	Huon to Port Davey	exploration	Mercury	5 Apr 1871	*
Scott JR	Port Esperance to Adamsons Pk	exploration	Pap. Proc. Roy. Soc. Tasm.	1872: 50-54	*
Scott JR	Port Davey in 1875	exploration	Pap. Proc. Roy. Soc. Tasm.	1875: 94-107	includes illustrations, *
Meredith GC	Macquarie Harbour to Pieman R	exploration	NS718/1, AOT	1876	field note book, *
Scott JR	Routes to the West Coast	track locations	House of Assembly J.	1876: 104	
Sprent CP	Mount Bischoff	exploration	House of Assembly J.	1876: 43	

Notes: * indicates reference to fires; CSO = Colonial Service Office; LSD = Lands and Surveys Department; AOT = Archives Office of Tasmania.

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Author(s)	Location or title	Subject	Source	Date and issue	Notes
Counsel EA	Malborough to Pieman River	track location	House of Assembly J.	1878: 47	also Legislative Council J. 1878 report 56
Frodsham T	Vale of Rasselas, Macquarie Hbr	track location	House of Assembly J.	1878: 48	also Legislative Council J. 1878 report 55
Sprent CP	West Coast	exploration	House of Assembly J.	1878: 51	
Jones D	Macquarie Harbour to Huon	track cutting	House of Assembly J.	1881: 126	includes map, *
Thureau G	West Coast	mine report	House of Assembly J.	1881: 82	
Moore TB	Lake St Clair to Macquarie Hbr	exploration	House of Assembly J.	1883: 56	*
Innes EG	Linda Track	track notes	Tasmanian Mail	29 Jan 1887	*
Legge WV	Lake St Clair	exploration	Pap. Proc. Roy. Soc. Tasm.	1887: 114-127	includes map, *
Perrin GS	Woods and forests of Tasmania	timber industry	House of Assembly J.	1887: 59	*
Sprent CP	Ouse to Mt Lyell	track cutting	House of Assembly J.	1887: 58	
Walker JB	Lk St Clair, Mt Lyell, West Coast	recreation	journal	1887	published by Royal Society of Tasmania, *
Andrew J	Lk St Clair to the west	notes	Pap. Proc. Roy. Soc. Tasm.	1888: 49-53	
Moore TB	King River to Frenchmans Cap	exploration	NS573/1/10, AOT	1887	similar to article in Skyline 20: 5-9, *
Roth HL	The Aborigines of Tasmania	book	Aborigines of Tasmania	1890	*
Piguenit WC	Huon to Port Davey	exploration	Trans. Aust. Ass. Adv. Sci.	1892: 3 to 10	includes illustrations
Frodsham T	Mt Field to Mt Arrowsmith	exploration	House of Assembly J.	1896: 82	includes map
Innes EG	Mt Field and Gordon River	track cutting	House of Assembly J.	1896: 74	*
Meredith GC	Gordon River to the Serpentine R.	exploration	NS718, AOT	1896	field note book
Meredith GC	Gordon River to the Serpentine R.	track cutting	House of Assembly J.	1896: 53	
Nicholls HM	Mt Field and Gordon River	exploration	House of Assembly J.	1896: 74	
Innes EG	Mole Creek to Mt Read	track cutting	House of Assembly J.	1897: 43	
Marsden EA	Vale of Rasselas to Linda Tk	track location	LSD 1866f/421, AOT	1897	original report
Stephens T	exploration routes	notes	Pap. Proc. Roy. Soc. Tasm.	1897: 189-196	
Walker JB	Aboriginal tribal divisions	research paper	Pap. Proc. Roy. Soc. Tasm.	1897: 176-187	
Mercury Newspaper		Mt Lyell	1897/98 fires	Mercury	31-Dec-1897
Counsel EA	Timber Industry of Tasmania	timber industry	House of Assembly J.	1898: 48	*
Marsden EA	Tyenna to Port Davey	track cutting	LSD 6849c, AOT	1898	original report, *
Meredith GC	Cox Bight, Bathurst Harbour	exploration	NS718/9, AOT	1898	field note book, *
Perrin GS	Forests of Tasmania	timber industry	House of Assembly J.	1898: 48	*
Mercury Newspaper	Mt Lyell, Mt Read	1897/98 fires	Mercury	4 Jan 1898	*
Mercury Newspaper	Lake St Clair	1897/98 fires	Mercury	6 Jan 1898	*
Tasmanian Mail	West Coast	1897/98 fires	Tasmanian Mail	8 Jan 1898	*
Tasmanian Mail	Mt Lyell	1897/98 fires	Tasmanian Mail	15 Jan 1898	*
Mercury Newspaper		letter	Mercury	15 Jan 1898	*
Reynolds WR	Sheffield to Rosebery	exploration	House of Assembly J.	1899: 43	
Walker JB	The Tasmanian Aborigines	research paper	Pap. Proc. Roy. Soc. Tasm.	1898-99: 65-73	also House of Assembly J. 1899 report 82
Ewart R	Red Hills to Eldon Bluff	track cutting	House of Assembly J.	1900: 44	Surveyor-General report, includes maps
Moore JA	Linda Track to the Jane River	track cutting	House of Assembly J.	1900: 44	Surveyor-General report, includes maps, *

Notes: * indicates reference to fires; CSO = Colonial Service Office; LSD = Lands and Surveys Department; AOT = Archives Office of Tasmania.

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Author(s)	Location or title	Subject	Source	Date and issue	Notes
Moore TB	Birchs Inlet to Port Davey	track cutting	House of Assembly J.	1900: 44	Surveyor-General report, includes maps, *
Ewart R	Lake Selina to Lake St Clair	track cutting	House of Assembly J.	1901: 47	Surveyor-General report, includes maps
Moore TB	Hastings to Port Davey	track cutting	House of Assembly J.	1901: 47	Surveyor-General report, includes maps
Wallace WH	West Coast mine report	mine report	House of Assembly J.	1901: 4	includes photos of recently burnt areas, *
Webster R	Magnet to Balfour	track cutting	House of Assembly J.	1901: 47	Surveyor-General report, includes maps
Ewart R	Mt Pelion to Gormanston	track cutting	House of Assembly J.	1902: 42	Surveyor-General report, includes maps
Richards W	Hartz Mountains	recreation	Weekly Courier	15 Feb 1902	*
Twelvetrees WH	Cox Bight tin field	exploration	AC19/6, AOT	1906	unpublished report
Tyler WH and Harper WT	South Coast track	track location	Mercury	19 Apr 1906	*
Innes EG	Linda Track to Prince of Wales Ra	track cutting	House of Assembly J.	1908: 13	Surveyor-General report, *
Marriott R	Gordon Bend to Prince of Wales Ra	track cutting	House of Assembly J.	1908: 13	Surveyor-General report, *
Moore TB	Bathurst Hbr to Hastings	track cutting	House of Assembly J.	1908: 13	Surveyor-General report
Thirkell RAC	Mt Arrowsmith to Gordon River	track cutting	House of Assembly J.	1908: 13	Surveyor-General report, *
Twelvetrees WH	Gordon R. to Prince of Wales Ra.	exploration	House of Assembly J.	1908: 13	Surveyor-General report, *
Ward LK	Linda Track	exploration	House of Assembly J.	1908: 13	Surveyor-General report, *
Twelvetrees WH	Tyenna to Gordon River	exploration	House of Assembly J.	1909: 21	Surveyor-General report, *
Ward LK	Linda Track to the Jane River	exploration	House of Assembly J.	1909: 21	Surveyor-General report, *
Philp JE	Track to Frenchmans Cap	track location	NS 573/1/10, AOT	1910	track notes
Condor H	Macquarie Harbour to Port Davey	track cutting	Mercury	31 Mar 1915	
Hills L	Macquarie Hbr to Spero R.	exploration	Geol. Survey Bull.	1914: 18	
Twelvetrees WH	geological report	annual report	Mines Department	1915	
Hales RC	Gordon - Tyenna track	track cutting	NP 21/14, AOT	1918	Public Works Department report
Seager PS and Lord CE	Mt Field National Park	annual review	House of Assembly J.	1922: 17	National Park Board: report, *
Howard C	Low Rocky Point to Fitzgerald	exploration	House of Assembly J.	1927: 4	Director of Mines report
Smithies F	Frenchmans Cap	recreation	The Weekly Courier	29 Apr 1931	
Philp JE	Where tracks are made	exploration	NS 21/22/1, AOT	1937	unpublished manuscript, *
McAulay I	Pt Davey	recreation	Walkabout	1-Aug-39	*
Thwaites J	Frenchmans Cap	recreation	Tasmanian Tramp	1934: 3, 5-11	*
Johnston B	Linda Track to Jane River	recreation	Tasmanian Tramp	1935: 4, 5-12	
Warren R	Frenchmans Cap	recreation	Tasmanian Tramp	1936: 5, 44-48	*
Harvey DM	Frenchmans Cap	recreation	NS 573/1/10, AOT	Easter 1946	*
Franks SM	Land exploration in Tasmania	history	MA thesis	1958	unpublished, University of Tasmania, *
Gowlland R & K	Trampled wilderness	history	book	1978	Richmond Printers, Devonport, *
Binks CJ	Explorers of western Tasmania	history	book	1982	Mary Fisher Bookshop, Launceston, *
McShane I	T.B. Moore-a bushman of learning	history	Honours thesis	1982	unpublished, University of Tasmania, *
Flanagan R	A terrible beauty.	history	book	1985	Greenhouse Publications

Notes: * indicates reference to fires; CSO = Colonial Service Office; LSD = Lands and Surveys Department; AOT = Archives Office of Tasmania.

Historical photographs showing the effects of fires

Photographer	Location	Source	Date	Notes
Beattie Photo	Spring River, Port Davey	Weekly Courier	18 April 1903 page 17	shows effect of 1897/98 fires
	Mt La Perouse	Weekly Courier	8 Aug 1903 page 18	shows effect of 1897/98 fires
Smithies F	Frenchmans Cap	NS 573/4/3, AOT	1928 to 1931	shows effect of 1897/98 fires
Thwaites JB	Linda Track	NS 1155/2, AOT	1928	shows effect of 1897/98 fires
	Pindars Pk, Southern Ranges	30/4834, AOT	1920s	shows effect of 1897/98 fires
	Mt Read	Wallace 1901	1901	shows effect of 1897/98 fire
Smithies F	Lyell Highway, Nelson River	Weekly Courier	14 Dec 1933 page 2	very extensively burnt
Major RH	Frenchmans Cap	NS 385/7/4, AOT	1937	360° panorama, shows effect of 1933/34 fires
Major RH	Navarre Plains, Surprise Valley	NS 385/7/11, AOT	1938	panorama, shows effect of 1933/34 fires
Major RH	Raglan Range	NS 385/7/10, AOT	1938	panorama, shows effect of 1933/34 fires
Major RH	Mt Eliza	NS 385/7/9, AOT	1938	360° panorama, shows effect of 1933/34 fires
Major RH	Mt Jukes to Frenchmans Cap	NS 385/7/29, AOT	1939	panorama, shows effect of 1933/34 and 1939 fires
Major RH	Warners Lookout, Jane River	NS 385/7/13, AOT	1939	panorama, shows effect of 1933/34 fires
Major RH	Lake Judd, Huon Plains	NS 385/7, AOT	1940	extensive panorama, shows effect of 1933/34 fires
Major RH	Vale of Rasselas	NS 385/7/30-31, AOT	1942	panorama, shows effect of 1933/34 fires
Pinkard D	Spires	unpublished	1950	shows effect of 1950 Spires fire

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Appendix 1. Historical references

Historical maps

Author	Location	Reference/source	Date	Notes
Bateman JR	lower Gordon River	published in Porter 1834	1833	republished by Sullivans Cove Press 1981
Cotton H	southwest Tasmania	CSO 24/130/4347/403	1850	
Thomas ?	Gordon, Wedge and Boyd Rivers	Lands and Survey Department	1860	Exploration Map 27, DELM
Jones D	Gordon to Huon Rivers	House of Assembly Journal 1881: 126	1881	
Legge WV	Lake St Clair	Pap. and Proc. of the Roy. Soc. Tasm.1887: 114-127	1887	
Frodsham T	Florentine to Weld Rivers	Lands and Survey Department	1890	Track Plan 5, DELM
Frodsham T	Mt Field to Mt Arrowsmith	House of Assembly Journal 1896: 82	1896	
Innes EG	Mt Field to Gordon River	Lands and Survey Department	1896	1" to 5 miles, Exploration Map 18, DELM
Marsden EA	Mt Field to Mt Arrowsmith	Lands and Survey Department	1896	Track Plans 6 and 10, DELM
Trappes FM	Tyenna to Gordon River	Lands and Survey Department	1896	Track Plan 7, DELM
Marsden EA	Tyenna to Port Davey	Lands and Survey Department	1898	Track Plan 12, DELM
Moore JL	Linda Track to Jane River	Lands and Survey Department	1900	1" to 1 mile, Track Plan 13, DELM
Moore TB	Birchs Inlet to Port Davey	Lands and Survey Department	1900	1" to 2 1/2 miles, Track Plan 15, DELM
Moore TB	Birchs Inlet to Port Davey	Lands and Survey Department	1900	1" to 5 miles, Track Plan 16, DELM
Moore TB	Hastings to Port Davey	Lands and Survey Department	1901	Track Plan 18, DELM
Moore TB	Cox Bight to Port Davey Track	Lands and Survey Department	1902	Track Plan 34, DELM
Moore TB	Mt Darwin to Gordon River	Lands and Survey Department	1903	Track Plan 35, DELM
Moore TB	Port Davey to Hartz Mountains	Lands and Survey Department	1905	Track Plan 36, DELM
Thirkell RAC	Linda Track to Gordon River	Lands and Survey Department	1908	Track Plan 40, DELM
Ewart R	Gordon River from Pyramid Island	Lands and Survey Department	1909	Track Plan 42, DELM
Lands and Survey	Western Explorer	Lands and Survey Department	1909	
Condor H	Spero River to Mainwaring River	Lands and Survey Department	1915	2" to 1 mile, Track Plan 44, DELM
Hales RC	Tyenna to Gordon River	Lands and Survey Department	1918	1" to 2 1/2 miles, Track Plan 45, DELM
Department of Mines	South West Tasmania	Department of Mines	1930	
Department of Mines	West coast of Tasmania	Department of Mines	1930	
Lands and Survey	Spero Bay to the Channel	Lands and Survey Department	1938	
Department of Mines	South West Tasmania	Department of Mines	1943	1" to 2 1/2 milesExploration Map 25, DELM
Lands and Survey	South West Tasmania	Lands and Survey Department	1944	1" to 4 miles
Lands and Survey	North West Tasmania	Lands and Survey Department	1944	1" to 4 miles
Hobart Walking Club	Picton - La Perouse	NS 667/7, Archives Office of Tasmania	1944/48	
Hobart Walking Club	Cox Bight to Ironbound Range	NS 667/5, Archives Office of Tasmania	1949	Drawn by R. N. Smith
Hobart Walking Club	South West Tasmania	NS 667/2, Archives Office of Tasmania	1952	Drawn by R. N. Smith
Hobart Walking Club	Federation Peak	NS 667/1, Archives Office of Tasmania	1958	Drawn by J. E. Young and J. E. Davis
Hobart Walking Club	Mt Anne	NS 667/6, Archives Office of Tasmania	1960	Drawn by D. W. Wilson
Department of Mines	South West Tasmania	Department of Mines	1960	Exploration Maps 24 and 25, DELM
Hobart Walking Club	Western Arthurs	NS 667/3, Archives Office of Tasmania	1967	

Note: DELM = Land Information Services, Department of Environment and Land Management, Hobart.

