

## DISTURBANCE ECOLOGY OF TASMANIAN HIGHLAND GRASSLAND — AN OVERVIEW AND IMPLICATIONS FOR CONSERVATION MANAGEMENT

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(with two text-figures, one plate and one appendix)

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Active manipulation of disturbances such as fire and grazing is often necessary to maintain or enhance biodiversity values in grasslands. However in many instances information is lacking on the disturbance regimes most likely to achieve conservation aims. This paper provides an overview of the effects of fire and grazing in Tasmanian highland grasslands, and the implications of these for conservation management of this vegetation. In Tasmania, highland grassland is defined as occurring above 600 m above sea level. The vegetation is typically dominated by species of *Poa*. Highland grassland is grazed by a suite of native herbivores and has a history of stock grazing, which continues at some sites of high biodiversity value. There is evidence that Indigenous Tasmanians regularly burnt highland grasslands and that Indigenous burning was instrumental in maintaining grassland at sites that otherwise would be forest. For highland grasslands below 1000 m asl, a reduction in the biomass of dominant grasses through disturbance is necessary in order to maintain plant species diversity. The use of periodic fire, together with native grazing, is likely to be beneficial in this regard. The combination of fire and grazing is also likely to prevent woody plant invasion and maintain vegetation structural heterogeneity. The near ubiquity of native grazing species means there is no ecological imperative for stock grazing. Low productivity of grasslands occurring above 1000 m means that competitive exclusion of interstitial species by grasses is unlikely and therefore active application of disturbance as a management tool will rarely, if ever be necessary. Disturbance management should be accompanied by a well-designed monitoring program and regular review of the management strategy.

**Key Words:** herbivory, fire regimes, alpine, sub-alpine, vegetation management, *Poa*, grasslands.

### INTRODUCTION

Natural grasslands have been heavily transformed by human activity (Henwood 2010). Apart from conversion to introduced pastures, crops or urban settlements, a major factor in this transformation is alteration in disturbance regimes (Schnoor *et al.* 2015). Disturbance regimes are a critical determinant of grassland structure and composition (Belsky 1992, Tremont & McIntyre 1994, Leonard & Kirkpatrick 2004). Where grasslands are managed for conservation, active manipulation of disturbances such as fire and grazing is often necessary to maintain or enhance biodiversity values (Kirkpatrick *et al.* 2005). However, in many instances information is lacking on the disturbance regimes most likely to achieve conservation aims. A particularly contentious issue is the use of livestock grazing as a tool for achieving biodiversity conservation goals (Kirkpatrick *et al.* 2005, Lunt *et al.* 2007). While several studies have indicated that livestock grazing can promote biodiversity values (e.g., Gilfedder & Kirkpatrick 1994, Leonard *et al.* 2004), its effects are contingent on a range of factors such as vegetation composition, landscape context and site history (Lunt *et al.* 2007). Interactions of livestock grazing with other disturbances, in particular fire, also need to be considered (Fuhlendorf *et al.* 2008).

This paper addresses these issues in the context of highland grasslands in Tasmania, Australia. We define grassland as vegetation with <5% tree cover, and in which the tallest vegetation stratum with a cover of more than 10% is dominated by grasses or herbs. In Tasmania, highland grassland is defined as (usually) *Poa*-dominated

grassland occurring above 600 m asl (the upper limit of *Themeda triandra* Forsk. in Tasmania), including grasslands occurring in the alpine (*sensu* Kirkpatrick 1983) zone (Kirkpatrick & Duncan 1987); see below for detailed description of the vegetation. These grasslands are also referred to as “montane grasslands” in some sources e.g., Bowman *et al.* (2013). This definition of highland grassland largely equates to that of the TASVEG community “Highland *Poa* grassland” (Kitchener & Harris 2013). While the focus of this paper is on grassland so defined, we recognise that highland grassland has floristic affinities and often co-occurs with grassy woodland, shrubland and sedgeland, and therefore some of the discussion may also be relevant to these communities.

There is currently approximately 26 000 ha of highland grassland in Tasmania (TVMMP 2013), comprising a significant proportion of remaining native grassland in temperate Australia (Balmer *et al.* 2004). No precise estimate is available as to what proportion of the pre-European invasion extent of highland grassland its current extent represents. However Kirkpatrick (1999) stated that about 60% of the pre-European extent of Tasmanian grassland overall remains, and that most of this occurs above 600 m. Highland grasslands in good condition have high biodiversity value, being floristically rich and often supporting threatened flora and fauna species (Kirkpatrick 1991). While 68% of highland grassland occurs within secure public and private reserves (DPIPWE 2016), some important examples are unreserved. Unreserved highland grasslands are subject to a range of threats, including outright loss through inundation or

conversion to exotic pasture or tree plantations. However even those within the reserve system may be reduced in extent or quality due to inappropriate disturbance regimes (e.g., Kirkpatrick & Balmer 1991, Bowman *et al.* 2013). Therefore understanding the effects of disturbance, and the disturbance regimes most conducive to maintaining biodiversity values, is crucial for effective conservation management of this vegetation.

