

IMPACT OF CHANGES IN LIGHTNING FIRE INCIDENCE ON THE VALUES OF THE TASMANIAN WILDERNESS WORLD HERITAGE AREA

by Jamie B. Kirkpatrick, Jenny K. Styger and Jon B. Marsden-Smedley

(with two text-figures)

Kirkpatrick, J.B., Styger, J.K. & Marsden-Smedley, J.B. 2018 (14:xii): Impact of changes in lightning fire incidence on the values of the Tasmanian Wilderness World Heritage Area. *Papers and Proceedings of the Royal Society of Tasmania* 152: 27–32.

<https://doi.org/10.26749/rstpp.152.27> ISSN: 0080–4703. Discipline of Geography and Spatial Sciences, School of Technology, Environments and Design, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia. (JBK*, JKS, JBM-S).

*Author for correspondence. Email: j.kirkpatrick@utas.edu.au

The Tasmanian Wilderness World Heritage Area has ecosystems and cultural landscapes that have been created and/or influenced by the interactions between the physical environment, the biological environment, fire regimes and people. Lightning is the dominant cause of fire in the 2010s, yet was rarely recorded as a cause of fire before 1980, when arsonists caused most fires. The main potential impact of this change in primary cause of fire incidence on the values of the Tasmanian Wilderness World Heritage Area is the loss of ecosystems dominated by highly fire-sensitive palaeoendemics, organosols and Aboriginal cultural landscapes. At the same time as these values are threatened, a lack of burning threatens some fire-dependent vegetation types. We suggest an increase in planned burning of fire-tolerant and fire-requiring vegetation, maintenance of ignition suppression, an improvement in rapid response capability and an improvement in rapid detection of lightning fires is required in order to maintain many world heritage values.

Key Words: Tasmanian Wilderness World Heritage Area, lightning fire, management, Tasmania.

INTRODUCTION

The Tasmanian Wilderness World Heritage Area (TWWHA), managed by the Parks and Wildlife Service, has been listed by UNESCO for its globally significant natural and cultural values (Australian Government 2016). The TWWHA is home to globally significant biodiversity and geodiversity, contains areas of globally significant Aboriginal cultural heritage as well as encompassing areas of great natural beauty (TWWHA Management Plan 2016). The globally significant palaeoendemic plants of the TWWHA are concentrated in places where fire has been rare or absent (Jordan *et al.* 2016). In contrast, about a quarter of the TWWHA's vegetation is moorland, typically on nutrient-poor soils, which is dependent on frequent fire in order to maintain its species and structural diversity (Balmer & Storey 2010). Interactions between fire, vegetation and topography have moulded the spatial patterns of most of the globally significant ecosystems of the TWWHA (Jackson 1968).

Fire has been part of the landscape and ecology of the TWWHA for many millennia. People have used fire for management in the region for at least 35 000 years (Kee *et al.* 1993, Cosgrove 1995, Allen 1996, Bowdler 2010) and, at most, 70 000 years (Jackson 1999). Aboriginal people were likely to have deliberately burned buttongrass moorlands and grasslands. Infrequent fires in scrub and eucalypt forest and the very few fires that occurred in rainforest, subalpine and alpine areas were likely to have been the results of natural ignition and/or escapes (Marsden-Smedley 1998, Johnson & Marsden-Smedley 2002, Marsden-Smedley & Kirkpatrick 2000). The available evidence suggests that while most fires prior to the British invasion of Tasmania were probably small- to medium-sized (< 1000 ha), large fires did burn parts of the present TWWHA, at a frequency

of approximately once in 250 years (J. Marsden-Smedley unpublished data).

Following the forced removal of Aboriginal people from the region, the fire regime changed to a pattern of fewer small-scale fires and more frequent extensive fires. During the 1930s, two extensive fires burned much of the TWWHA, but since 1939 no extensive fires in the TWWHA have occurred (Marsden-Smedley 1998, Johnson & Marsden-Smedley 2002), although there have been a few medium-sized fires such as the ecologically devastating 1960/61 Central Plateau fire and the large but ecologically benign 2012/13 Giblin River fire (Parks and Wildlife Service unpublished fire history database).