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
1	Cape Sorell	53090	53090	100	1985	Marsden-Smedley 1993a
2	Sassy Creek	52480	52480	90	1970	Jarman et al. 1988b
3	Waterloo Creek	52510	52510	110	1970	Jarman et al. 1988b
4	Moores Valley	52660	52660	70	1976	Jarman et al. 1988b
5	Moores Valley	52680	52680	60	1945	Jarman et al. 1988b
6	Moores Valley	52620	52620	180	1933/34, 1950	Jarman et al. 1988b
7	Wanderer River	52560	52560	160	1960	Jarman et al. 1988b
8	Moores Valley	52640	52640	60	1976	Jarman et al. 1988b
9	Little Percy River	52770	52770	320	1940	Jarman et al. 1988b
10	Nye Bay	52040	52040	80	1977	Marsden-Smedley unpublished
11	Rocky Sprent River	52780	52780	320	1962?	Jarman et al. 1988b
12	Elliot Range	52960	52960	840	1939	Jarman et al. 1988b
13	Mt McCall	53080	53080	710	1966	Jarman et al. 1988b
14	Mt McCall	53080	53080	730	1945	Jarman et al. 1988b
15	Nelson Falls	53380	53380	360	1939	Marsden-Smedley unpublished
16	Rocky Sprent, Stranger Cr	52670	52670	260	1933/34?	Jarman et al. 1988b
17	Victoria Pass	53370	53370	560	1970	Marsden-Smedley unpublished
18	Mt Hean	52200	52200	700	1960	Jarman et al. 1988b
19	Olga River	52548	52548	80	1969	Maclean 1978
20	Olga River	52548	52548	70	1969	Maclean 1978
21	Red Point Hills	58000	58000	130	1948	Marsden-Smedley unpublished
22	Olga River	52570	52570	80	1933/34	Gellie 1980
23	Olga River	52554	52554	70	1933/34	Maclean 1978
24	Olga River	52555	52555	70	1933/34	Maclean 1978
25	Lightning Plains	53110	53110	380	1966	Jarman et al. 1988b
26	Orange River	52604	52604	83	pre 1920s	Maclean 1978
27	Propsting Ra	52310	52310	830	1933/34	Jarman et al. 1988b
28	Lyell Hwy	53332	53332	395	1977	Marsden-Smedley unpublished
29	Lyell Hwy	53337	53337	380	1986	Marsden-Smedley 1993a
30	Collingwood Plain	53297	53297	390	1984	Marsden-Smedley unpublished
31	Settlement Point	52151	52151	20	1970	Byrant 1991
32	Going Hill	51954	51954	213	1974, ≈1921	Marsden-Smedley unpublished
33	Port Davey, Payne Bay	52130	52130	10	1975	Jarman et al. 1988b
34	Fire Hill	51970	51970	117	1974, ≈1921	Marsden-Smedley unpublished

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
35	Norman Cove	51965	51965	20	1974, ≈1921	Marsden-Smedley unpublished
36	Fire Hill	51969	51969	40	≈1974, ≈1921	Marsden-Smedley unpublished
37	Stonehaven Hill	53268	53268	380	1974	Marsden-Smedley unpublished
38	Mt Sprent	52625	52625	820	1933/34, 1948	Marsden-Smedley unpublished
39	Stonehaven Hill	53268	53268	380	1974	Marsden-Smedley 1993a
40	Mt Sprent	52629	52629	630	1933/34	Parks and Wildlife unpublished
41	Stephens Bay	51964	51964	20	≈1974, ≈1921	Marsden-Smedley unpublished
42	Spain Bay	51973	51973	10	1974, ≈1921	Marsden-Smedley unpublished
43	Mt Sprent	52632	52632	500	1933/34	Parks and Wildlife unpublished
44	Chatfield Point	51937	51937	40	≈1974, ≈1921	Marsden-Smedley unpublished
45	Davey River	52290	52290	20	1978	Jarman et al. 1988b
46	Sunset Hill	51973	51973	60	≈1974, ≈1921	Marsden-Smedley unpublished
47	Artist Hill	53264	53264	390	1980	Marsden-Smedley 1993a
48	Davey River	52268	52268	80	1969	Byrant 1991
49	Davey River	52290	52290	30	1968	Jarman et al. 1988b
50	Hannant Inlet	50097	50097	20	1983	Marsden-Smedley unpublished
51	Noyhener Beach	51925	51925	20	1964, ≈1921	Marsden-Smedley unpublished
52	Bramble Cove	52030	52030	20	1974	Byrant 1991
53	Murgab Creek	51936	51936	20	≈1921	Marsden-Smedley unpublished
54	Jane River Tk, Adelaide River	53170	53170	510	1966	Jarman et al. 1988b
55	Jane River Tk, Loddon River	53190	53190	480	1966	Jarman et al. 1988b
56	Flying Cloud Point	51875	51875	40	≈1921	Marsden-Smedley unpublished
57	Murgab Creek	51940	51940	60	1964, ≈1921	Marsden-Smedley unpublished
58	Island bay	51895	51895	200	1964, ≈1921	Marsden-Smedley unpublished
59	Window Pane Bay	51877	51877	40	≈1921	Marsden-Smedley unpublished
60	Southwest Cape Range	51943	51943	290	1964, ≈1921	Marsden-Smedley unpublished
61	Window Pane Bay	51876	51876	20	≈1921	Marsden-Smedley unpublished
62	Window Pane Bay	51873	51873	20	≈1921	Marsden-Smedley unpublished
63	Spring River	52160	52160	100	1933/34, 1897/98	Marsden-Smedley unpublished
64	South West Cape Range	51863	51863	200	1964, ≈1921	Marsden-Smedley unpublished
65	Hannant Creek	51945	51945	120	1964, 1933/34	Marsden-Smedley unpublished
66	Spring River	52140	52140	40	1972, 1933/34, 1897/98	Marsden-Smedley unpublished
67	Greystone Bluff	52300	52300	740	≈1900?	Jarman et al. 1988b
68	Greystone Bluff	52300	52300	900	1933/34	Jarman et al. 1988b
69	Greystone Bluff	52310	52310	660	1933/34?	Jarman et al. 1988b
70	Twelvetrees Range	52650	52650	380	1952	Jarman et al. 1988b

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
71	Pasco Range	51946	51946	360	1964, 1933/34	Marsden-Smedley unpublished
72	South West Cape Range	51843	51843	680	≈1921	Marsden-Smedley unpublished
73	Twelvetrees Range	52640	52640	690	1952	Jarman et al. 1988b
74	Spring River	52102	52102	10	1933/34, 1897/98	Marsden-Smedley unpublished
75	Window Pane Creek	51880	51880	80	1964	Marsden-Smedley unpublished
76	Border Hill	52100	52100	50	1967, 1933/34, 1897/98	Marsden-Smedley unpublished
77	Window Pane Creek	51857	51857	300	1964	Marsden-Smedley unpublished
78	Border Hill	52103	52103	10	1933/34, 1897/98	Marsden-Smedley unpublished
79	Border Hill	52107	52107	10	1897/98	Marsden-Smedley unpublished
80	South West Cape Range	51815	51815	580	1964, ≈1921	Marsden-Smedley unpublished
81	South West Cape Range	51800	51800	400	1964, ≈1921	Marsden-Smedley unpublished
82	Lindsay Hill	52050	52050	40	1933/34, 1897/98	Marsden-Smedley unpublished
83	Window Pane Creek	51840	51840	280	1964	Marsden-Smedley unpublished
84	Spring River	52068	52068	20	≈400	Marsden-Smedley unpublished
85	Spring River	52069	52069	30	1933/34, 1897/98	Marsden-Smedley unpublished
86	Spring River	52070	52070	40	1967, 1933/34, 1897/98	Marsden-Smedley unpublished
87	Lindsay Hill	52035	52035	70	1967, 1933/34, 1897/98	Marsden-Smedley unpublished
88	Farrell Point	52014	52014	20	1967, 1933/34, 1897/98	Marsden-Smedley unpublished
89	Window Pane Creek	51827	51827	560	1964	Marsden-Smedley unpublished
90	Wilson Bight	51788	51788	20	1964, 1981	Marsden-Smedley unpublished
91	South West Cape Range	51810	51810	200	1964	Marsden-Smedley unpublished
92	Horseshoe Creek	51960	51960	20	1964, 1933/34	Marsden-Smedley unpublished
93	Joan Point	52006	52006	10	≈1976, 1933/34, 1897/98	Marsden-Smedley unpublished
94	Spring River	52205	52205	120	1933/34, 1897/98	Marsden-Smedley unpublished
95	Amy Range	51800	51800	280	1964	Marsden-Smedley unpublished
96	Horseshoe Inlet	51987	51987	90	≈1976, 1933/34, 1897/98	Marsden-Smedley unpublished
97	King William Saddle	53264	53264	800	1974	Marsden-Smedley 1993a
98	Crossing Plains	52230	52230	190	1933/34, 1897/98	Marsden-Smedley unpublished
99	Ketchem Bay	51801	51801	40	1964, 1977	Marsden-Smedley unpublished
100	Ketchen bay	51808	51808	20	1954, 1964	Gellie 1980
101	The Hermit	52580	52580	500	1952	Jarman et al. 1988b
102	High Rocky Pk	52960	52960	860	1950	Jarman et al. 1988b
103	Rufus Canal Rd	53309	53309	750	1974	Marsden-Smedley unpublished
104	Ketchem Bay	51804	51804	80	1977, ≈1921	Marsden-Smedley unpublished
105	Woureddy Creek	51950	51950	80	1976, 1933/34, 1897/98	Marsden-Smedley unpublished
106	Ketchem Island	51798	51798	20	≈1921	Marsden-Smedley unpublished

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

#	Location	Easting	Northing	Alt	Year burnt	Source
107	Hidden Bay	51807	51807	60	≈1964, ≈1921	Marsden-Smedley unpublished
108	Woureddy Creek	51954	51954	20	≈1976, 1933/34, 1897/98	Marsden-Smedley unpublished
109	Crossing Plains	52244	52244	180	1897/98 (≈2 ha only)	Marsden-Smedley unpublished
110	Forest Lag, Bathurst Harbour	51974	51974	10	1933/34	Brown and Podger 1982
111	King William Cr	53281	53281	730	1984	Marsden-Smedley 1993a
112	Crossing Plains	52264	52264	200	1969	Byrant 1991
113	Charlies Hill	51931	51931	20	≈1976, 1933/34, 1897/98	Marsden-Smedley unpublished
114	New Harbour	51814	51814	140	≈1964, 1933/34	Marsden-Smedley unpublished
115	Melaleuca	51921	51921	5	1971	Marsden-Smedley 1993a
116	Rufus Canal Rd	53299	53299	750	1984	Marsden-Smedley unpublished
117	Cox Bight, Bouy Cr	51830	51830	20	1971	Jarman et al. 1988b
118	New Harbour	51833	51833	10	1933/34	Marsden-Smedley unpublished
119	Crossing Plains	52263	52263	180	1933/34, 1897/98	Marsden-Smedley unpublished
120	Spires, SW of Mt Curly	52880	52880	1000	1950	Jarman et al. 1988b
121	Spires, Perambulator Ridge	52920	52920	940	1950	Jarman et al. 1988b
122	Melaleuca	51916	51916	5	1972	Marsden-Smedley 1993a
123	Watersmeet, Lk St Clair	53367	53367	750	≈1850?, 1933/34, ≈1965	Marsden-Smedley unpublished
124	Navarre Plains	53304	53304	730	1986	Marsden-Smedley unpublished
125	Crossing Plains	52260	52260	180	1952	Jarman et al. 1988b
126	Navarre Plains	53306	53306	730	1986	Marsden-Smedley unpublished
127	Navarre Plains, Coates Creek	53332	53332	750	1981	Marsden-Smedley unpublished
128	Crossing River	52271	52271	170	1933/34	Marsden-Smedley unpublished
129	New Harbour	51838	51838	40	1975, 1933/34	Marsden-Smedley unpublished
130	Melaleuca	51915	51915	5	1974	Marsden-Smedley 1993a
131	Melaleuca	51907	51907	5	1980	Marsden-Smedley 1993a
132	Little Navarre River	53312	53312	730	1989	Marsden-Smedley unpublished
133	Crossing Plains	52274	52274	190	1933/34, 1897/98	Marsden-Smedley unpublished
134	Spires, Mt Curly	52900	52900	900	1950	Jarman et al. 1988b
135	Spires, Lake Curly	52910	52910	700	1950	Jarman et al. 1988b
136	Spires, Gell River	52920	52920	700	1950	Jarman et al. 1988b
137	Moth Creek	51860	51860	60	1975, 1933/34	Marsden-Smedley unpublished
138	Melaleuca	51915	51915	5	1986	Marsden-Smedley 1993a
139	Spires, Gell River	52920	52920	710	1950	Jarman et al. 1988b
140	St Clair Rd	53355	53355	730	1974	Marsden-Smedley unpublished
141	St Clair Rd	53357	53357	730	1974	Marsden-Smedley unpublished
142	Cox Bight, New Harbour Ra	51830	51830	80	1933/34	Jarman et al. 1988b