We provide an overview of the effects of fire and grazing in Tasmanian highland grasslands, and their implications for conservation management. Our paper builds upon previous reviews that have included highland grassland in discussion of the ecology of Tasmanian grassy vegetation generally (Kirkpatrick *et al.* 1988, Kirkpatrick 1991, 1999). In addition to focusing specifically on the highland portion of Tasmanian grassland, we also synthesise more recent research with that included in previous reviews. While our paper does not take the form of a systematic literature review, we have endeavoured to be comprehensive in our

inclusion of relevant literature (focusing on peer-reviewed journal papers), in particular that published since 1999 (when the last review of Tasmanian grassy vegetation was published; the results of a systematic review of this more recent literature are included in appendix 1).

## VEGETATION DESCRIPTION AND ENVIRONMENTAL RELATIONSHIPS

Highland grasslands are typically dominated by one or more species of *Poa* (in particular *P. gunnii* Vickery and *P. labillardierei* Steud.), which may occur as a short or long (~10–100 cm) dense sward or as more isolated tussocks amidst forb-rich lawn (pl. 1). Heavily grazed areas may be dominated by *Rytidosperma nudiflorum* (P. Morris) Connor & Edgar. Grasslands in good condition exhibit a diverse array of forbs, with Asteraceae spp., *Velleia montana* Hook.f., *Ranunculus* spp., *Viola* spp. and *Geranium*



PLATE 1 — Examples of Tasmanian highland grasslands. A: long unburnt grassland exhibiting dense *Poa* tussocks and low abundance of interstitial species. B: Regularly burnt grassland. The area in the foreground has been burnt 1–2 years previously. Note space between *Poa* tussocks and abundance of forbs. The yellowish grassland patch in the left mid-ground has remained unburnt for longer.

spp. being common constituents. Emergent shrubs are also usually present, including *Epacris gunnii* Hook.f., *Acrothamnus hookeri* (Sond.) Quinn, *A. montanus* (R.Br.) Quinn, *Olearia algida* N.A. Wakef. and *Richea acerosa* (Lindl.) F.Muell. Scattered taller shrubs may also occur, such as *Hakea macrocarpa* R.Br., *Richea scoparia* Hook.f., *Coprosma nitida* Hook.f and *Tasmania lanceolata* (Poir.) A.C.Sm. With increasing waterlogging, monocots such as *Empodisma minus* (Hook.f.) L.A.S.Johnson & D.F.Cutler, *Baloskion austral* (R.Br.) B.G.Briggs & L.A.S.Johnson and *Lepidosperma filiforme* Labill. become more prominent, and grassland grades into sedgeland or rushland. There is usually a sharp boundary between grasslands and adjoining forest or woodland (Fensham & Kirkpatrick 1992).

The most extensive areas of highland grassland occur on the Central Plateau, with outlying occurrences in the northwest and smaller, more isolated pockets in the

northeast (Kirkpatrick 1999; fig. 1). These grasslands occur on relatively fertile, well-drained soils derived from dolerite, basalt, carbonate rocks and alluvium, although grassland on siltstone-derived soils occur in snow patches in the Cradle Mountain area and at the Walls of Jerusalem (Parry *et al.* 2016). Kirkpatrick & Duncan (1987) identified six distinct highland grassland communities. The distribution of these communities was related to variation in soil fertility, summer temperature, drainage and precipitation. In addition, highland grasslands exhibit lower productivity at higher altitudes, due to lower temperatures and associated effects including frost heave, such that grasslands above ~1000 m asl take much longer to recover from disturbance than those below (i.e., decades cf. years; Gibson & Kirkpatrick 1989, Bridle *et al.* 2001, Kirkpatrick & Bridle 2013).