The cause of fires in the TWWHA has changed over the decades from predominately human-ignited to predominately lightning-ignited. Before 1980, Bowman & Jackson (1981) estimated that lightning fires were only responsible for about 0.1% of fires and about 0.01% of the area burned. Since circa 2000, lightning has become the main ignition source of fires in the TWWHA (Parks and Wildlife Service unpublished fire history database, figs 1, 2). An increase in lightning ignitions has also been recorded in the alpine mountains of mainland Australia as well as globally (Zylstra 2018).

The increase in lightning-ignited fires could result in the return to extensive fires, such as those seen in the 1890s and 1930s. Lightning fires pose a particular threat to the TWWHA as they are more likely than human-ignited fires to occur in remote areas, making suppression more difficult (Flannigan & Wotton 1991). In addition, lightning storms often result in numerous ignitions across the landscape, overwhelming the suppressive capacity of the fire management agencies (Flannigan *et al.* 2009).

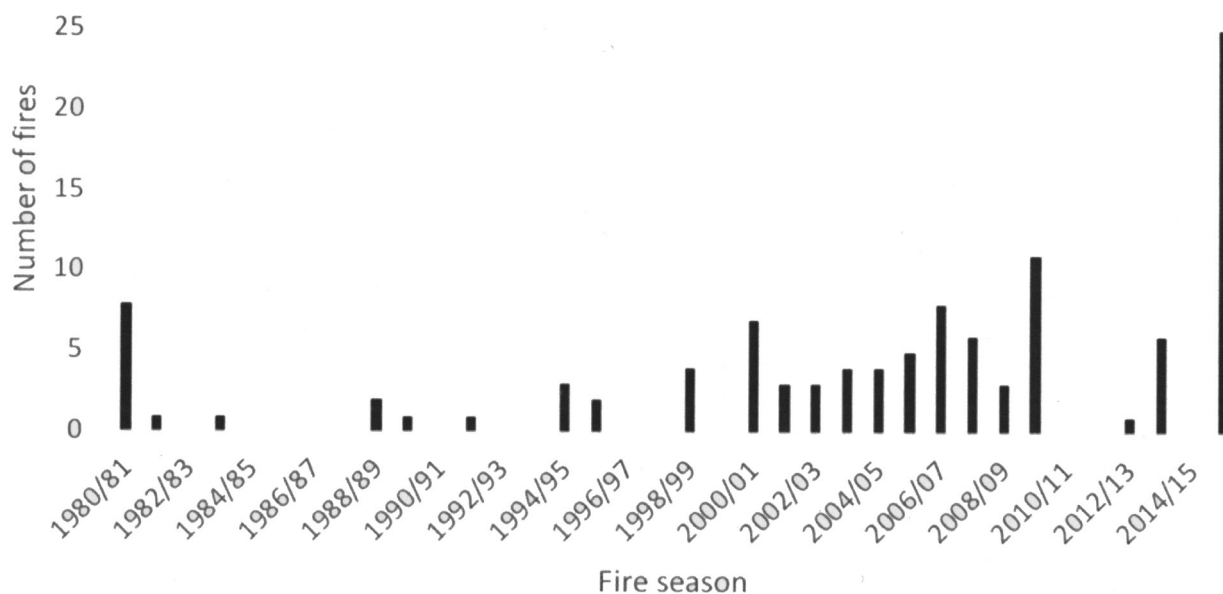


FIG. 1 — Number of fires each fire season, 1980/81–2015/16.