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
143	Cox Bight, New Harbour Ra	51830	51830	530	1933/34	Jarman et al. 1988b
144	Spires, Badger Flat	52920	52920	660	1950	Jarman et al. 1988b
145	McPartlan Pass	52549	52549	320	1972	Marsden-Smedley 1993a
146	Sentinel Range	52526	52526	840	1933/34, 1952	Marsden-Smedley unpublished, Parks and Wildlife unpublished
147	Sentinel Range	52533	52533	600	1933/34, 1952	Marsden-Smedley unpublished, Parks and Wildlife unpublished
148	Sentinel Range	52538	52538	400	1933/34, 1952	Marsden-Smedley unpublished, Parks and Wildlife unpublished
149	Cox Bight, Freney Lagoon	51830	51830	10	1971	Jarman et al. 1988b
150	Sentinel Range	52530	52530	680	1933/34, 1952	Jarman et al. 1988b, Marsden-Smedley unpublished
151	Sentinel Range	52530	52530	760	1933/34, 1952	Jarman et al. 1988b, Marsden-Smedley unpublished
152	Cox Bight	51840	51840	60	1971	Jarman et al. 1988b
153	Melaleuca, Mt Counsel	51880	51880	710	≈1850?	Jarman et al. 1988b
154	Sentinel Range	52540	52540	400	1933/34, 1972	Marsden-Smedley unpublished, Parks and Wildlife unpublished
155	Sentinel Range	52534	52534	600	1933/34, 1972	Marsden-Smedley unpublished, Parks and Wildlife unpublished
156	Sentinel Range	52534	52534	840	1933/34	Marsden-Smedley unpublished, Parks and Wildlife unpublished
157	Cox Bight, Pt Eric	51840	51840	15	1971	Jarman et al. 1988b
158	Melaleuca, Mt Counsel	51880	51880	670	≈1850?	Jarman et al. 1988b
159	Melaleuca, Mt Counsel	51890	51890	750	1949, 1933/34	Jarman et al. 1988b
160	Arthur Plains, Moraine A	52270	52270	300	1967	Jarman et al. 1988b
161	Airstrip Road	52563	52563	320	1988, 1970, 1962	Marsden-Smedley 1993a
162	Junction Creek	52272	52272	300	1979, 1933/34, 1897/98	Marsden-Smedley unpublished
163	Cox Bight, Goring Cr	51840	51840	20	1971	Jarman et al. 1988b
164	Mt Norold	52090	52090	830	1933/34	Jarman et al. 1988b
165	Island Rd	52576	52576	320	1986	Marsden-Smedley 1993a
166	Clear Hill Road	52535	52535	360	≈1672	J. M. Balmer unpublished
167	Clear Hill Road	52573	52573	460	1851, ≈1813	J. M. Balmer unpublished
168	Clear Hill Road	52571	52571	535	1922, ≈1851	J. M. Balmer unpublished
169	Scotts Peak	52310	52310	300	1950, 1933/34, 1897/98	Marsden-Smedley unpublished
170	Arthur Plains, Junction Cr	52260	52260	260	1933/34, 1952	Jarman et al. 1988b
171	Junction Creek	52277	52277	260	1933/34, 1897/98	Marsden-Smedley unpublished
172	Junction Creek	52287	52287	280	1933/34, 1897/98	Marsden-Smedley unpublished
173	Clear Hill Road	52642	52642	350	1958, 1933/34, ≈1723	J. M. Balmer unpublished
174	Clear Hill Road	52664	52664	400	1972, ≈1851	J. M. Balmer unpublished
175	Clear Hill Road	52702	52702	400	1980, 1962, ≈1738	J. M. Balmer unpublished
176	Clear Hill Road	52643	52643	370	1960, ≈1900	J. M. Balmer unpublished
177	Clear Hill Road	52654	52654	400	≈1765	J. M. Balmer unpublished
178	Clear Hill Road	52637	52637	350	1960, ≈1922, ≈1550	J. M. Balmer unpublished

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
179	Clear Hill Road	52696	52696	420	1972, 1948, ≈1851	J. M. Balmer unpublished
180	Clear Hill Road	52696	52696	420	1950, ≈1851	J. M. Balmer unpublished
181	Red Point Hills	51797	51797	180	1948	Marsden-Smedley unpublished
182	Mt Solitary	52387	52387	600	1960	Gellie 1980
183	Red Point Hills	51858	51858	230	≈1956, 1933/34	Marsden-Smedley unpublished
184	Clear Hill Road	52629	52629	360	1956, ≈1559	J. M. Balmer unpublished
185	Mt Wright	52810	52810	920	1940	Jarman et al. 1988b
186	Faraway Creek	51855	51855	30	1933/34	Marsden-Smedley unpublished
187	Clear Hill Road	52472	52472	340	1943, 1881	J. M. Balmer unpublished
188	Huon Crossing	52457	52457	320	1950	Bowman 1980; Marsden-Smedley 1993a
189	Arthur Plains, Moraine K	52210	52210	800	1933/34, 1952	Jarman et al. 1988b
190	Vale of the Rasselas	52848	52848	480	1933/34	Gellie 1980
191	Crossing River	52035	52035	160	1933/34	Gellie 1980
192	Deception Ridge	52442	52442	320	1961	Bowman 1980; Marsden-Smedley 1990
193	Condominium Creek	52424	52424	320	1979	Marsden-Smedley 1990
194	Spica Hills	51850	51850	20	1933/34	Marsden-Smedley unpublished
195	Edgar	52366	52366	320	1950, 1933/34	Bowman 1980; Marsden-Smedley 1990, 1993a
196	Manuka Swamp	52486	52486	320	1933/34	Marsden-Smedley 1990
197	Frodshams Pass	52590	52590	580	1962	Marsden-Smedley unpublished
198	Manuka Swamp	52449	52449	320	1950	Bowman 1980; Marsden-Smedley 1993a
199	Clear Hill Road	52438	52438	360	1933/34, ≈1632	J. M. Balmer unpublished
200	Clear Hill Road	52440	52440	380	1917, ≈1691	J. M. Balmer unpublished
201	Sandfly Creek	52505	52505	320	1981	Marsden-Smedley 1993a
202	Clear Hill Road	52528	52528	350	1972, ≈1771	J. M. Balmer unpublished
203	Clear Hill Road	52516	52516	360	1972, 1967, 1950, ≈1890, ≈1817	J. M. Balmer unpublished
204	Clear Hill Road	52510	52510	370	1950, ≈1773	J. M. Balmer unpublished
205	Gelignite Creek	52514	52514	320	1943, 1971	Marsden-Smedley 1990
206	Woody Island, Scotts Pk Rd	52493	52493	320	1943, 1979	Balmer 1990
207	Gordon/Tiger Range	52848	52848	750	1945, ≈1905	J. M. Balmer unpublished
208	Mt Eliza medium	52432	52432	650	1950	Bowman 1980; Parks and Wildlife unpublished
209	Gordon/Tiger Range	52857	52857	750	1851	J. M. Balmer unpublished
210	Lousia Plains	51847	51847	20	1933/34	Marsden-Smedley unpublished
211	Arthur Plains, Seven Mile Cr	52240	52240	220	1952	Jarman et al. 1988b
212	Styx Valley	52503	52503	360	1969, ≈1792	J. M. Balmer unpublished
213	Mt Eliza high	52431	52431	960	1950	Bowman 1980; Parks and Wildlife unpublished
214	Arthur Plains, Nine Mile Cr	52220	52220	220	1952	Jarman et al. 1988b

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

Id	Location	Easting	Northing	Alt	Year burnt	Source
215	Gordon/Tiger Range	52829	52829	630	1955, ≈1837	J. M. Balmer unpublished
216	Ironbound Range, west side	51841	51841	200	1933/34	Marsden-Smedley unpublished
217	Styx Valley	52485	52485	400	1959, ≈1663	J. M. Balmer unpublished
218	Needles	52690	52690	560	1952	Jarman et al. 1988b
219	Gordon River Road	52693	52693	440	1872, ≈1721	J. M. Balmer unpublished
220	Gordon/Tiger Range	52954	52954	600	1875	J. M. Balmer unpublished
221	Gordon/Tiger Range	52953	52953	630	1914, ≈1851	J. M. Balmer unpublished
222	Gordon/Tiger Range	52948	52948	450	1952, ≈1886	J. M. Balmer unpublished
223	Needles	52680	52680	740	1933/34, 1957	Jarman et al. 1988b
224	Needles	52690	52690	920	1933/34	Jarman et al. 1988b
225	Humboldt Divide	52693	52693	680	1952	Balmer 1990
226	Styx Valley	52548	52548	430	1960, 1937, ≈1851	J. M. Balmer unpublished
227	Styx Valley	52580	52580	410	1976, ≈1736	J. M. Balmer unpublished
228	Wylds Crag	53047	53047	570	1948, ≈1424	J. M. Balmer unpublished
229	Gordon River Road	52558	52558	410	1949, 1922, ≈1744	J. M. Balmer unpublished
230	Wylds Crag	53056	53056	320	1963, 1892, ≈1814	J. M. Balmer unpublished
231	Deadmans Bay	51798	51798	20	≈1976	Marsden-Smedley unpublished
232	Wylds Crag	53084	53084	330	1956	J. M. Balmer unpublished
233	Deadmans Bay	51805	51805	20	≈1976, ≈1986	Marsden-Smedley unpublished
234	Wylds Crag	53088	53088	280	1975, 1942, ≈1748	J. M. Balmer unpublished
235	Deadmans Bay / Turua Beach	51808	51808	20	≈1956	Marsden-Smedley unpublished
236	Styx Valley	52610	52610	600	1951	J. M. Balmer unpublished
237	Styx Valley	52610	52610	600	1951, ≈1540	J. M. Balmer unpublished
238	Turua Beach	51815	51815	60	≈1956	Marsden-Smedley unpublished
239	Menzies Bluff	51802	51802	80	≈1906	Marsden-Smedley unpublished
240	Styx Valley	52611	52611	580	1950, ≈1655	J. M. Balmer unpublished
241	Harrisons Opening	52269	52269	100	1933/34, 1972, 1993	Marsden-Smedley unpublished
242	Styx Valley	52608	52608	550	1951, 1802	J. M. Balmer unpublished
243	Russell River Valley	52599	52599	420	1960, ≈1655	J. M. Balmer unpublished
244	Weld Valley	52396	52396	290	1944, ≈1737	J. M. Balmer unpublished
245	Weld Valley	52395	52395	290	1953, 1933/34, ≈1869	J. M. Balmer unpublished
246	Weld Valley	52393	52393	300	1944, ≈1805	J. M. Balmer unpublished
247	Mt Bobs, Boomerang	52073	52073	720	1897, 1933/34	Kirkpatrick and Harwood 1980
248	Russell River Valley	52594	52594	320	1950, ≈1771	J. M. Balmer unpublished
249	Mt Field	52704	52704	360	1944	J. M. Balmer unpublished
250	Mt Field	52740	52740	640	1933/34, ≈1691	J. M. Balmer unpublished

Appendix 2. Sites in southwest Tasmania assessed for their fire ages

H	Location	Easting	Northing	Alt	Year burnt	Source
251	Styx River Valley	52604	52604	400	1950, ≈1655	J. M. Balmer unpublished
252	Mt Field	52742	52742	250	1964, 1948, ≈1710	J. M. Balmer unpublished
253	Mt Field	52743	52743	250	1962, ≈1771	J. M. Balmer unpublished
254	Flat Rock Plain	51727	51727	425	≈1956	Marsden-Smedley unpublished
255	Granite Beach	51727	51727	320	1897/98	Marsden-Smedley unpublished
256	Mt Field	52745	52745	240	1945, ≈1872	J. M. Balmer unpublished
257	South Cape Range	51728	51728	400	1897/98	Marsden-Smedley unpublished
258	Styx River Valley	52626	52626	380	1933/34, ≈1655	J. M. Balmer unpublished
259	South Cape Range	51723	51723	370	1897/98	Marsden-Smedley unpublished
260	L. Osbourne, Hartz Mtn	52147	52147	890	1933/34	Marsden-Smedley unpublished
261	Hartz Mtn	52147	52147	850	1933/34	Marsden-Smedley unpublished
262	Fourfoot Plain	52249	52249	330	1971	Marsden-Smedley unpublished
263	King William Creek	53278	53278	780	1984	Marsden-Smedley unpublished
264	Artist Hill	53265	53265	380	1977	Marsden-Smedley unpublished
265	Dead Horse Plain	52275	52275	60	1989, 1983	Marsden-Smedley unpublished
266	Ironbound Range	51816	51816	640	≈1650	Marsden-Smedley unpublished
267	Lousia River	51846	51846	30	≈1735	Marsden-Smedley unpublished
268	South Cape Range	51729	51729	400	≈1800	Marsden-Smedley unpublished