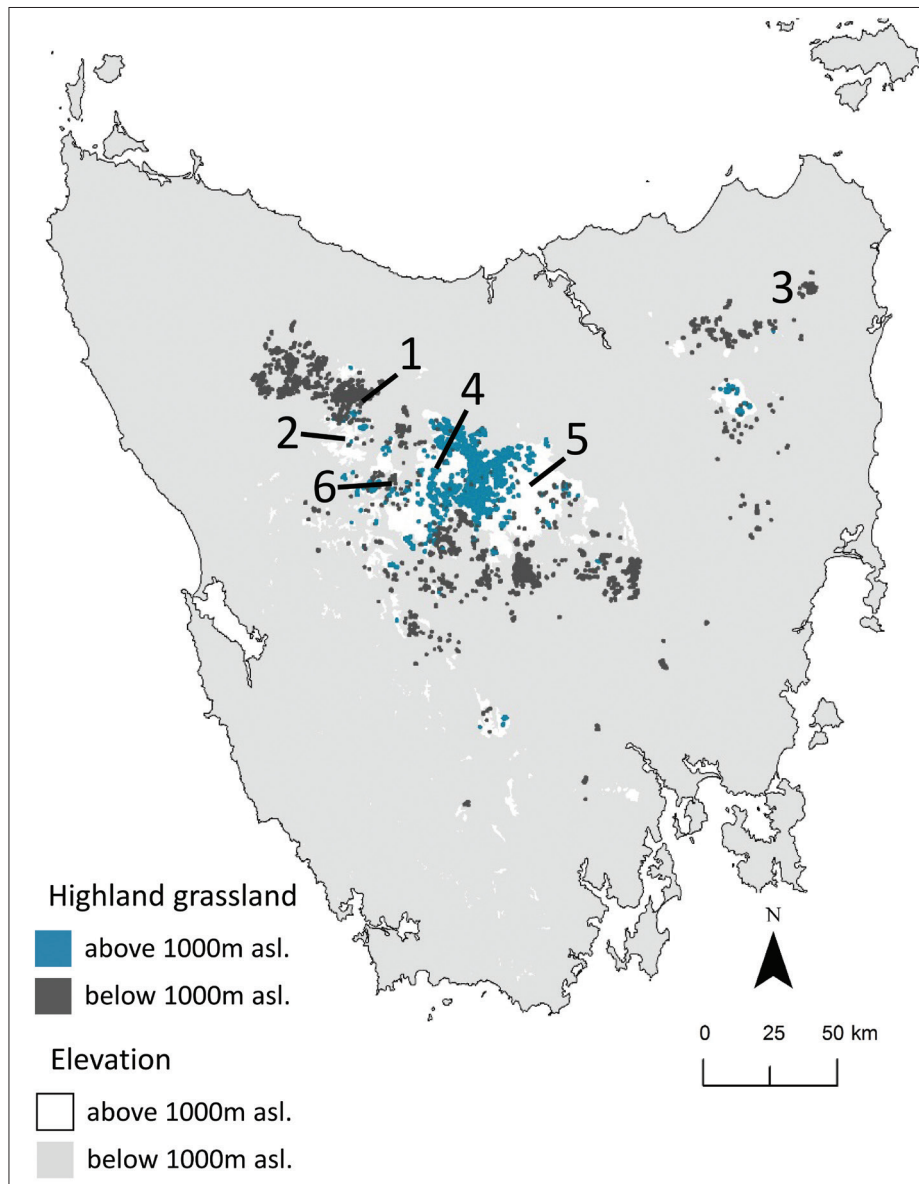


FIG. 1 — Distribution of highland grassland in Tasmania, and locations mentioned in text. 1 = Vale of Belvoir, 2 = Cradle Valley, 3 = Paradise Plains, 4 = Walls of Jerusalem, 5 = Central Plateau, 6 = Lee's Paddocks. Data sources: Land Tasmania (2007), TVMMP (2013).

## DISTURBANCE ECOLOGY OF GRASSLANDS

### General patterns

Grubb (1986) examined the mechanisms allowing the persistence of sparsely and patchily distributed species in English chalk grasslands. He proposed a model for this system in which most species remain relatively rare due to competition from the dominant perennial grasses, while defoliation of these grasses through disturbances such as fire and grazing produce niches in which less competitive species can persist. Grubb's model has been demonstrated to be widely applicable to grassland system dynamics. Grasslands subject to moderate disturbance exhibit higher species richness than those that are undisturbed (e.g., Stuwe & Parsons 1977, Fensham & Kirkpatrick 1989). However, where disturbance is frequent and/or intense, the resultant stress on plants may outweigh the benefits of reduced competition, resulting in a decline in both the dominant grasses and interstitial species (McIntyre & Lavorel 1994). In these circumstances weedy (often exotic) colonising species are promoted and species richness is reduced. The fact that grassland species richness is maximised at an intermediate point on a continuum between no disturbance and severe disturbance appears to be in accord with the intermediate disturbance hypothesis (Connell 1978). However the level of disturbance that promotes species richness is contingent on a number of factors, including productivity and evolutionary history, and therefore varies across systems (Milchunas *et al.* 1988).