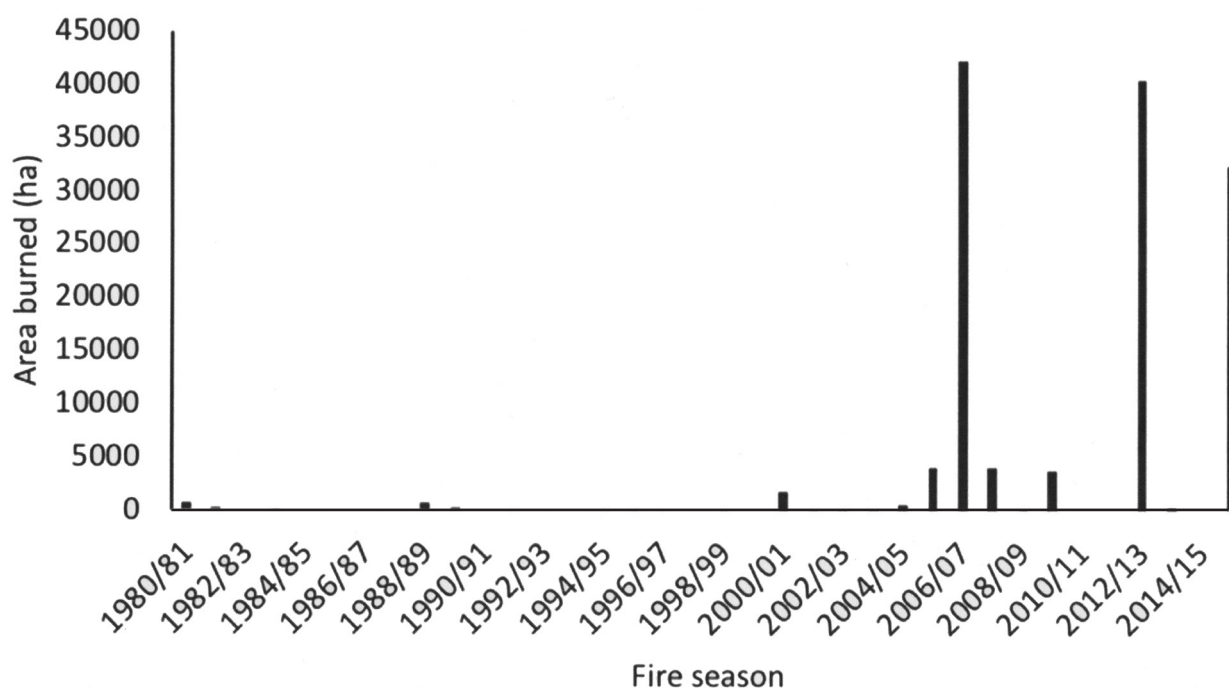


FIG. 2 — Area burned in each fire season, 1980/81–2015/16.

In the present paper, we review the potential impact of increased lightning fires on world heritage and other natural values in the TWWHA, and discuss management approaches to mitigate this threat.

POTENTIAL IMPACTS OF CHANGES IN LIGHTNING FIRE ON NATURAL VALUES

The major adverse impacts predicted from increases in fires are on the Gondwanan rainforest and alpine communities (particularly those containing endemic coniferous and/or

deciduous species) from which fire has been long absent (Jordan *et al.* 2016). The main species of concern are the native conifers, King Billy Pine (*Athrotaxis selaginoides* D. Don), Pencil Pine (*Athrotaxis cupressoides* D. Don), Huon Pine (*Lagarostrobos franklinii* (Hook.f.) Quinn), Diselma (*Diselma archeri* Hook.f.), and the dwarf pines *Microcachrys tetragona* (Hook.) Hook.f. and *Pherosphaera hookeriana* W. Archer, along with Deciduous Beech (*Nothofagus gunnii* (Hook.f.) Oerst). These clades have no capacity to vegetatively recover when foliage is fully burned, do not store disseminules in their canopies or soil, and mostly have poor seed dispersal. This means that if burned by even a single fire, these species

are typically rendered locally extinct for extended time periods (e.g., in excess of 500 to 1000 years; Kirkpatrick & Dickinson 1984, Brown 1988, Peterson 1990; Robertson & Duncan 1991, Kirkpatrick *et al.* 2010).

Of secondary concern are adverse fire impacts to organosols, *Sphagnum* peatlands, and eucalypt forests. Organosols and peatlands have the potential to be degraded by fire, especially if fires occur under conditions when their peat soils are dry enough to sustain subterranean burning; in some cases for periods of weeks or months after the initial ignition. Fires will also degrade (Hill 1982, Hill & Read 1984, Read 2005) and potentially eliminate (di Folco & Kirkpatrick 2013) rainforests. In addition, very frequent fires have the potential to destroy eucalypt forests, especially where the eucalypts rely on seed regeneration (Bowman *et al.* 2014).