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
1	Cape Sorell	1940s	
2	Cape Sorell	1940s	
3	Cape Sorell	1940s	
4	Cape Sorell	1940s	
5	Cape Sorell	1940s	
6	Cape Sorell	1940s	
7	Cape Sorell	1940s	
8	Cape Sorell	1930s	
9	Cape Sorell	1930s	Appears to have been lit at Macquarie Harbour and burnt to the west coast, may link up to fire 10.
10	Cape Sorell	1930s	Probably part of fire 9.
11	Cape Sorell	1930s	
12	1933/34 fire	1933/34	Burnt from Macquarie Harbour to Southport Lagoon in at least 4 fire runs.
13	Mainwarring River	1920s?, maybe 1915	Forest fire, was probably more extensive on its eastern boundary, linked up with fires 14 and 15?.
14	Nye Bay	1920s?, maybe 1915	May have been more extensive on its northern boundary, linked up with fires 13 and 15?
15	Dewitt Range	1920s?, maybe 1915	May have been more extensive on its northern boundary, linked up with fires 13 and 15?
16	Sandblow Bay	1930s, probably 1938	Small fire probably lit in wet and windy conditions, possibly by Denny King, see McAulay 1939.
17	Kelly Basin	1940s	
18	Kelly Basin	1940s	
19	Kelly Basin	1940s	
20	Kelly Basin	1940s	
21	King River	1940s	
22	Frenchmans Cap	1939	Western and northwestern boundary unknown, 31-1-39 to 2-2-39?, also burnt in 1897/98, 1933/34.
23	Lyell Highway	1940s	Also burnt in 1939 (fire 22).
24	St Clair	1933/34	Fire started to the north or north east of L. Petrarch, also burnt about 1850.
25	Mt Arrowsmith	1940s	
26	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
27	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
28	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
29	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
30	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
31	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
32	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
33	Jane River	1930s	May be spot fire from the 1939 fires (fire 22).
34	Jane River	1930s	
35	Wylds Crag	≈1900	May be 1897.

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
36	Adamsfield	1940s	Probably burnt 1948, also 1933/34 and about 1850.
37	Adamsfield	1940s	Probably burnt March 1940, see AOT NS 385/7/20a, 23,30,31
38	Adamsfield	1930s	Probably burnt March 1940, see AOT NS 385/7/20a, 23,30,31
39	Mt Sprent	1940s	Also burnt in 1933/34.
40	Wedge River	1940s	
41	Wedge River	1940s	
42	Gelignite Creek	1940s	
43	Mt Field	1920s	
44	Mt Field	1920s	
45	Mt Field	1933/34	Northeastern boundary unknown
46	Jubilee Range	1930s	
47	Snowy Range	1930s	
48	Snowy Range	1930s	Eastern boundary unknown
49	Lake Skinner	1930s	Lit by Denny King?
50	Schnells Ridge	1930s	Probably spot fire from the 1933/34 fires (fire 12).
51	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
52	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
53	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
54	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
55	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
56	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
57	Huon River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
58	Hartz Mountains	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
59	Hartz Mountains	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
60	Lake Sydney	1890s	Probably 1897.
61	Hartz Mountains	1933/34	Probably part of the 1933/34 fires (fire 12).
62	Solly River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
63	Solly River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
64	Solly River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
65	Solly River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
66	Solly River	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
67	Mt Lousia	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
68	Ironbound Ra.	1933/34	Probably spot fire from the 1933/34 fires (fire 12).
69	Red Point Hills	1948	
70	Red Point Hills	1948	
71	Melaleuca	1940s	

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
72	Melaleuca	1940s	
73	Bathurst Narrows	1940s	
74	New River Lagoon	1930s	
75	Rocky Boat Harbour	1930s	
76	Rocky Boat Harbour	1930s	
77	Surprise Rvt	1930s	Next to old track to the south coast.
78	Surprise Rvt	1940s	Next to old track to the south coast.
79	South Cape Range	1930s	
80	Catamaran River	1930s	Probably spot fire from the 1933/34 fires (fire 12).
81	Catamaran River	1930s	Probably spot fire from the 1933/34 fires (fire 12).
82	Blowhole Valley	1940s	
83	Southport Lagoon	1930s	
84	Ketchem Bay	1930s	Probably spot fire from the 1933/34 fires (fire 12).
85	South Cape Rvt	1940s	
86	Cape Sorell	1991	PWS fire records.
87	Cape Sorell	1992	PWS fire records.
88	Cape Sorell	1990	PWS fire records.
89	Cape Sorell	1989	PWS fire records.
90	Cape Sorell	1989	PWS fire records.
91	Cape Sorell	1987	PWS fire records.
92	Cape Sorell	1976	PWS fire records.
93	Cape Sorell	1982	PWS fire records.
94	Cape Sorell	1970s	PWS fire records, probably 1976.
95	Cape Sorell	1976	
96	Cape Sorell	1976	
97	Cape Sorell	1976	PWS fire records.
98	Point Hibbs	1976	PWS fire records.
99	Point Hibbs	1950s	
100	Spero Bay	1977	PWS fire records.
101	Spero Bay	1950s	
102	Macquarie Hbr	1982, 1989/90	PWS fire records.
103	Macquarie Hbr	1976, 1982, 1988/89	PWS fire records.
104	Macquarie Hbr	1950s	
105	Macquarie Hbr	1988/89	PWS fire records.
106	Macquarie Hbr	1982	PWS fire records.
107	Macquarie Hbr	1982, 1989/90	PWS fire records.

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
108	Macquarie Hbr	1989/90	PWS fire records.
109	Macquarie Hbr	1989/90	PWS fire records.
110	Macquarie Hbr	1985/86	PWS fire records, also partly burnt in 1982.
111	Farm Cove	1976/77	PWS fire records.
112	Farm Cove	1986	PWS fire records.
113	Bird River	1977	PWS fire records.
114	Bird River	1977	PWS fire records.
115	Bird River	1976	PWS fire records.
116	Kelly Basin	1976	PWS fire records.
117	Bird River	1977	PWS fire records.
118	Craycroft Hills	1981	PWS fire records.
119	King River	1983	PWS fire records.
120	King River	1981	PWS fire records, may also have been partly burnt in 1982.
121	King River	1983	PWS fire records.
122	King River	1975	PWS fire records.
123	King River	1967	PWS fire records.
124	King River	1970	PWS fire records.
125	King River	1982	PWS fire records.
126	King River	1976	PWS fire records.
127	King River	1983	PWS fire records.
128	King River	1983	PWS fire records.
129	King River	1965	PWS fire records.
130	King River	1975	PWS fire records.
131	King River	1977	PWS fire records.
132	King River	1980	PWS fire records.
133	Raglan Range	1966	PMG fire of 1966, Raglan Range also burnt in 1897/98, 1933/34, 1939, PWS fire records.
134	Nelson River	1976	PWS fire records.
135	Nelson River	1976	PWS fire records.
136	Victoria Pass	1970	
137	Cardigan Flats	1993	PWS fire records.
138	Cardigan Flats	1993	PWS fire records.
139	Cardigan Flats	1976	PWS fire records.
140	Pigeon House Hill	1972	PWS fire records.
141	Pigeon House Hill	1992	PWS fire records.
142	Collingwood River	1989	PWS fire records.
143	Collingwood River	1989	PWS fire records.

Id	Location or name	Year burnt	Notes
144	Collingwood River	1989	PWS fire records.
145	Collingwood River	1979	PWS fire records.
146	Collingwood River	1980	PWS fire records.
147	Collingwood River	1979	PWS fire records.
148	Franklin River	1984	PWS fire records.
149	Franklin River	1980	PWS fire records.
150	Franklin River	1970	PWS fire records.
151	Wombat Glen	1970, 1985, 1993	PWS fire records.
152	Navarre Plains	1979	
153	Mt Arrowsmith	1992	PWS fire records.
154	Coates Creek	1988	PWS fire records.
155	Mt Rufus	1980	PWS fire records.
156	Lake Petrarch	1976	escaped toilet paper fire, PWS fire records, reburnt part of the area burnt in 1933/34 (fire 24).
157	Lake Petrarch	1995	PWS fire records.
158	Navarre Plains	1979	Probably part of fire 152.
159	Lake Vera	1980	escaped toilet paper fire or camp fire, boundary from PWS fire records.
160	Lake Vera	1980	Spot fire from fire 159, PWS fire records.
161	Jane River	1970	PWS fire records.
162	Gordon River	1976	PWS fire records.
163	Birchs Inlet-Low Rocky	1973/74	PWS fire records.
164	Birchs Inlet-Low Rocky	1985	PWS fire records.
165	Birchs Inlet-Low Rocky	1950s, 1976	1976 fire Forestry HRB, PWS fire records.
166	Birchs Inlet-Low Rocky	1950s, 1976	1976 fire Forestry HRB, PWS fire records.
167	Birchs Inlet-Low Rocky	1976	Forestry HRB, PWS fire records.
168	Birchs Inlet-Low Rocky	1976, 1985	1976 fire Forestry HRB, 1985 fire part of fire 164, PWS fire records.
169	Birchs Inlet-Low Rocky	1976	Forestry HRB, PWS fire records.
170	Birchs Inlet-Low Rocky	1978	PWS fire records.
171	Birchs Inlet-Low Rocky	1976	Forestry HRB, PWS fire records.
172	Birchs Inlet-Low Rocky	1976	PWS fire records.
173	Birchs Inlet-Low Rocky	1976	Forestry HRB, PWS fire records.
174	Birchs Inlet-Low Rocky	1978	PWS fire records.
175	Birchs Inlet-Low Rocky	1978	PWS fire records.
176	Birchs Inlet-Low Rocky	1978	PWS fire records.
177	Birchs Inlet-Low Rocky	1978	PWS fire records.
178	Birchs Inlet-Low Rocky	1978	PWS fire records.
179	Birchs Inlet-Low Rocky	1978	PWS fire records.

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
180	Birchs Inlet-Low Rocky	1978	PWS fire records.
181	Birchs Inlet-Low Rocky	1978	PWS fire records.
182	Birchs Inlet-Low Rocky	1978	PWS fire records.
183	Birchs Inlet-Low Rocky	1978	PWS fire records.
184	Birchs Inlet-Low Rocky	1977	PWS fire records.
185	Birchs Inlet-Low Rocky	1969/70	PWS fire records.
186	Rocky Sprent River	1950s	On track to Rocky Sprent River.
187	Rocky Sprent River	1974/75	PWS fire records.
188	Giblin River	1977	PWS fire records.
189	Olga River	1969/70	Forestry HRB?, PWS fire records.
190	Mulchay Bay	1986	PWS fire records.
191	Bond Bay	1950s	PWS fire records.
192	Settlement Point	1975/76	PWS fire records.
193	Upper Gordon River	1982	PWS fire records.
194	King William Range	1969/70	PWS fire records.
195	King William Range	1969/70	PWS fire records.
196	King William Range	1973	
197	King William Range	1973	PWS fire records.
198	Spires	1972/73	PWS fire records.
199	Spires	1952	Extensive fire, burnt most scrub patches
200	Denison River	1973	PWS fire records.
201	Denison River	1973	PWS fire records.
202	Denison River	1970s	PWS fire records.
203	Denison River	1972/73, 1983	PWS fire records.
204	Denison River	1983	PWS fire records.
205	Denison River	1983	PWS fire records.
206	Denison River	1983	PWS fire records.
207	Denison River	1983	PWS fire records.
208	Denison River	1983	PWS fire records.
209	Denison River	1983	PWS fire records.
210	Denison River	1983	PWS fire records.
211	Denison River	1983	PWS fire records.
212	Jane River	1977	PWS fire records.
213	Vale of the Rasselas	1982	PWS fire records.
214	Vale of the Rasselas	1982	PWS fire records.
215	Vale of the Rasselas	1982	PWS fire records.

Appendix 3. Recorded fires in southwest Tasmania

Id	Location or name	Year burnt	Notes
216	Vale of the Rasselas	1982	PWS fire records.
217	Vale of the Rasselas	1982	PWS fire records.
218	Vale of the Rasselas	1982	PWS fire records.
219	Vale of the Rasselas	1981	PWS fire records.
220	Vale of the Rasselas	1981	PWS fire records.
221	Gordon Gorge	1989	PWS fire records.
222	Wedge River	1972	Starfish fire, Escaped Forestry HRB, PWS fire records.
223	Hamilton Range	1982	PWS fire records.
224	Hamilton Range	1971	PWS fire records.
225	Hamilton Range	1983	Signal fire, PWS fire records.
226	Gordon River	1972/73	PWS fire records.
227	Gordon River	1971/72	PWS fire records.
228	Gordon River	1970s	PWS fire records.
229	Serpentine River	1972/73	PWS fire records.
230	Adamsfield	1972/73	PWS fire records.
231	Adamsfield	1972/73	PWS fire records.
232	Adamsfield	1972/73	PWS fire records.
233	Adamsfield	1972/73	PWS fire records.
234	Adamsfield	1972/73	PWS fire records.
235	Adamsfield	1972/73	PWS fire records.
236	Adamsfield	1971/72	PWS fire records.
237	Adamsfield	1987	PWS fire records.
238	Gelignite Creek	1972	PWS fire records.
239	Sandfly Creek	1975	PWS fire records.
240	Huon Crossing	1977	PWS fire records.
241	Condominium Creek	1978	Escaped fire research burn, PWS fire records.
242	Condominium Creek	1970/71	PWS fire records.
243	Condominium Creek	1973/74	PWS fire records.
244	Scotts peak	1971/72	PWS fire records.
245	Lake Pedder	1950	Mineral exploration.
246	Crumbledown	1986	PWS fire records.
247	Junction Creek	1979	PWS fire records.
248	Jubilee Range	1988	probably started from fuel stove accident, boundary from PWS fire records.
249	Snowy Range	1990	PWS fire records.
250	Harrisons Opening	1993	2 patches burnt, PWS fire records.
251	Hartz Mountains	1981	PWS fire records.