Most natural grasslands are subject to grazing by wild and/or domestic animals. Many grasslands also experience periodic natural or anthropogenic fire. These disturbances are similar in that they remove vegetation biomass (Bond 2005) and therefore may promote species richness. For this reason conservation managers often apply one or other (or both) of these disturbances to grasslands. However fire and grazing differ in a number of ways, which means they may produce distinct vegetation outcomes (Lunt 1997a,b, Kirkpatrick *et al.* 2005). The key difference between fire and grazing as disturbances is in selectivity of biomass removed (Bond 2005). Fire is unselective, consuming all sufficiently dry vegetation that it encounters. In contrast, grazing animals will preferentially consume some elements of the vegetation over others. The degree of selectivity and the species selected vary amongst grazing species. For example, sheep preferentially target forbs (Leigh & Holgate 1978), while Eastern Grey Kangaroos (*Macropus giganteus* Shaw, 1790) feed mostly on grasses (Lunt 1991). For bulk feeders, such as cattle, feeding preference is based more on the vertical stature of plants, rather than species; i.e., the preference is for taller more accessible foliage over shorter plants (Noy-Meir *et al.* 1989). Other effects of grazers, such as trampling (Ferguson *et al.* 2010) and nutrient cycling and redistribution in the form of dung and urine (McNaughton 1984) can also be ecologically important.

A striking example of the potential for variation in the type of disturbance to shape grassy vegetation was

provided by Lunt (1997a). In this study, the original grassy forest vegetation of the Gippsland Plain was found to have segregated under different disturbance regimes into grassland, associated with frequent burning and no grazing, and remnant grassy forest, which was lightly grazed by stock, with these "new" communities containing different subsets of the original flora. A major difference between these derived vegetation types was a preponderance of tall forbs in the burnt, ungrazed grassland remnants (Lunt 1997b). Similarly, different grazing species may also result in different outcomes in the vegetation. For example, Bridle & Kirkpatrick (1999) found that grassland on the Central Plateau subject to sheep grazing differed in structure and composition from that grazed by rabbits and Bennett's Wallabies (*Macropus rufogriseus* (Desmarest, 1817)).

The interactive effects of fire and grazing can be profound, as well as being difficult to predict by considering either disturbance in isolation (Fuhlendorf *et al.* 2010, Kirkpatrick *et al.* 2011). A well-known interaction of fire and grazing is the movement of grazers to regenerating recently burnt areas in order to consume nutritious "green pick", a phenomenon that has been widely exploited by hunters and pastoralists (Cubit 1996, Murphy & Bowman 2007). In South African savanna, the "magnet effect" of recently-burnt grassland was found to result in high grazing intensity and maintenance of grazing lawns when the burnt area was relatively small (Archibald & Bond 2004). When fires were large, grazing animals were more dispersed and therefore grazing intensity at any one point was reduced. Where grazers are strongly attracted to recently burnt areas the intense grazing and subsequent abandonment of patches can result in a shifting mosaic of vegetation states (Fuhlendorf & Engle 2004). The ecological heterogeneity brought about by this pattern of disturbance can be important in maintaining biodiversity (Fuhlendorf *et al.* 2008). However the strength of the "magnet effect" can vary depending on factors such as the relative palatability and landscape context of burnt and unburnt vegetation (Kirkpatrick *et al.* 2011, Styger *et al.* 2011).

While fire can influence patterns of grazing, the converse is also true. Where grazing intensity is sufficient to form grazing lawns, fuel loads may be maintained at such low levels that fire is rarely possible (Leonard *et al.* 2010). However, in grasslands dominated by unpalatable tussock grasses, selective grazing of comparatively palatable new growth can elevate dead fuel levels and therefore increase the likelihood of fire. When fire occurs in such systems, intensive post-fire grazing can cause grassland to shift from the unpalatable and flammable tussock state to the palatable, rarely burnable lawn state (Kirkpatrick *et al.* 2011, 2016). Conversely, a decrease in grazing intensity, for example due to population decline in grazers in response to disease, predation or other factors, could lead to a vegetation transition in the opposite direction.

Fire and grazing may have synergistic effects on grassland vegetation. For example, in North American prairie, plant species richness was found to be higher in grassland where fire and grazing co-occurred compared to grassland subject to either disturbance alone (Collins & Barber 1985).

The combination of fire and grazing may be effective in preventing tree or shrub invasion of grassland where either disturbance alone would not have this effect (Kirkpatrick 2004). An example of the potential negative consequences of the combination of fire and grazing is the Central Plateau, where frequent burning and overgrazing by sheep resulted in severe sheet erosion and the transformation of grassland into shrubland (Jackson 1973, Kirkpatrick & Duncan 1987).