The organic soils of the TWWHA are continuous over oligotrophic parts of the landscape, ranging from typically shallow (i.e., 0.1–0.3 metres depth) black muck peats under moorland to red mor organosols under rainforest (di Folco 2007). The moorland organic soils most at risk from climate change and lightning fires are those with high organic contents, which most commonly occur in gullies and flat sites (di Folco 2007). Under previous climatic conditions, these organosols would have been protected from burning by having high moisture contents, but if the predicted increased dryness resulting from climate change occurs (Department of Premier and Cabinet 2012) then they will have the potential to be degraded by large-scale peat fires. The diverse alpine organic soils (Kirkpatrick *et al.* 2014) can be truncated by fire. Their recovery takes decades to centuries (Kirkpatrick & Dickinson 1984, Bridle & Kirkpatrick 1997). In wet scrub communities, the accumulation of organic material in the duff and fibric layers of the soil can be rapid with tens of centimetres accumulating within 60 years (di Folco & Kirkpatrick 2013). However, there may be catastrophic losses of these duff and fibric layers during and immediately following fires due to their highly flammable nature and subsequent erosion through aeolian and fluvial processes on exposed surfaces.

The *Eucalyptus regnans* F. Muell. tall eucalypt forests are the globally outstanding example of the hot fire paradox, eliminated if there are two hot fires within a 10–30 year time period (Ashton 1976, Balmer *et al.* 2004) or if the interval between fires exceeds the circa 500 year eucalypt lifespan (Wood *et al.* 2010). Most of these forest types in the TWWHA are dominated by mature and/or old growth eucalypts, although there are also many forests with a range of tree ages, the product of incomplete mortality following lower intensity ground fires (Turner *et al.* 2009). If there are closely repeated landscape-scale catastrophic fires, such as those in 1898 and 1934 in Tasmania, the remaining *E. regnans* forests might meet the fate of some of the *E. delegatensis* R.T. Baker ssp. *delegatensis* forests in Victoria on the mainland of Australia, where there are extensive areas in which the eucalypts have become locally extinct following very extensive fires in 2003, 2007 and 2009 (Bowman *et al.* 2014).

Almost all of the TWWHA which is below the climatic treeline is climatically capable of supporting rainforest, even extremely poorly-drained sites (Kirkpatrick 1977, 1984). In the absence of fire, tree and shrub species that require large gaps or disturbed ground for regeneration would be confined to river banks, places where landslips were frequent (Cullen 1991) and rocky subalpine areas (Kirkpatrick & Balmer 1991). Thus, fire is important in allowing the persistence of many species and communities in the TWWHA. Values that could be lost with a reduction in fire include Aboriginal cultural landscapes, along with the main fire-dependent vegetation formations of eucalypt forest, wet scrub, grassland and buttongrass moorland (Jackson 1968).

Despite the general undesirability of fire in the alpine zone, some alpine daisy shrubs, which are wind-dispersed and short-lived, can become highly abundant after fire, dying out after approximately half a century (Kirkpatrick *et al.* 2002). In long unburned areas they are only able to persist in areas where fluvial erosion provides a constant regeneration niche. Additionally, fire may be construed to have positive conservation effects on cushion plants in the alpine and subalpine parts of the TWWHA, in places where rushes, sedges and shrubs overwhelm cushion plants (Harding & Kirkpatrick 2018). Where all the species in the cushion mosaic are able to recover rapidly after a fire, in contrast to the invading shrubs, fire may have a positive conservation effect on TWWHA values. However, in the central and western mountains, the frequent presence of the fire-sensitive cushion plant *Dracophyllum minimum* F. Muell. (Kirkpatrick & Dickinson 1984) in the mosaics makes fire undesirable.

The buttongrass (*Gymnoschoenus sphaerocephalus* Hook.f.) moorlands are a globally distinct ecosystem of high universal value (Balmer *et al.* 2004), characterised by flammability at globally high moisture levels (Marsden-Smedley & Catchpole 1995) and being able to survive at globally low phosphorus contents (Jackson 1977). Depending on their topographic position and geologic fertility, an absence of fire for 20–100 years will see the species-rich moorland become species-poor wet scrub and eventually rainforest after 250–500 years (Jarman *et al.* 1988). The invertebrate fauna of the moorland, some of which (such as *Allanaspides*) are ancient, rapidly recover from fire (Driessen *et al.* 2013, Driessen & Kirkpatrick 2017), although *Acarina* might be an exception (Green 2010). Moorland is critical habitat for two rare parrots, which prefer recently burned (i.e., Orange-bellied Parrots *Neophema chrysogaster* Latham, 1790) or less recently burned (i.e., Ground Parrots *Pezoporus wallicus* (Kerr, 1792)) moorlands (Driessen 2010).