Appendix 3. Recorded fires in southwest Tasmania

ID	Location or name	Year burnt	Notes
252	Hartz Mountains	1982	PWS fire records.
253	Hartz Mountains	1987	PWS fire records.
254	Gelignite Creek	1982	PWS fire records.
255	Condominium Creek	1976/77	PWS fire records.
256	Condominium Creek	1975	PWS fire records.
257	North River	1971	PWS fire records.
258	North River	1950s	
259	North River	1950s	
260	Old River	1950s	Probably 1957, mineral exploration
261	Fulton Cove	1984	PWS fire records.
262	Schooner Cove	1983	PWS fire records.
263	Clatons	1976	PWS fire records.
264	Horseshoe Cove	1976	PWS fire records.
265	Melaleuca	1975	PWS fire records.
266	Melaleuca	1987	PWS fire records.
267	Melaleuca	1989	PWS fire records.
268	Cox Bight	1970/71	PWS fire records.
269	Cox Bight	1950s	
270	Ketchem Bay	1977	PWS fire records.
271	Ketchem Bay	1977	PWS fire records.
272	Red Point Hills	1976/77	PWS fire records.
273	Cox Bight	1975	PWS fire records.
274	Deadmans Bay	1987	PWS fire records.
275	Rocky Boat Inlet	1976	PWS fire records.
276	Flat Rock Plain	1950s	
277	Hastings	1988	PWS fire records.
278	Blowhole Valley	1950s	

Appendix 4. Fuel modelling site data

Site Airstrip Road
Community type: Standard blanket moor (B1 a);
Community description:
Low open moorland dominated by *Gymnoschoenus sphaerocephalus* with *Leptospermum nitidum* subdominant. Extensive areas of bare ground, probably due to the site's young age.

Site Island Road;
Community type: Standard blanket moor (B1 a);
Community description:
Low open moorland dominated by *Gymnoschoenus sphaerocephalus* with *Leptospermum nitidum* subdominant. Extensive areas of bare ground, probably due to the site's young age.

Site Sandfly Creek;
Community type: Standard blanket moor (B1 a);
Community description:
Low dense moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Lepidosperma filiforme* with *Empodisma minus, Allocasuarina monilifera, Leptospermum nitidum, Melaleuca squamea, Bauera rubioides* and *Sprengelia incarnata* subdominant. Very dense vegetation in the bottom 20 cm of the community.

Site McPartlan Pass;
Community type: Standard blanket moor (B1 a);
Community description:
Low moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Leptospermum nitidum* with *Lepidosperma filiforme, Lepyrodia tasmanica, Leptospermum scoparium, Melaleuca squamea, Sprengelia incarnata* and *Leptocarpus tenax* subdominant.

Site Edgar;
Community type: Standard blanket moor (B1 a);
Community description:
Moorland co-dominated by *Leptospermum nitidum, Gymnoschoenus sphaerocephalus* and *Sprengelia incarnata* with *Empodisma minus, Restio hookeri, Restio complanatus* and *Leptocarpus tenax* subdominant. This community is grading towards layered blanket moor (B4), probably due to its older age.

Site Melaleuca 3;
Community type: Standard blanket moor (B1 a);
Community description:
Low open moorland co-dominated by *Leptospermum nitidum, Melaleuca squarrosa* and *Gymnoschoenus sphaerocephalus* with *Lepidosperma filiforme, Xyris* sp., *Sprengelia incarnata, Leptospermum scoparium* and *Leptocarpus tenax* subdominant.

Site Melaleuca 4;
Community type: Standard blanket moor (B1 a);
Community description:
Low open moorland co-dominated by *Gymnoschoenus sphaerocephalus, Melaleuca squamea, Sprengelia incarnata* and *Leptospermum nitidum* with *Restio complanatus, Restio hookeri, Lepidosperma filiforme* and *Leptocarpus tenax* subdominant.

Site Melaleuca 5;
Community type: Standard blanket moor (B1 a);
Community description:
Open moorland co-dominated by *Gymnoschoenus sphaerocephalus, Leptospermum nitidum* and *Melaleuca squamea* with *Empodisma minus, Restio hookeri, Leptocarpus tenax* and *Lepidosperma filiforme* subdominant.

Site Melaleuca 2;
Community type: Standard blanket moor (B1 a);
Community description:
Dense moorland co-dominated by *Melaleuca squarrosa, Gymnoschoenus sphaerocephalus* and *Leptocarpus tenax* with *Leptospermum nitidum* and *Baeckea leptocaulis* subdominant. Community was grading towards wet standard (B2).

Site Melaleuca 1;
Community type: Standard blanket moor (B1 a);
Community description:
Open moorland co-dominated by *Gymnoschoenus sphaerocephalus, Baeckea leptocaulis, Agastachys odorata* and *Sprengelia incarnata* with *Leptospermum nitidum, Epacris corymbiflora, Restio hookeri, Lepidosperma filiforme* and *Leptocarpus tenax* subdominant.

Site Lyell P1;
Community type: Sedgey twine-rush (E6);
Community description:
Low open moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Restio hookeri*, with *Patersonia fragilis, Leptocarpus tenax* and *Lepyrodia tasmanica* subdominant.

Site Lyell P4;
Community type: Sedgey twine-rush (E6);
Community description:
Low moorland co-dominated by *Leptocarpus tenax, Gymnoschoenus sphaerocephalus, Leptospermum nitidum* and *Empodisma minus*, with *Sprengelia incarnata* and *Lepyrodia tasmanica* subdominant. Vegetation density was highly variable, which is reflected by the large range in the measured fuel loads.

Site Lyell P9;
Community type: Sedgey twine-rush (E6);
Community description:
Low moorland co-dominated by *Gymnoschoenus sphaerocephalus, Leptocarpus tenax* and *Sprengelia incarnata* with *Melaleuca squamea, Empodisma minus* and *Lepyrodia tasmanica* subdominant.

Site Lyell P10;
Community type: Sedgey twine-rush (E6);
Community description:
Low open moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Xyris* sp., with *Leptocarpus tenax* and *Lepyrodia tasmanica* subdominant.

Site Stonehaven Creek;
Community type: Sedgey twine-rush (E6);
Community description:
Dense moorland co-dominated by *Gymnoschoenus sphaerocephalus, Leptospermum nitidum, Melaleuca squamea* and *Leptocarpus tenax*, with *Empodisma minus* and *Lepyrodia tasmanica* subdominant.

Site King William Saddle 1;
Community type: Common highland sedgey (E9 a);
Community description:
Low dense moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Eucalyptus coccifera*, with *Leptospermum nitidum, Leptocarpus tenax, Ehrharta tasmanica, Empodisma minus and Lepidosperma filiforme* subdominant. This community may be lower in height than lowland moorlands due to the effect of winter snow cover.

Site King William Saddle 2;
Community type: Common highland sedgey (E9 a);
Community description:
Low open moorland (due to its young age) co-dominated by *Gymnoschoenus sphaerocephalus* and *Eucalyptus coccifera*, with *Leptospermum nitidum, Leptocarpus tenax, Ehrharta tasmanica, Empodisma minus and Lepidosperma filiforme* subdominant.

Site King William Creek;
Community type: Common highland sedgey (E9 a);
Community description:
Low dense moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Eucalyptus coccifera*, with *Sprengelia incarnata, Lepidosperma filiforme, Leptocarpus tenax, Empodisma minus and Restio australis* subdominant. This community may be lower in height than lowland moorlands due to the effect of winter snow cover.

Site Coates Creek;
Community type: Common highland sedgey (E9 a);
Community description:
Low open moorland co-dominated by *Gymnoschoenus sphaerocephalus* and *Restio australis*, with *Ehrharta tasmanica, Empodisma minus and Lepidosperma filiforme* subdominant. Very low cover of heath species in this community. This community may be lower in height than lowland moorlands due to the effect of winter snow cover.

Appendix 5. Fuel moisture data

Id	Run	Time	Weather data							Fuel particle		Use	Dead-fuel moisture				Stick moisture			
		Time	T dry	T dew	RH	wind	cloud	rad	rain	temp	RH	Use	low	med	high	av.	low	med	high	av.
		EST	°	°	%	kph	%	W/sqm	mm	°	%		%	%	%	%	%	%	%	%
1	1	18:00	10.5	8.4	85.1	5.7	50	36		13.0	73.4	T	27.1	41.1	37.6	35.3	15.1	15.1	16.6	15.6
2	1	6:00	6.8	5.5	98.2	4.8	100	14	0.05	6.5	93.1	T	36.8	52.5	49.5	46.3	23.3	24.1	23.8	23.7
3	1	8:00	8.9	5.9	91.0	2.1	50	307		11.7	67.4	T	30.1	43.0	41.9	38.3	21.8	22.5	22.6	22.3
4	1	10:00	11.5	8.8	79.2	3.2	0	780		20.7	46.4	M	19.5	34.2	26.1	26.6	17.7	17.6	19.2	18.2
5	1	12:00	13.7	8.6	74.0	5.9	0	899		26.0	33.0	M	17.8	23.0	35.7	25.5	13.3	13.4	15.1	13.9
6	1	14:00	17.0	8.8	63.9	5.2	0	780		21.7	43.6	M	14.4	21.1	19.8	18.4	11.4	11.3	11.3	11.3
7	1	16:00	17.0	9.6	68.4	7.9	0	459		18.7	55.4	M	19.4	21.5	26.3	22.4	10.6	10.4	10.9	10.6
8	1	18:00	12.6	9.3	82.5	5.4	13	54		14.0	73.3	M	18.5	24.9	22.3	21.9	12.3	11.5	11.7	11.8
9	1	6:00	8.9	8.3	100.0	0.1	100	15	1.50	10.0	89.1	T	119.1	86.7	98.6	101.5	39.4	37.5	35.6	37.5
10	1	10:00	10.5	8.3	88.1	3.4	100	254		13.3	71.1	T	48.3	64.2	70.3	60.9	31.8	34.4	33.8	33.3
11	1	12:00	11.5	8.5	83.3	7.0	100	294		14.7	66.3	T	38.3	53.2	44.2	45.2	24.8	26.7	25.6	25.7
12	1	14:00	12.6	5.8	71.6	7.1	88	322		17.8	44.7	M	23.6	34.4	29.5	29.2	19.0	20.0	19.6	19.5
13	1	16:00	13.2	7.0	73.5	8.0	50	311		16.3	53.6	M	16.9	16.7	25.2	19.6	15.7	15.7	16.2	15.9
14	1	18:00	10.5	7.6	86.5	3.9	0	57		11.5	76.5	M	21.9	33.0	27.7	27.5	16.8	16.8	16.6	16.7
15	1	6:00	6.3	6.6	99.4	0.6	75	30	0.05	7.0	97.2	T	38.4	39.8	31.5	36.6	24.7	24.8	23.8	24.4
16	1	8:00	9.4	6.8	85.7	1.9	50	315		10.8	76.0	T	26.8	35.6	33.0	31.8	21.7	22.0	23.1	22.3
17	1	10:00	13.2	7.6	74.4	3.3	38	597		16.8	54.1	T	19.6	17.0	29.5	22.0	16.8	16.8	18.6	17.4
18	1	12:00	17.1	7.8	59.6	5.8	0	909		26.3	30.6	T	13.4	18.6	14.8	15.6	12.6	12.8	13.0	12.8
19	1	14:00	16.5	7.4	59.6	6.7	0	789		26.3	29.9	M	13.1	15.4	19.2	15.9	11.6	11.6	10.9	11.3
20	1	16:00	18.2	5.2	49.6	6.7	0	468		19.7	38.5	M	13.0	12.4	10.9	12.1	10.6	10.6	10.6	10.6
21	1	18:00	14.8	9.5	69.2	3.3	0	66		14.7	71.1	M	17.8	19.6	21.7	19.7	10.8	10.8	11.6	11.1
22	1	6:00	6.3	5.2	100.0	2.5	100	18	0.20	6.3	92.6	T	46.7	43.6	41.5	43.9	30.2	26.9	23.5	26.9
23	2	12:00	18.0	12.3	56.5	5.9	0	1028		31.3	31.1	M	10.4	10.5	8.9	9.9	5.1	5.2	5.1	5.1
24	2	14:00	20.9	13.8	51.3	6.5	0	962		29.0	39.1	M	8.2	7.8	6.8	7.6	4.0	4.1	4.7	4.3
25	2	16:00	23.2	12.0	44.6	4.6	0	682		27.0	39.2	M	8.5	9.0	7.4	8.3	3.5	3.4	3.3	3.4
26	2	18:00	19.9	13.4	59.0	4.9	0	275		17.7	75.9	M	13.0	12.2	9.8	11.7	4.1	4.0	3.7	3.9
27	2	6:00	9.02	8.3	94.0	6.5	75	42	0.05	12.0	77.7	T	35.1	34.9	32.8	34.3	12.1	11.2	9.5	10.9
28	2	8:00	12.1	9.4	83.0	8.1	100	159		14.7	70.5	M	24.3	22.5	21.3	22.7	10.0	10.0	9.0	9.7
29	2	10:00	13.9	10.0	76.7	6.5	100	278		16.7	64.6	M	18.8	17.9	18.8	18.5	8.0	8.1	7.8	8.0
30	2	12:00	15	11.6	80.0	3.3	90	409		20.7	55.8	M	17.5	13.9	13.5	15.0	6.9	6.9	7.0	6.9
31	2	14:00	16.7	12.9	78.2	3.8	100	313		18.0	71.9	M	15.0	13.5	13.4	14.0	7.0	6.9	6.3	6.7
32	2	16:00	14.6	11.0	79.0	4.2	100	218		18.3	62.2	M	15.5	16.6	14.0	15.3	6.9	6.8	6.6	6.8
33	2	18:00	12.9	11.7	80.8	4.9	90	103		15.0	80.7	M	17.5	16.8	14.4	16.3	6.9	7.0	6.6	6.8
34	2	6:00	8.8	7.3	96.0	0.2	100	23	0.10	10.0	83.3	T	32.8	32.4	27.0	30.7	11.7	12.1	10.9	11.6
35	2	8:00	10.3	7.9	86.6	2.3	100	158		13.3	69.4	M	25.0	26.0	25.0	25.3	10.6	11.2	10.6	10.8
36	2	10:00	13.9	9.5	74.9	4.4	100	276		16.3	63.6	M	19.8	16.6	17.0	17.8	8.0	8.4	8.5	8.3