## DISTURBANCE IN TASMANIAN HIGHLAND GRASSLANDS

### Grazing

Grazing and fire are the major disturbances in Tasmanian highland grasslands. Grazing by Bennett's Wallabies, Common Wombats (*Vombatus ursinus* Shaw, 1800) and (below 1000 m) Tasmanian Pademelons (*Thylogale billardierii* Desmarest, 1822) is essentially ubiquitous in this vegetation. At some sites these species occur at high densities and remove considerable amounts of vegetation biomass (Leonard *et al.* 2010). Rabbits also occur in most grasslands. In addition, some areas are seasonally grazed by domestic stock, mainly cattle. Cattle and sheep grazing in highland grasslands was common in the nineteenth and twentieth centuries (Shepherd 1973). Highland sheep grazing largely ended when the Tasmanian Wilderness World Heritage Area was extended to include the eastern Central Plateau in 1989 (Kirkpatrick 2007). Cattle grazing has also gradually declined, but is still practised in a number of locations, including grasslands with high conservation value (e.g., Vale of Belvoir, Lees Paddocks). Bridle & Kirkpatrick (1999) found that sheep had greater impacts on the vegetation than rabbits and native herbivores. Where cattle are grazed at low density, they appear not to have severe negative effects on grassland vegetation, but do negatively affect associated wetland areas through pugging and erosion (Tengia *et al.* 2016).

In the absence of grazing, highland grasslands below 1000 m asl conform to the generally observed pattern of increasing dominance by tussock-forming grasses, with a concomitant decline in species richness as smaller-statured species are outcompeted (Gibson & Kirkpatrick 1989). However, this process may be less pronounced than in other grassy systems, such as lowland *Themeda* grasslands, due to the relative unpalatability of *Poa* (Leonard *et al.* 2010). In addition, a number of palatable native (e.g., *Microseris lanceolata* (Walp.) Sch.Bip., *Craspedia* spp.) and exotic (e.g., *Hypochaeris radicata* L.) taxa, and tall forbs generally, occur more frequently when grazing is removed (Bridle & Kirkpatrick 1999). Many of these species also produce more flowers in the absence of grazing, and therefore their reduced occurrence in grazed grassland may be a result of both direct predation and indirect effects on reproductive success (Bridle & Kirkpatrick 2001). Grazing also reduces shrub cover (Gibson & Kirkpatrick 1989) and eucalypt seedling establishment (Fensham & Kirkpatrick 1992)

and so may be important in preventing a transition to shrubland or woodland (Kirkpatrick *et al.* 2016).

The maintenance of inter-tussock spaces and the creation of bare ground by grazers provides regeneration niches for a number of highland grassland forb species, including the nationally endangered *Leucochrysum albicans albicans* (A.Cunn.) Paul G. Wilson (Gilfedder & Kirkpatrick 1994). However overgrazing by stock (combined with fire) produced severe sheet erosion and a transition to shrubland on the Central Plateau (Jackson 1973, Kirkpatrick & Duncan 1987). These negative impacts of grazing are most pronounced in grasslands above 1000 m, where vegetation recovery from disturbance is extremely slow (Gibson & Kirkpatrick 1989, Bridle *et al.* 2001, Kirkpatrick & Bridle 2013). This slow recovery and associated soil erosion is exacerbated by frost heave in soils exposed by vegetation removal, which in turn is most severe in areas of relatively low rainfall (e.g., eastern Central Plateau), due to shorter periods of snow lie (Cullen 1995).

### Fire

Historical and archaeological sources indicate that burning by Tasmanian Aboriginal peoples has been a key driver of vegetation patterns (Moss *et al.* 2007, Fletcher & Thomas 2010). There is considerable evidence that in western Tasmania, Aboriginal burning was instrumental in the maintenance of buttongrass moorland in areas climatically capable of supporting rainforest (Jackson 1968, di Folco & Kirkpatrick 2013). Similarly, analysis of fire scars on *Athrotaxis cupressoides* D. Don on the Central Plateau indicates that Indigenous Tasmanians applied patchy, low intensity fire to grassy vegetation in this area, with the fire return interval estimated to be 22–24 years (Holz *et al.* 2015). In addition, there is evidence that Indigenous burning was instrumental in maintaining the treelessness of highland grasslands occurring within a forest matrix. In the case of Paradise Plains, a grassland surrounded by rainforest in northeastern Tasmania, the presence of burnt *Nothofagus* logs dating from the pre-European era suggests that Aboriginal burning extended, if not created, this grassland (Ellis 1985). Similarly, the invasion of grasslands by fire-sensitive shrubs in the period since European colonisation also suggests the role of Aboriginal burning in previously excluding woody species (Bowman *et al.* 2012). Where the main woody invader is the serotinous obligate seeder *Leptospermum lanigerum* (Sol. ex Aiton) Sm., it can be inferred that such burning occurred at intervals less than the eight years it takes this species to reach reproductive maturity (Wood *et al.* 2017).