Finally, a fire frequency which eliminates or reduces shrubs whilst promoting more highly palatable grasses and forbs will benefit world heritage values by maintaining enhanced numbers of native herbivores which will in turn support enhanced numbers of marsupial carnivores (Kirkpatrick *et al.* 2011, Styger *et al.* 2011).

MANAGEMENT RESPONSES

The consequences of changing patterns of ignitions on TWWHA values depend upon the rapidity of the fire suppression response, with suppression only possible during a brief temporal window post-ignition, after which efforts can only be concentrated on containment.

If the drier summers that are predicted to occur in western Tasmania with climate change (Department of Premier and Cabinet 2012, Love *et al.* 2016) occur, and are associated with a continuation of dry lightning ignitions, then the probability of rainforest burning will probably be greater than has been the case in the past. However, if an increased frequency of ignition occurs when rainforest soils are wet, therefore burning only moorland, the burned moorland could provide a barrier to the movement of fire into rainforest, lowering the probability of rainforest loss. Planned aerial ignition of large areas of moorland when the rainforest is too moist to burn will achieve the same outcome (Marsden-Smedley & Kirkpatrick 2000, King 2004, King *et al.* 2006). Rainforests are highly unlikely to sustain burning if there has been more than 50 mm of precipitation in the previous month, irrespective of the daily fire danger rating (Styger & Kirkpatrick 2015).

The very large increase in lightning fires in the past 45 years (Parks and Wildlife Service unpublished fire history database), in association with predicted increases in vegetation and soil dryness resulting from climate change, indicates that the option of relying on inherent ecosystem resilience is highly unlikely to result in the maintenance of TWWHA values. The most probable outcome of such a regime of benign neglect (Brown 1996) is high-level adverse impacts on many of the world heritage listed values of the region.

A better option for the management of the TWWHA is the implementation of a comprehensive regime of planned burning in fire-dependent vegetation types, in association with active fire suppression in fire-sensitive vegetation types. This strategy offers the highest probabilities of achieving the TWWHA's management goals (King *et al.* 2006, 2008, 2013, Department of Primary Industries, Parks, Water and Environment 2015, Bentley & Penman 2017). Systems for performing such a fire management regime have already been published and operationally tested (Marsden-Smedley 2009), but have not been implemented in a political context in which protection of built property has been the main goal in planned burning programs for the State as a whole.

Suppression activities should take place as soon as practical after an ignition occurs, when the fire is still small, as this will optimise chances for success. To achieve this rapid response, additional resources for current remote area firefighting and improved lightning detection systems for the TWWHA will be required.

CONCLUSION

The ecosystems of the TWWHA are a highly complex mosaic of states and a cat's cradle of potential transitions, mediated

by the region's climate, fire regimes and site productivity. Any change in the incidence and severity of fire is likely to adjust the balance of the states, which vary continuously between each other, but appear to be distinct because of feedbacks between vegetation state and differences in propensity to burn (Jackson 1968, Wood & Bowman 2012, Harris *et al.* 2018). The fire-sensitive palaeoendemics dominate vegetation that has a high degree of stability compared to most other states, but even this vegetation exhibits directional change at the century scale (Kirkpatrick & Bridle 2013). Moorland and grassland on moderately fertile to fertile ground are highly unstable without repeated disturbance by fire, disappearing under shrubs and trees within decades (Balmer & Storey 2010, Bowman *et al.* 2013, Wood *et al.* 2017). Shifts between vegetation types as a result of a change in fire regimes are highly variable in their potential reversibility. This variability relates to the fire adaptations and dispersal capacities of the species present in the previous state and the distance of the area that has experienced a transition from surviving vegetation in the previous state. For example, vegetation that has changed from heathland to scrub may return to a structural heathland after a fire event, but at the cost of the loss of those taxa which do not have a persistent seed store or well dispersed seeds (Bargmann & Kirkpatrick 2015).

In order to protect the formal and informally recognised values of the TWWHA from increased lightning fires, active management is required. We recommend a comprehensive planned burning regime (see King *et al.* 2006) augmented with increased remote area fire suppression capabilities during the fire season. An improved lightning detection system for western Tasmania is also required to identify and suppress lightning fires before they grow to a size at which they are unable to be contained.