Id	Run	time	Weather data							Fuel particle			Dead-fuel moisture				Stick moisture			
			T dry	T dew	RH	wind	cloud	rad	rain	temp	RH	Use	low	med	high	av.	low	med	high	av.
		EST	°	°	%	kph	%	W/sqm	mm	°	%		%	%	%	%	%	%	%	%
37	2	12:00	15.4	12.5	70.9	5.8	75	516		22.3	53.4	M	14.4	14.3	16.6	15.1	6.6	6.9	7.1	6.9
38	2	14:00	16.8	11.9	64.7	3.3	25	805		21.0	55.9	M	14.2	14.6	11.6	13.5	5.8	6.0	5.9	5.9
39	2	16:00	18.8	12.4	55.8	5.0	50	456		24.7	46.3	M	12.3	12.7	13.1	12.7	5.3	5.5	5.9	5.5
40	2	18:00	18.3	10.1	58.6	2.0	25	226		21.7	47.6	M	15.6	14.3	12.7	14.2	4.8	4.9	5.4	5.0
41	2	6:00	6.1	6.1	100.0	2.2	0	84	0.15	8.0	87.7	T	33.0	27.2	26.1	28.8	13.0	11.4	9.9	11.4
42	3	12:00	20.0	13.0	64.4	3.3	0	978		31.0	33.1	M	10.0	11.9	13.0	11.6	5.7	5.7	6.3	5.9
43	3	14:00	23.3	14.9	59.7	7.9	0	915		32.7	34.2	M	10.6	11.2	11.1	10.9	5.0	5.1	5.2	5.1
44	3	16:00	24.3	14.7	55.6	5.3	0	633		21.3	65.8	M	12.3	12.1	10.2	11.6	4.7	4.6	4.6	4.6
45	3	18:00	21.8	14.8	64.6	3.8	0	224		18.7	78.1	M	11.7	16.0	13.2	13.7	5.0	5.0	5.1	5.0
46	3	6:00	9.1	9.2	100.0	0.4	0	40	0.20	9.7	96.9	T	41.0	35.9	30.0	35.6	15.0	12.6	10.7	12.8
47	3	8:00	14.8	14.7	100.0	2.2	0	440		16.0	91.9	M	31.5	30.7	32.9	31.7	13.1	12.3	11.2	12.2
48	3	10:00	20.3	14.7	71.0	3.7	0	799		26.0	49.5	M	18.5	16.5	22.0	19.0	8.6	8.0	10.2	8.9
49	3	12:00	25.8	16.6	57.9	5.8	0	974		36.0	31.7	M	11.5	12.9	11.0	11.8	6.1	5.8	6.8	6.2
50	3	14:00	27.9	17.8	54.3	4.6	0	911		37.3	31.7	M	9.1	9.5	10.0	9.5	4.1	4.0	4.0	4.1
51	3	16:00	26.2	18.3	62.2	3.4	100	201		25.7	63.7	M	13.0	13.0	11.3	12.5	4.7	4.7	4.7	4.7
52	3	18:00	25.0	18.4	67.3	2.3	50	145		23.3	73.8	M	15.1	14.6	13.4	14.4	5.0	5.0	5.2	5.0
53	3	6:00	19.8	14.3	70.5	9.1	0	37	0.00	18.0	78.7	T	19.5	22.1	19.4	20.3	7.4	8.6	8.4	8.1
54	3	8:00	21.2	14.5	66.4	15.1	0	435		21.0	66.2	M	16.5	20.0	21.1	19.2	6.6	7.5	7.1	7.1
55	3	10:00	24.9	16.8	61.0	8.9	0	794		29.3	46.6	M	14.6	13.6	14.1	14.1	5.6	5.8	6.2	5.9
56	3	12:00	27.5	18.3	57.8	10.9	0	970		35.3	36.6	M	9.9	9.4	9.2	9.5	4.3	4.4	4.8	4.5
57	3	14:00	29.6	19.1	54.0	10.5	0	907		38.0	33.3	M	7.8	9.8	7.9	8.5	3.1	2.9	3.1	3.0
58	3	16:00	28.5	16.4	48.2	7.4	15	565		35.3	32.3	M	7.7	9.6	8.1	8.5	2.7	2.7	2.7	2.7
59	3	18:00	27.0	16.3	52.8	10.7	15	194		25.3	57.3	M	11.6	11.1	11.9	11.5	3.0	3.0	2.9	3.0
60	3	6:00	22.0	17.3	75.8	13.9	60	18	0.05	20.0	84.6	T	20.0	26.2	21.7	22.6	7.9	9.6	7.4	8.3
61	3	8:00	22.6	17.5	73.4	14.0	60	259		21.0	80.3	M	18.0	22.1	20.7	20.3	7.0	8.3	7.0	7.4
62	3	10:00	23.4	18.1	72.6	12.1	95	284		26.7	59.1	M	15.5	18.5	18.0	17.3	6.2	7.0	6.4	6.6
63	3	12:00	21.2	17.6	80.8	5.8	100	315	0.20	21.0	81.0	T	44.7	39.8	35.8	40.1	11.6	13.1	12.2	12.3
64	3	13:00	21.5	17.9	81.0	5.2	100	293	0.20	22.0	77.7	T	41.3	46.9	47.5	45.2	11.9	14.2	14.0	13.4
65	4	16:00	7.9	7.1	93.2	1.7	100	45	10	8.0	94.0	T	177.7	185.2	166.1	176.3	26.8	30.5	31.9	29.8
66	4	8:00	6.6	6.1	100.0	1.3	100	25	0.2	8.0	87.9	T	160.3	169.7	173.6	167.8	29.4	32.1	33.2	31.6
67	4	10:00	9.4	7.7	88.8	1.9	88	155		11.0	79.7	T	139.7	175.0	121.9	145.6	25.9	29.5	31.6	29.0
68	4	12:00	10.2	8.4	82.7	3.0	88	210		12.0	78.4	T	128.4	120.9	91.6	113.6	18.1	23.5	26.7	22.8
69	4	14:00	10.5	7.9	82.7	3.3	100	134		9.8	87.6	T	93.3	87.8	85.3	88.8	13.2	16.9	20.6	16.9
70	4	16:00	10.1	8.3	82.3	1.3	100	44		9.5	92.0	T	55.3	98.4	86.3	80.0	11.8	14.4	17.2	14.5
71	4	8:00	7.0	6.6	100.0	1.1	100	24	0.1	8.0	90.9	T	61.7	96.9	73.2	77.3	13.9	15.3	16.3	15.2
72	4	10:00	9.6	6.8	82.5	2.3	100	119		9.8	81.2	T	80.5	72.8	82.9	78.7	12.6	14.1	15.1	13.9
73	4	12:00	9.9	6.7	78.4	3.2	88	207		10.5	77.3	T	50.9	72.4	54.0	59.1	10.9	12.4	13.5	12.2

Appendix 5. Fuel moisture data

			Weather data							Fuel particle			Dead-fuel moisture				Stick moisture			
Id	Run	time EST	T dry °	T dew °	RH %	wind kph	cloud %	rad W/sqm	rain mm	temp °	RH %	Use	low %	med %	high %	av. %	low %	med %	high %	av. %
74	4	14:00	10.6	6.5	74.9	3.6	100	132		8.0	89.9	T	33.3	48.0	53.2	44.8	9.5	10.5	11.5	10.5
75	4	16:00	10.5	6.7	76.4	1.9	75	71		8.0	91.7	T	34.4	53.6	59.4	49.1	9.3	10.1	10.8	10.1
76	4	8:00	11.4	7.6	79.4	3.7	88	31	0.0	10.0	84.9	T	31.6	42.2	47.1	40.3	9.4	10.6	10.3	10.1
77	4	10:00	11.7	8.3	80.4	4.0	88	151		11.3	81.4	T	31.2	48.3	40.3	39.9	9.3	10.4	10.0	9.9
78	4	12:00	12.8	9.2	78.8	5.0	88	205		12.8	78.3	T	31.6	39.5	40.6	37.3	9.0	9.9	9.9	9.6
79	4	14:00	13.2	9.5	78.5	3.9	88	168		13.0	79.2	T	39.9	35.6	35.2	36.9	8.6	9.3	9.4	9.1
80	4	16:00	12.4	9.9	83.5	3.2	100	41		12.0	86.9	T	36.6	40.3	33.2	36.7	8.8	9.5	9.6	9.3
81	5	10:00	21.4	12.9	58.4	8.1	0	750		26.0	44.1	M	13.2	16.6	17.0	15.6				
82	5	12:00	25.7	5.4	27.0	11.5	0	925		32.7	18.0	M		8.5	9.9	9.2	8.5	8.1	8.8	8.5
83	5	14:00	27.4	9.6	32.8	8.2	0	860		34.0	22.3	M	6.3	5.9	6.6	6.3	4.5	4.6	4.3	4.5
84	5	16:00	27.6	5.9	24.6	10.1	0	576		30.0	21.6	M	6.5	7.0	5.7	6.4	4.3	4.0	4.2	4.2
85	5	18:00	22.8	4.1	29.2	6.4	0	168		19.3	36.2	M	7.1	10.1	11.6	9.6	4.3	4.3	4.2	4.3
86	5	6:00	11.0	8.5	83.8	4.6	0	9	0.00	6.7	100	T	23.1	27.2	23.2	24.5	14.2	15.7	12.6	14.2
87	5	8:00	26.0	14.1	47.9	9.3	0	386		12.0	100	M	21.7	21.7	24.4	22.6	13.3	15.6	13.7	14.2
88	5	10:00	30.7	13.2	34.4	13.7	0	745		32.0	31.7	M	8.5	12.5	12.3	11.1	7.3	8.3	8.7	8.1
89	5	12:00	33.8	16.0	34.9	11.5	0	920		36.0	30.5	M	6.6	5.8	7.2	6.5	4.6	5.0	4.5	4.7
90	5	14:00	34.4	14.7	31.0	14.5	0	855		36.7	26.9	M	7.2	6.4	5.5	6.3	3.0	3.1	2.7	2.9
91	5	16:00	32.2	13.5	32.4	13.1	0	570		32.0	32.3	M	7.6	5.9	7.6	7.0	2.7	2.7	2.0	2.5
92	5	18:00	27.4	9.6	32.3	6.4	0	163		25.0	37.6	M	7.9	8.3	8.6	8.3	3.0	3.1	3.2	3.1
93	5	6:00	12.7	12.4	97.5	3.1	0	7	0.00	12.3	100	T	26.2	23.3	25.5	25.0	14.8	14.9	13.0	14.2

Note: EST = Eastern Australian Standard time; T dry = dry bulb temperature; T dew = dew point temperature; RH = relative humidity; wind = wind speed at 1.7 m; cloud = cloud cover; rad = solar radiation; rain = amount of last precipitation event; use: M = model development data, T = model test data; low = low density moorland; med = medium density moorland; high = high density moorland; dead fuel moisture test data in Appendix 6.