However burning alone cannot account for the exclusion of fire-tolerant sclerophyllous species from grassland, where these species are present nearby (Fensham & Fairfax 2006). Fensham & Kirkpatrick (1992) found that competitive exclusion by grasses was key factor in preventing woody invasion of highland grasslands. Soils may also play a role in causing treelessness. Lunt (1997c) found that the distribution of grassland on the Gippsland plain in Victoria closely matched that of flat plains with clay loam

soils, and ascribed the absence of trees from these areas to the combined effects of winter waterlogging and summer drought. In Tasmania, where vegetation and geological boundaries are closely congruent (such as the Vale of Belvoir), the occurrence of grasslands may similarly be a product of soil properties. Soil properties may also play a role in feedbacks between plant growth rates and fire regimes, which in turn influence grassland/forest boundary dynamics (Wood *et al.* 2017).

Graziers and hunters have used fire to manage highland grasslands since the 1820s, and it is possible that their practices were learnt from Indigenous Tasmanians (Cubit 1996, Holz *et al.* 2014). The aim of burning in the high country was to produce palatable feed for stock and game (Kirkpatrick & Bridle 2013). Fires were generally lit in early spring (when highland grassland has a high proportion of frost-killed dead foliage and is most flammable (Leonard 2009) such that fresh growth was produced in the following summer. In the more productive grasslands below 1000 m, patches were burnt rotationally with a typical inter-fire interval of 2–4 years (Cubit 1996, Wood *et al.* 2016). Examination of areas burnt recently by graziers indicate that these fires result in fine-grained patchiness of burn severity, including the occurrence of unburnt patches, reflecting variation in fuel curing and load (S. Leonard pers. obs.).

Tasmanian highland grasslands below 1000 m asl exhibit the general pattern of grass biomass removal by fire facilitating the persistence of interstitial species (Ferguson *et al.* 2009, Kirkpatrick *et al.* 2016). Kirkpatrick & Balmer (1991) suggested that the prolonged absence of fire from grassland at Cradle Valley resulted in a decline in forb abundance. The removal of fire from highland grasslands may also lead to the accumulation of peat, which in turn may facilitate a transition to sedgeland (Kirkpatrick 1991). Bare ground created by fire may provide niches for woody plant establishment (Fensham & Kirkpatrick 1992). In the absence of grazing this would result in succession to shrubland or woodland (Kirkpatrick 2004), however this is unlikely in almost all Tasmanian highland grassland, which is grazed by native animals. Conversely, the unpalatable shrub *Richea acerosa* can come to dominate grassy vegetation when fire is absent and grazing pressure relatively high (Kirkpatrick & Bridle 2016). However, as noted above, frequent firing and heavy grazing has led to shrub invasion on the Central Plateau. These observations highlight the complexity and unpredictability of responses that may arise due to changes in disturbance regimes in highland grasslands, particularly where disturbances interact (Kirkpatrick *et al.* 2011).

Grazing of highland grassland in the wake of fire may bring about a transition from a tussock-dominated structure to grazing lawn (Leonard *et al.* 2010, Kirkpatrick *et al.* 2011). It is possible that subsequent fires within a grassland will cause grazers to abandon existing lawns and concentrate on the newly burnt area, initiating the kind of shifting mosaic of grassland structure observed in North American prairie (Fuhlendorf & Engle 2004). However, in contrast to the prairies, Tasmanian grasslands

occur as relatively small patches within extensive tracts of less palatable vegetation. This means that they are likely to be foci for grazing whether they are recently burnt or not (Kirkpatrick *et al.* 2011), and so the potential for a grazing-induced mosaic to form may be limited. Nonetheless, a number of highland grasslands exhibit a mix patches with lawn or tussock structure (Leonard *et al.* 2010) and future research to determine the relationships of such structural heterogeneity to fire and grazing regimes would be beneficial.