ACKNOWLEDGEMENTS

Adele Wright from the Fire Management Section of the Tasmanian Parks and Wildlife Service provided access to the fire history and fire-attributes vegetation databases. Staff in the Tasmanian Climate Change Office provided resources and assistance with producing this paper. In particular, we would like to thank Shona Prior, Tony Press, Jane Colton and Adrian Pyrke.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

- Allen, J. 1996: *Site descriptions, stratigraphies and chronologies*. Report of the southern forests archaeological project, volume 1. School of Archaeology, Latrobe University, Melbourne: 277 pp.
- Ashton, D.H. 1976: The development of even-ages stands of *Eucalyptus regnans* F. Muell. in central Victoria. *Australian Journal of Botany* **24**: 397–414.
- Australian Government, 2016: *World Heritage Places – Tasmanian Wilderness*. <http://www.environment.gov.au/heritage/places/world/tasmanian-wilderness/> (accessed 22 June 2017).

- Balmer, J., Whinam, J., Kelman, J., Kirkpatrick, J.B. & Lazarus, E. 2004: A review of the floristic values of the Tasmanian Wilderness World Heritage Area. Nature Conservation Report 2004/3. Department of Primary Industries Water and Environment, Hobart: 129 pp.
- Balmer, J. & Storey, D. 2010: A review of vegetation responses to fire in buttongrass moorland. In Balmer, J.B. (ed.): Proceedings of the 2007 buttongrass moorland management workshop, Nature Conservation Report 2010/4. Department of Primary Industries, Parks, Water and Environment, Hobart: 22–29.
- Bargmann, T. & Kirkpatrick, J.B. 2015: Transition from heathland to scrub in south-eastern Tasmania – extent of change since the 1970s, floristic depletion and management implications. *Biodiversity and Conservation* **24**: 213–228.
- Bentley, P.D. & Penman, T.D. 2017: Is there an inherent conflict in managing fire for people and conservation? *International Journal of Wildland Fire* **26**: 455–468.
- Bowdler, S. 2010: The empty coast: conditions for human occupation in southeast Australia during the late Pleistocene. In Haberle, S., Stevenson, J. & Prebble, M. (eds): *Terra Australis. Volume 32, Altered Ecologies: Fire, Climate and Human Influence on Terrestrial Landscapes*. ANU Press, Canberra: 177–185.
- Bowman, D.M.J.S. & Jackson, W.D. 1981: Vegetation succession in Southwest Tasmania. *Search* **12**: 358–362.
- Bowman, D.M.J.S., Wood, S.W., Neyland, D., Sanders, G.J. & Prior, L.D. 2013: Contracting Tasmanian montane grasslands within a forest matrix is consistent with cessation of Aboriginal fire management. *Austral Ecology* **38**: 627–638.
- Bowman, D.M.J.S., Murphy, B.P., Neyland, D.L.J., Williamson, G.J. & Prior, L.D. 2014: Abrupt fire regime change may cause landscape-wide loss of mature obligate seeder forests. *Global Change Biology* **20**: 1008–1015.
- Bridle, K. & 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, M.J. 1988: The distribution and conservation of King Billy pine. Forestry Commission, Hobart.
- 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.
- Cosgrove, R. 1995: Late Pleistocene behavioural variation and time trends: the case from Tasmania. *Archaeologica Oceania*, **30**: 83–104.
- Cullen, P.J. 1991: Regeneration of *Athrotaxis selaginoides* and other tree species in landslide faces within rainforest in Tasmania. In Banks, M.R. (ed.): *Aspects of Tasmanian Botany: a tribute to Winifred Curtis*. Royal Society of Tasmania, Hobart: 191–200.
- Department of Premier and Cabinet 2012: Appendix 1 – Predicted changes to Tasmania's climate. http://www.dpac.tas.gov.au/divisions/climatechange/adapting_to_climate_change_in_tasmania/appendix_1_predicted_changes_to_tasmanias_climate (accessed 10 October 2016).
- di Folco, M.B. 2007: Tasmanian organic soils. Unpublished PhD thesis, University of Tasmania, Hobart.
- di Folco, M.B. & Kirkpatrick, J.B. 2013: Organic soils provide evidence of spatial variation in human-induced vegetation change following European occupation of Tasmania. *Journal of Biogeography* **40**: 197–205.