Appendix 6. Fire behaviour data

Id	Fire	Age yrs	Hgt cm	Cvr %	Slope °	Fuel load total t/ha	Fuel load dead t/ha	Fuel load cont.	Mf dead %	Mf live %	Fuel cons front %	Fuel cons total %	Tdry °	Tdew °	RH %	Cld %	Rain days	Rain mm	Wind 10m kph	Wind 1.7m kph	Use	Head fire ROS m/min	Head fire FH m	Head fire Fa °	Head fire FL m	Head fire Fd m	Flank fire ROS m/min	Flank fire FH m	Back fire ROS m/min	Back fire FH m
1	McpRb1	20	31	80	0	10.9	4.3	hgh	16.3	96.9	90	100	17.8	7.7	51	80	1	3.0	17.7	12.2	M	10.8	5.3	30	10.6	5.0				
2	McpRb3.1	20	27	65	0	10.0	3.7	hgh	17.1	86.7	90	100	15.3	8.0	61	13	2	7.0	4.1	2.1	M	1.7	3.1	75	3.2	1.8				
3	McpRb3.2	20	27	65	0	10.0	3.7	hgh	17.1	86.7	90	100	15.3	8.0	61	13	2	7.0	7.2	5.6	M	5.6	3.6	60	4.8	3.2				
4	McpRb4.1	20	28	65	0	10.0	3.7	hgh	17.0	96.8	90	100	15.2	9.4	68	100	3	7.0	5.9	0.7	M	0.6	1.4	90	1.4	0.3				
5	McpRb4.2	20	28	65	0	10.0	3.7	hgh	17.0	96.8	90	100	15.2	9.4	68	100	3	7.0	8.4	6.8	M	3.5	3.1	60	3.5	2.3				
6	McpRb14	20	31	75	0	10.6	4.1	hgh	15.3	99.7	90	100	17.4	7.0	50	0	2	7.0	13.1	10.8	M	7.8	2.8	45	3.9	2.7				
7	McpRb15	20	27	60	0	9.6	3.5	hgh	15.2	132.5	90	100	17.6	9.6	59	0	1	3.0	20.5	13.9	M	11.8	4.6	30	9.1	8.3				
8	McpRb16	20	26	55	0	9.3	3.3	mod	22.4	94.2	90	100	15.6	7.0	55	13	2	3.0	15.2	10.8	M	9.0	3.7	45	5.4	8.0				
9	McpRb17	20	27	60	0	9.6	3.5	hgh	21.9	109.9	90	100	23.0	6.1	33	0	3	3.0	22.8	15.2	M	12.5	3.7	45	5.4	8.0	6.1	3.7		
10	McpRb18	20	29	85	0	11.1	4.5	mod	23.2	101.3	90	100	19.8	6.8	43	0	3	3.0	15.3	10.5	M	12.1	4.7	45	6.6	4.2			1.9	2.7
11	McpRb19	20	27	85	0	11.1	4.5	hgh	24.8	86.3	75	90	14.3	4.3	50	25	0	8.0	9.7	8.2	M	4.9	2.0	60	2.5	2.2	1.3	1.7	0.6	1.5
12	McpRb20	20	29	80	0	10.9	4.3	hgh	14.4	94.8	75	90	16.2	3.8	44	13	0	8.0	11.7	9.7	M	4.7	2.8	60	3.0	2.4				
13	McpRb21	20	29	85	0	11.1	4.5	hgh	15.5	88.2	90	100	15.1	4.1	48	0	1	8.0	11.4	9.2	M	12.4	3.8	45	6.1	4.2			1.3	
14	McpRb22	20	23	55	0	9.3	3.3	mod	9.4	82.9	90	100	16.5	4.3	44	0	1	8.0	11.2	8.0	M	7.7	3.2	45	4.9	4.3			1.1	2.5
15	McpRb23	20	27	50	0	8.9	3.1	hgh	8.2	76.2	90	100	16.2	4.4	45	0	1	8.0	15.0	10.8	M	7.4	3.3	30	6.4	4.4				
16	McpRb24	20	22	45	0	8.5	2.8	hgh	15.2	85.9	90	100	19.9	4.9	37	13	1	5.0		10.0	M	10.0	4.1	30	7.3	4.3	6.1	3.3		
17	McpRb25	20	24	45	0	8.5	2.8	mod	10.0	86.4	90	100	22.0	4.7	32	0	1	5.0		9.3	M	9.1	4.7	30	9.2	4.1				
18	McpRb26	20	33	60	0	9.6	3.5	low	11.9	89.3	90	100	22.0	6.3	36	0	1	5.0		6.0	M	9.6	5.1	45	7.0	3.0	6.0	1.5		
19	McpTf1	20	30	60	0	9.6	3.5	hgh	87.8	95.7	50	75	8.8	5.9	81	100	5	18.0	17.2	12.5	U	0.0	0.0							
20	McpRb27	20	30	60	0	9.6	3.5	hgh	65.7	99.1	50	75	8.8	6.6	85	88	5	18.0	16.3	13.3	M	1.9	1.6	30	3.0	1.7				
21	McpRb28	20	30	50	0	8.9	3.1	hgh	51.4	95.2	50	75	9.0	6.5	83	75	5	18.0	16.7	12.9	M	4.3	2.0	45	2.9	1.6				
22	McpRb29	20	30	65	0	10.0	3.7	hgh	53.6	106.7	50	75	8.9	6.7	85	88	5	18.0	14.3	10.4	M	2.5	2.3	45	3.4	2.0				
23	McpTf2	20	24	45	0	8.5	2.8	hgh	93.4	143.2	50	75	9.6	6.5	80	75	6	18.0	8.6	7.5	U	0.0	0.2							
24	McpTf3	20	24	45	0	8.5	2.8	hgh	84.4	96.2	50	75	10.0	5.8	75	63	6	18.0	10.1	8.4	U	0.0	0.0							
25	McpRb30	20	24	45	0	8.5	2.8	mod	55.8	97.4	50	75	10.3	5.7	72	50	6	18.0	9.5	7.7	M	1.1	1.5	45	2.1	1.1				
26	McpRb31	20	24	70	0	10.3	3.9	mod	50.2	73.5	50	75	10.3	6.1	75	50	6	18.0	10.7	8.2	M	1.4	1.5	45	2.1	1.1				
27	McpRb32	20	27	50	0	8.9	3.1	mod	51.6	114.4	50	75	7.1	6.6	96	88	8	18.0	3.2	3.1	M	2.5	1.6	60	1.9	1.5	0.8	0.6		
28	McpRb33	20	27	50	0	8.9	3.1	mod	39.2	110.6	50	75	9.3	7.5	88	100	8	18.0	3.1	2.8	M	3.4	1.6	45	2.0	1.8				
29	McpRb34	20	30	65	0	10.0	3.7	hgh	20.5	98.4	75	90	11.8	7.0	71	0	2	7.0	11.2	9.3	M	9.1	2.7	45	3.9	4.5	3.5	2.7		
30	McpRb35	20	25	50	0	8.9	3.1	hgh	14.8	90.3	75	90	13.8	7.2	64	0	2	7.0	9.4	9.2	M	6.6	3.3	45	4.7	4.3				
31	McpRb37	20	32	70	0	10.3	3.9	hgh	8.3	101.4	90	100	19.2	10.4	56	0	3	3.0	17.1	12.1	M	14.3	3.0	30	6.3	4.0	1.3	3.7		
32	McpRb38	20	26	55	0	9.3	3.3	hgh	9.2	113.5	90	100	17.3	6.9	50	25	2	3.0	11.7	10.6	M	8.7	4.0	45	5.7	4.0				
33	McpRb39	20	27	65	0	10.0	3.7	hgh	10.2	107.0	90	100	18.2	7.6	50	0	2	3.0	11.0	8.9	M	7.9	3.0	45	4.6	3.7			0.5	1.2
34	McpRb50	20	30	65	0	10.0	3.7	mod	25.6	107.2	75	90	15.5	10.2	70	100	1	8.0		10.0	M	10.2	3.2	30	6.7	5.0				
35	IslTf1	5	20	20	0	3.4	0.5	mod	20.9	89.5	10	10	17.6	9.9	60	0	4	3.0	4.2	3.6	U	0.0	0.0							
36	IslRb1	5	25	35	0	4.3	0.8	mod	11.7	104.2	90	100	18.2	9.6	57	0	4	3.0	10.3	8.4	M	2.6	1.8	45	2.4	2.3	0.4	0.2		

Id	Fire	Age	Hgt	Cvr	Slope	Fuel load total	Fuel load dead	cont.	Mf dead	Mf live	Fuel cons front	Fuel cons total	Tdry	Tdew	RH	Cld	Rain	Rain	Wind 10m	Wind 1.7m	Use	Head fire ROS	Head fire FH	Head fire Fa	Head fire FL	Head fire Fd	Flank fire ROS	Flank fire FH	Back fire ROS	Back fire FH
		yrs	cm	%	°	t/ha	t/ha		%	%	%	%	°	°	%	%	days	mm	kph	kph		m/min	m	°	m	m	m/min	m	m/min	m
37	IslRb2	5	25	35	0	4.3	0.8	mod	10.1	93.7	90	100	19.7	10.6	55	0	4	3.0	14.6	11.1	M	4.9	1.5	30	3.0	2.1				
38	AirRb1	4	20	40	0	4.1	0.7	mod	16.0	101.7	75	90	14.3	5.5	55	0	2	2.0	3.4	2.7	M	1.3	0.8	75	0.9	0.8				
39	AirRb2	4	25	35	0	3.9	0.6	hgh	19.3	114.8	75	90	15.1	9.7	69	0	2	8.0	8.9	6.4	M	2.0	0.8	30	1.5	1.6	0.8	0.3	0.4	0.2
40	AirRb3	4	20	40	0	4.1	0.7	hgh	11.2	101.2	75	90	17.5	10.0	61	0	2	8.0	7.5	5.8	M	1.4	1.1	75	1.1	0.5	0.6	0.2		
41	AirRb4.1	4	20	30	0	3.7	0.6	hgh	11.1	108.7	75	90	16.7	10.4	66	0	5	3.0	8.8	8.0	M	1.4	0.8	60	1.0	1.5				
42	AirRb4.2	4	20	30	0	3.7	0.6	hgh	9.9	105.9	75	90	17.9	10.1	60	0	5	3.0	10.3	9.3	M	2.2	1.3	75	1.4	1.5	0.3	0.6		
43	AirRb4.3	4	25	35	0	3.9	0.6	hgh	9.9	105.9	75	90	18.8	10.9	60	0	5	3.0	15.0	12.3	M	3.7	1.6	45	2.3	2.5				
44	Lp4Hr1	6	30	100	0	12.6	5.5	hgh	67.6		50	75	14.0	-0.3	38	75	1	10.0		4.2	M	1.7	2.2	60	2.6	1.5				
45	Lp4Hr2	6	25	60	0	9.8	3.6	hgh	67.6		50	75	12.0	-0.3	43	75	2	10.0		9.4	M	3.1	2.7	60	3.3	2.0				
46	Lp4Hr3	6	25	60	0	9.8	3.6	hgh	45.8		50	75	11.0	7.3	77	75	2	10.0		5.3	M	0.6	1.8	75	1.9	1.5	0.4	0.4		
47	Lp4Hr4.1	6	25	60	0	9.8	3.6	low			50	75	13.0	5.3	59	100	3	10.0		2.0	T	0.8	0.5	90	0.5	0.5				
48	Lp4Hr4.2	14	40	100	30	19.1	10.4	hgh			50	75	13.0	5.3	59	100	3	10.0		2.0	T	6.5	5.0	75	5.0	4.0				
49	Lp9Hr1	10	29	80	0	14.6	6.9	hgh	38.5		75	90	16.4	-0.1	33	50	2	12.0		4.8	M	3.1	2.0	75	2.1	2.3				
50	McpTf4	20	20	45	0	8.5	2.8	low	97.9		10	10	13.0	5.5	60	88	0	8.0		6.5	U	0.0	0.0							
51	McpTf5	20	35	90	0	11.4	4.7	hgh	97.9		10	10	13.0	5.5	60	88	0	8.0		9.5	U	0.0	0.0							
52	McpTf6	20	35	75	0	10.6	4.1	hgh	55.1		25	25	12.8	4.3	56	88	0	8.0		12.0	U	1.2	0.3	60	0.4	1.0				
53	McpTf7	20	35	90	0	11.4	4.7	hgh	55.1		25	25	12.8	4.3	56	88	0	8.0		12.0	U	0.7	0.2							
54	CpsHr1	15	29	70	0	9.1	3.2	hgh	44.1				12.5	2.4	50	75	1	10.0		12.5	T	7.0	2.0							
55	AppHr1	15	45	100	0	10.6	4.1	hgh	25.7		75	90	14.0	2.2	45	0	3	4.0		14.0	T	1.5	3.5	60	4.1	2.0			0.3	1.0
56	MulWf1	16	30		0	9.5	3.6		6.0				27.0	8.2	30	0	9	5.0		35.0	M	54.0								
57	BirWf1	25	35		0	11.0	4.4		10.0				21.0	9.1	46	0	6	5.0		36.3	M	55.0								
61	RbyWf4	12	50	100	8	9.6	3.5	hgh	32.7	106.9	90	100	17.0	12.9	77	0	6	2.0		5.0	T	2.9	5.0	75	5.0	8.0	0.5	2.0		
62	PhhWf1	10	40	100	0	16.2	8.1	hgh	14.1	127.8	75	90	27.5	13.7	43	0	8	5.0		12.0	T	8.3	5.6	45	7.9	6.0				
63	PhhWf2	10	40	100	0	16.2	8.1	hgh	14.1	127.8	75	90	27.5	13.7	43	0	8	5.0		11.0	T	8.0	5.6	45	7.9	6.0	2.5	2.9		
64	KgrRb1	7	30	60	0	6.2	1.6	mod	13.4		75	90	20.7	11.4	55	0			7.6	6.5	T	1.9	0.4	75	0.4	0.9				
65	CarHr1	16	35	100	0	20.4	11.4	hgh	22.7		50	75	16.0	4.1	45	100				4.0	T	1.9	3.5	60	3.7	1.3				
66	CarHr2	16	35	100	0	20.4	11.4	hgh	18.3		50	75	17.0	5.8	47	12				3.5	T	1.1	1.1	75	1.4	1.0				
67	CarHr3	16	35	100	0	20.4	11.4	hgh	25.1		50	75	14.0	5.1	55	100				11.5	T	8.7	3.5	45	8.7	8.0				
68	CarHr4	16	35	100	0	20.4	11.4	hgh	32.5		50	75	12.0	3.8	57	25				5.5	T	3.0	3.0	60	4.2	3.0				
69	ScaHr1	12	30	90	0	17.5	7.9	hgh	14.0		75	75	16.8	9.6	62	88	3	50.0		2.0	T	1.1	2.0	75	2.1	1.0				
70	Lp7Hr1	12	30	90	0	17.5	7.9	hgh	14.5		75	75	17.5	11.6	68	0	3	50.0		4.0	T	1.7	1.5	75	1.6	1.9				
71	WomHr1	8	30	75	0	12.5	4.2	hgh	23.1		75	75	13.8	11.2	84	25	3	50.0		3.5	T	3.3	2.0	75	2.1	2.8				
72	CarTf1	5	40	95	0	10.9	2.4	hgh	45.6		75	75	9.0	6.6	84	100	2	20.0		2.0	U	0.0	0.0							
73	CarTf2	10	45	100	0	16.8	6.6	hgh	44.7		75	75	9.0	6.6	84	100	2	20.0		2.0	U	0.0	0.0							
74	CarHr5	5	40	95	0	10.9	2.4	hgh	43.1		75	75	14.0	7.2	63	0	3	20.0		4.0	T	0.8	1.3							
75	CarHr6	10	45	100	0	16.8	6.6	hgh	35.5		75	75	9.3	5.2	75	25	3	20.0		4.0	T	2.7	2.0	75	2.1	3.0				
76	CarHr7	10	45	100	0	16.8	6.6	hgh	52.3		75	75	8.5	7.1	90	30	3	20.0		4.0	T	5.4	2.0	75	2.1	3.0				