## MANAGEMENT OF FIRE AND GRAZING IN TASMANIAN HIGHLAND GRASSLAND

There is ample evidence that a reduction in the biomass of dominant grasses through disturbance is necessary in order to maintain plant species diversity in Tasmanian highland grassland below 1000 m asl, as well as to prevent succession towards shrubland/forest or sedgeland (fig. 2). Grazing provides this to some degree, however the relative unpalatability of *Poa* means that grazing is likely to be concentrated on interstitial species rather than grass tussocks (Leonard *et al.* 2010). The ineffectiveness of native grazing alone in reducing *Poa* biomass is illustrated by the dense grass sward and low forb abundance in grasslands with large populations of wombats and wallabies, but a prolonged absence of fire (e.g., Cradle Valley; Kirkpatrick & Balmer 1991). Previous management-focused reviews have suggested that, in the absence of native grazers, stock grazing may be beneficial as a means of reducing grass biomass (Kirkpatrick 1991). However recent research has shown that low-density cattle grazing does not reduce tussock grass biomass in highland grassland (Leonard *et al.* 2010) and, while not having negative effects on grassland itself, does have negative effects on associated wetland areas through pugging and bank erosion (Tengia *et al.* 2016). Considering this, and the near ubiquity of native grazing, there would seem to be no ecological imperative for cattle grazing in highland grasslands.

The use of periodic fire is likely to be beneficial in managing highland grassland below 1000 m as it is an effective means of reducing *Poa* biomass (Kirkpatrick *et al.* 2011), creates regeneration niches for interstitial species and does not selectively consume these species (fig. 2). Fire may also inhibit woody plant invasion (Bowman *et al.* 2013, Kirkpatrick & Bridle 2015, Wood *et al.* 2016). The combination of fire and grazing is also likely to increase floristic diversity and structural heterogeneity within grasslands through promoting the formation of grazing lawns (Leonard *et al.* 2010, Kirkpatrick *et al.* 2011, 2016). In addition, the juxtaposition of *Poa* tussocks and short grassland appears to be important in maintaining populations of the endangered Ptunarra Brown Butterfly (*Oreixenica ptunarra* L.E. Couchman, 1953; Neyland 1993, Bell 1999). Further research is required to precisely determine the appropriate fire regime(s) for maintaining biodiversity values in highland grassland. Examples of grasslands in good condition that have a history of

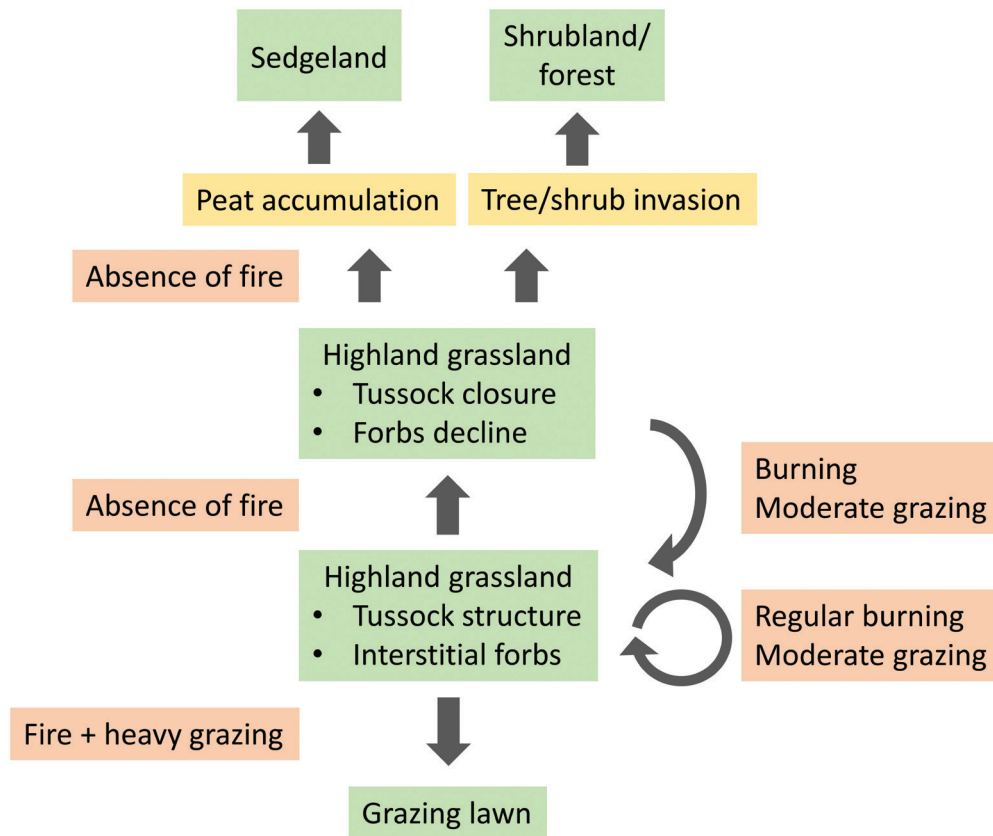


FIG. 2 — Summary of main transitions possible within Tasmanian highland grassland occurring below 1000 m asl in relation to variation in disturbance regimes. In the prolonged absence of fire grasslands typically exhibit accumulation of grass biomass, with concomitant decline in interstitial species. Absence of fire may also lead to tree/shrub invasion or peat accumulation, and eventual transition to shrubland/forest or sedgeland. Conversely, when fire is followed by heavy grazing, tussock grassland may be converted to lawn. Green boxes represent vegetation states, orange boxes disturbance regimes, and yellow boxes processes leading to vegetation transitions.