Appendix 6. Fire behaviour data

Id	Fire	Age yrs	Hgt cm	Cvr %	Slope °	Fuel load total t/ha	Fuel load dead t/ha	Fuel load cont.	Mf dead %	Mf live %	Fuel cons front %	Fuel cons total %	Tdry °	Tdew °	RH %	Cld %	Rain days	Rain mm	Wind 10m kph	Wind 1.7m kph	Use	Head fire ROS m/min	Head fire FH m	Head fire Fa °	Head fire FL m	Head fire Fd m	Flank fire ROS m/min	Flank fire FH m	Back fire ROS m/min	Back fire FH m
77	CarHr8	10	45	100	0	16.8	6.6	hgh	49.7		75	75	10.3	6.4	76	30	3	20.0		4.0	T	3.7	2.5	75	2.6	4.0				
78	CarTf3	10	45	100	0	16.8	6.6	hgh	51.7		10	10	9.0	5.5	78	60	3	20.0		1.5	U	0.0	0.0							
79	CarTf4	5	40	95	0	10.9	2.4	hgh	47.8		5	5	6.0	5.5	96	0	4	20.0		1.0	U	0.0	0.0							
80	CarTf5	10	45	100	0	16.8	6.6	hgh	40.8		10	10	5.5	5.6	100	0	4	20.0		0.3	U	0.0	0.0							
81	CarHr9	10	45	100	0	16.8	6.6	hgh	47.8		75	75	6.0	6.1	100	0	4	20.0		0.4	T	0.3	0.5	90	0.5	0.3				
82	CarHr10	10	45	100	0	16.8	6.6	hgh	47.1		75	75	12.5	8.2	74	0	4	20.0		7.0	T	1.5	1.5	75	1.6	0.5				
83	StcHr1	20	40	100	0	25.1	15.7	hgh	37.4		75	75	15.0	9.7	70	40	5	8.4		0.5	T	0.5	1.5	90	1.5					
84	StcTf1	20	40	100	0	25.1	15.7	hgh	70.0		10	10	4.0	4.1	100	0	5	8.4		0.5	U	0.0	0.0							
85	FftTf1	6	20	40	5	5.0	0.9	low	31.5		5	5	7.5	6.8	94	90	2	10.0		1.0	U	0.0	0.0							
86	FftTf2.1	6	20	40	5	5.0	0.9	low	34.3		5	5	5.5	3.3	85	90	3	10.0		5.0	U	0.0	0.0							
87	FftTf3.1	21	45	75	5	10.3	4.8	mod	45.0		10	10	5.8	4.4	90	50	3	10.0		4.0	U	0.0	0.0							
88	FftTf2.2	6	20	40	5	5.0	0.9	low	31.9		5	5	6.5	3.3	80	10	3	10.0		4.0	U	0.0	0.0							
89	FftTf3.2	21	45	75	5	10.3	4.8	mod	43.5		10	10	6.5	3.9	83	10	3	10.0		3.0	U	0.0	0.0							
90	FftTf2.3	6	20	40	5	5.0	0.9	low	33.0		5	5	6.5	5.1	90	0	3	10.0		4.0	U	0.0	0.0							
91	FftTf2.4	6	20	40	5	5.0	0.9	low	33.0		5	5	6.5	5.1	90	0	3	10.0		4.0	U	0.0	0.0							
92	FftTf3.3	21	45	75	5	10.3	4.8	mod	40.0		10	10	6.5	5.1	90	0	3	10.0		4.0	U	0.0	0.0							
93	FftTf4.1	21	45	75	5	10.3	4.8	mod	40.7		10	10	7.3	5.4	87	75	4	10.0		1.0	U	0.0	0.0							
94	FftTf5.1	6	20	40	5	5.0	0.9	low	37.8		5	5	8.0	5.0	81	90	4	10.0		0.5	U	0.0	0.0							
95	FftTf4.2	21	45	75	5	10.3	4.8	mod	36.4		10	10	9.3	5.8	78	60	4	10.0		1.0	U	0.0	0.0							
96	FftTf5.2	6	20	40	5	5.0	0.9	low	33.1		5	5	8.6	5.5	80	60	4	10.0		1.0	U	0.0	0.0							
97	FftHr1	21	45	75	5	10.3	4.8	mod	33.1		75	75	9.0	5.7	79	60	4	10.0		1.0	T	1.0	1.0							
98	FftTf4.3	21	45	75	5	10.3	4.8	mod	33.1		10	10	8.5	5.6	81	60	4	10.0		0.5	U	0.0	0.0							
99	CcrHr1	7	30	80	0	12.0	3.6	hgh	41.4		80	80	8.0	2.6	69	25	2	8.0		0.5	T	0.4	0.5	90	0.5	0.3				
100	CcrHr2	7	30	80	0	12.0	3.6	hgh	54.5		80	80	8.0	3.9	75	75	2	8.0		0.5	T	1.0	1.3	90	1.3	0.5				
101	CcrHr3	15	35	90	0	19.9	10.5	hgh	52.6		80	80	5.5	3.6	87	100	2	8.0		0.3	T	0.5	1.0	90	1.0	0.5				
102	CcrTf1	7	30	80	0	12.0	3.6	hgh	52.6		0	0	5.5	3.6	87	100	2	8.0		0.1	U	0.0	0.0							
103	CcrTf2	15	35	90	0	19.9	10.5	hgh	95.2		0	0	5.0	4.4	95	75	2	8.0		0.1	U	0.0	0.0							
104	CcrHr4	7	30	80	0	12.0	3.6	hgh	53.0		80	80	7.1	4.9	85	100	3	8.0		0.3	T	0.7	0.5	90	0.5	0.3				
105	CcrTf3	7	30	80	0	12.0	3.6	hgh	48.5		0	0	6.0	3.4	83	88	3	8.0		7.0	U	0.0	0.0							
106	CcrTf4	15	35	90	0	19.9	10.5	hgh	73.3		0	0	3.0	3.1	100	50	3	8.0		0.0	U	0.0	0.0							
107	CcrHr5	15	35	90	0	19.9	10.5	hgh	45.1		70	70	1.5	1.5	100	0	4	8.0		0.3	T	0.2	0.8	90	0.8	0.3				
108	CcrHr6	15	35	90	0	19.9	10.5	hgh	74.2		70	70	4.0	1.7	85	100	4	8.0		0.3	T	0.4	1.0	90	1.0	0.3				
109	WbkHr1	14	35	75	6	8.8	3.1	mod	26.4		75	75	9.0	7.1	87	0	5	15.0		1.0	T	0.7	0.4	90	0.4	0.5				
110	WbkHr2	14	20	45	-6	7.3	2.5	low	26.4		90	90	8.0	6.1	87	0	5	15.0		4.0	T	3.0	1.0	90	1.0	1.5				
111	FftHr2	7	20	40	5	5.4	1.0	low	17.6		90	90	17.0	10.2	64	0	3	25.0		1.0	T	1.9	0.6	75	0.6	1.0				
112	FftHr3	22	45	75	5	11.3	5.4	mod	17.6		75	100	14.0	9.1	71	50	3	25.0		3.0	T	2.5	4.0	75	4.1	8.0				
113	FftTf5	7	20	40	5	5.4	1.0	low	19.0		0	0	14.0	9.1	71	50	3	25.0		0.1	U	0.0	0.0							

Id	Fire	Age yrs	Hgt cm	Cvr %	Slope °	Fuel load total t/ha	Fuel load dead t/ha	cont.	Mf dead %	Mf live %	Fuel cons front %	Fuel cons total %	Tdry °	Tdew °	RH %	Cld %	Rain days	Rain mm	Wind 10m kph	Wind 1.7m kph	Use	Head fire ROS m/min	Head fire FH m	Head fire Fa °	Head fire FL m	Head fire Fd m	Flank fire ROS m/min	Flank fire FH m	Back fire ROS m/min	Back fire FH m
114	FftTf6	22	45	75	5	11.3	5.4	mod	19.0		0	0	14.0	9.1	71	50	3	25.0		0.1	U	0.0	0.0							
115	DdhHr1	8	30	50	0	6.1	1.3	mod	14.9		90	100	19.5	10.9	57	0	4	25.0		3.0	T	3.1	3.0	75	3.1	2.5				
116	DdhHr2	8	30	50	0	6.1	1.3	mod	14.9		90	100	20.5	11.7	57	0	4	25.0		3.0	T	3.3	2.1	75	2.2	6.0				
117	DdhTf1	8	30	50	0	6.1	1.3	mod	17.6		0	0	17.0	12.8	77	0	4	25.0		0.1	U	0.0	0.0							
118	TahTf1	8	40	80	0	7.3	1.6	mod	18.1		75	75	14.0	12.1	88	0	4	25.0		0.1	U	0.0	0.0							

Note: fire identifiers made up of three letters indicating the site (e.g. Fft indicates Fourfoot Plain), two letters indicating the fire type (Rb = research burn, Hr = hazard reduction burn, Tf = test fire, Wf = wildfire) followed by the fire number at that site; age = time since the last fire; hgt = fuel height; cvr = fuel cover; slope = site slope; cont. = fuel continuity; fuel cons. front = fuel fuel consumed in the fire front; fuel cons. total = total fuel consumption; Tdry = dry bulb temperature; Tdew = dew point temperature; RH = relative humidity; cld = cloud cover; rain days = days since last rain event; rain mm = amount of rain in last rain event; wind 10m = wind speed at 10m; wind 1.7m = wind speed at 1.7m; Use indicates what the data was used for: M = data used to develop the buttongrass moorland fire behaviour models (Equations 6.3. and 6.4), T = data used to test the fire models, U = non-sustaining fires, not used in this thesis; ROS = rate of fire spread; FH = flame height; Fa = flame angle; FL = flame length; Fd = flame depth.

Appendix 7. Papers and reports produced from this thesis

Refereed papers

Marsden-Smedley J. B. and Catchpole W. R. 1995. Fire behaviour modelling in Tasmanian buttongrass moorlands. I. Fuel modelling. International Journal of Wildland Fire 5: 203-214.

Marsden-Smedley J. B. and Catchpole W. R. 1995. Fire behaviour modelling in Tasmanian buttongrass moorlands. II. Fire behaviour. International Journal of Wildland Fire 5: 215-228.

Catchpole W. R., Catchpole E. A., Viney N. R., McCaw W. L. and Marsden-Smedley J. B. In press. Modelling fuel moisture response times and equilibrium moisture content from field data. International Journal of Wildland Fire.

Marsden-Smedley J. B. In press. Changes in southwest Tasmanian fire regimes since the early 1800s. Papers and proceedings of the Royal Society of Tasmania.

Poster papers

Marsden-Smedley J. B. 1991. Fire behaviour modelling in Tasmanian buttongrass moorlands. Poster paper presented at the 1991 Australian Bushfire Conference. Canberra, ACT, Australia.

Marsden-Smedley J. B., Catchpole W. R. and Pyrke A. 1996. Unbounded burning in Tasmanian buttongrass moorlands: Preliminary results. Poster paper presented at the 13th Conference on Fire and Forest Meteorology. Lorne, Victoria, Australia

Marsden-Smedley J. B., Rudman T. and Catchpole W. R. 1993. Fire modelling and fire behaviour in buttongrass moorlands. Poster paper presented at the Landscape Fires '93 conference. Department of Conservation and Land Management, Perth, Western Australia.

Submitted papers

Marsden-Smedley J. B. and Catchpole W. R. Submitted. Fire behaviour modelling in Tasmanian buttongrass moorlands: Fuel moisture. International Journal of Wildland Fire.

Papers in preparation

Marsden-Smedley J. B., Catchpole W. R. and Pyrke A. In preparation. Fire behaviour modelling in Tasmanian buttongrass moorlands: Fire extinguishment.

Marsden-Smedley J. B. and Rudman T. In preparation. Operational fire management in Tasmanian buttongrass moorlands.

Marsden-Smedley J. B. and Kirkpatrick J. B. In preparation. Changes in fire regime in southwest Tasmania: implications for management.

Unrefereed reports

Marsden-Smedley J. B. 1993. Fuel characteristics and fire behaviour in Tasmanian buttongrass moorlands. Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

Marsden-Smedley J. B. 1993. Orange-bellied parrot recovery plan: operational prescriptions for habitat management burns. Unpublished report for the Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

Marsden-Smedley J. B. and Williams K. J. 1993. Floristics and fire management in West Tamar buttongrass moorlands. Unpublished report for the Forestry Commission, Tasmania.

Marsden-Smedley J. B., Catchpole W. R. and Pyrke A. Unbounded burning in Tasmanian buttongrass moorlands. Unpublished report prepared for the Tasmanian Fire Research Fund. Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service

Unrefereed papers

Marsden-Smedley J. B. and Catchpole W. R. 1995. Fire behaviour modelling in Tasmanian buttongrass moorlands. In: A. B. Blanks (ed.). Bushfire '95. Proceedings of the Australian Bushfire Conference. 27 - 30 September 1995, Hobart, Tasmania. Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

Catchpole W. R., Bradstock R. A., Choate J., Foggarty L., Gellie N. Gellie N. J. H., Marsden-Smedley J. B., McCarthy G., McCaw L. and Pearce G. Unpublished. Report of the heathland fire behaviour modelling group meeting held at the 13th Conference on fire and forest meteorology. October 30, 1996. Lorne, Victoria, Australia.