“traditional” burning by graziers, which may in turn be based on Indigenous practise, provide circumstantial evidence that such burning regimes are beneficial (Bowman *et al.* 2013, Wood *et al.* 2017). Where grasslands are threatened by invasion by fire sensitive shrubs, the vital attributes of the invading species may be able to be used to guide fire management.

In the low productivity environment above 1000 m asl, slow growth rates and grazing by native animals mean that competitive exclusion of interstitial species by grasses is unlikely to compromise floristic diversity (Gibson & Kirkpatrick 1989). There would appear to be no ecological need to apply disturbance to these higher altitude grassland, especially as large tracts are still undergoing the long process of recovery from past over-grazing and burning (Bridle *et al.* 2001, Kirkpatrick & Bridle 2013). Livestock grazing in particular is antithetical to ecological values in this vegetation.

Active management of highland grassland below 1000 m utilising periodic low intensity patch burning, in combination with native grazing (which is practically unavoidable in any case), is likely to be conducive to maintaining ecological values in this vegetation. Where such a management regime prevails there is no

ecological imperative for cattle grazing. Above 1000 m active application of disturbance will seldom, if ever, be required. However, given that specific knowledge of optimal disturbance regimes for highland grassland is lacking, management should be accompanied by a well-designed monitoring program and the management strategy regularly reviewed.

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## APPENDIX 1 – Systematic review of literature concerning fire and grazing in Tasmanian highland grasslands, published since 1999

Here we summarise the results of a systematic review of papers concerning fire and/or grazing in Tasmanian highland grasslands published in peer reviewed journals since the publication of Kirkpatrick (1999) (the last major review covering this vegetation). Relevant papers were identified by searching the Scopus and Web of Science literature databases using various combinations of the search terms “fire”, “grazing”, “Tasmania”, “grassland”, “grassy”, “highland”, “montane” and “alpine”. Relevant papers were subjectively selected from search results, on the basis that they were focused on a) Tasmanian highland grasslands (alone, or in combination with other vegetation types), and b) fire and/or grazing. This process produced a list of 14 papers (see reference list above for full references). Six deal with effects of fire and grazing on flora and/or vegetation, three on grazing effects alone and two on fire effects alone. Two examine the process of woody invasion of grassland due to reduction in fire frequency, with one examining fire behaviour.

A number of “eras” or bodies of research are reflected in the results. Bridle & Kirkpatrick (1999, 2001) and Bridle *et al.* 2001 describe a series of studies of examining grazing effects and vegetation recovery following fire and over-grazing on the Central Plateau. Papers by Ferguson *et al.* (2009), Leonard (2009), Leonard *et al.* (2010) and Kirkpatrick *et al.* (2011, 2016) stem from a study of fire/ grazing interactions in highland (and lowland) grassland, while Bowman *et al.* (2013) and Wood *et al.* (2017) examine landscape-scale vegetation change due to changed fire regimes. Discussion of the findings of these studies, and their implications for highland grassland management are included in the main body of the current paper.

### Results of systematic review of papers concerning fire and/or grazing in Tasmanian highland grasslands published in peer reviewed journals since 1999

Author(s) & year	Topic
Leonard (2009)	Fire behaviour
Holz <i>et al.</i> (2015)	Fire effects, fire history
Kirkpatrick & Bridle (2013)	Fire effects, fire history
Bridle <i>et al.</i> (2001)	Fire/grazing effects
Ferguson <i>et al.</i> (2009)	Fire/grazing effects (on bryophytes)
Kirkpatrick & Bridle (2016)	Fire/grazing effects
Kirkpatrick <i>et al.</i> (2011)	Fire/grazing effects
Kirkpatrick <i>et al.</i> (2016)	Fire/grazing effects
Leonard <i>et al.</i> (2010)	Fire/grazing effects
Bridle & Kirkpatrick (1999)	Grazing effects
Bridle & Kirkpatrick (2001)	Grazing effects
Tengia <i>et al.</i> (2016)	Grazing effects
Bowman <i>et al.</i> (2013)	Vegetation change in relation to changed fire regimes
Wood <i>et al.</i> (2017)	Vegetation change in relation to changed fire regimes