- Department of Primary Industries, Parks, Water and Environment 2015: Fire regimes for nature conservation in the Tasmanian Wilderness World Heritage Area. Nature Conservation Report 15/2. Hobart: 49 pp.
- Driessen, M. 2010: A review of fauna responses to fire in buttongrass moorland. In Balmer, J.B. (ed): Proceedings of the 2007 buttongrass moorland management workshop, Nature Conservation Report 2010/4. Department of Primary Industries, Parks, Water and Environment, Hobart: 30–35.
- Driessen, M. & Kirkpatrick, J.B. 2017: The implications of succession after fire for the conservation management of moorland invertebrate assemblages. *Journal of Insect Conservation* **21**: 15–37.
- Driessen, M., Kirkpatrick, J.B. & McQuillan, P.B. 2013: Shifts in composition of monthly invertebrate assemblages in moorland differed between lowland and montane locations but not fire-age. *Environmental Entomology* **42**: 58–73.
- Flannigan, M.D. & Wotton, B.M. 1991: Lightning-ignited forest fires in northwestern Ontario. *Canadian Journal of Forest Research* **21**: 277–287.
- Flannigan, M.D., Krawchuk, M.A., de Groot, W.J., Wotton, B.M. & Gowman L.M. 2009: Implications of changing climate for global wildland fire. *International Journal of Wildland Fire* **18**: 483–507.
- Green, D. 2010: The soil mites of buttongrass moorland (Tasmania) and their response to fire as a management tool. In Sabelis, M.W. (ed.): *Trends in Acarology. Proceedings of the 12th International Congress*. Springer, Dordrecht: pp 179–183.
- Harding, M. & Kirkpatrick, J.B. 2018: Short-term recovery of cushion plant communities after fire on the Central Plateau, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **152**: 9–15.
- Harris, R.M.B., Remenyi, T., Fox-Hughes, P., Love, P. & Bindoff, N.L. 2018: Exploring the future of fuel loads in Tasmania, Australia: shifts in vegetation in response to changing fire weather, productivity and fire frequency. *Forests* **9**: 210.
- Hill, R.S. 1982: Rainforest fire in Western Tasmania. *Australian Journal of Botany* **30**: 583–589.
- Hill, R.S. & Read, J. 1984: Post-fire regeneration of rainforest and mixed forest in western Tasmania. *Australian Journal of Botany* **32**: 481–493.
- 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 *Proceedings of a Symposium on nutrient cycling and indigenous forest ecosystems*. CSIRO, Perth: 122–123.
- Jackson, W.D. 1999: The Tasmanian legacy of man and fire. *Papers and proceedings of the Royal Society of Tasmania* **133**: 1–14.
- Jarman, S.J., Kantvilas, G. & Brown, M.J. 1988: Buttongrass moorland in Tasmania. Research Report 2. Tasmanian Forest Research Council, Hobart: 158 pp.
- Johnson, K.J. & Marsden-Smedley, J.B. 2002: Fire history of the northern part of the Tasmanian Wilderness World Heritage Area and its associated regions. *Papers and Proceedings of the Royal Society of Tasmania* **136**: 145–152.
- Jordan, G.J., Harrison, P.A., Worth, J.R.P., Williamson, G.J. & Kirkpatrick, J.B. 2016: Palaeoendemic plants provide evidence for persistence of open, well-watered vegetation since the Cretaceous. *Global Ecology and Biogeography* **25**: 127–140.
- Kee, S., Prince, B., Dunnett, G. & Thomas, I. 1993: Holocene Aboriginal settlement patterns. In Smith, S.J. & Banks, M.R. (eds): *Tasmanian wilderness – world heritage values*. Royal Society of Tasmania: Tasmania: 58–66.
- King, K.J. 2004: Simulating the effects of anthropogenic burning on patterns of diversity. Unpublished PhD thesis, Australian National University: Canberra.
- King, K.J., Bradstock, R.A., Cary, G.J., Chapman, J. & Marsden-Smedley, J.B. 2008: The relative importance of fine scale fuel mosaics on reducing fire risk in south west Tasmania, Australia. *International Journal of Wildland Fire* **17**: 421–430.
- King, K.J., Cary, G.J., Bradstock, R., Chapman, J., Pyrke, A.F. & Marsden-Smedley, J.B. 2006: Simulation of prescribed burning strategies in south west Tasmania, Australia: effects on unplanned fires, fire regimes and ecological management values. *International Journal of Wildland Fire* **15**: 527–540.
- King, K.J., Cary, G.J., Bradstock, R.A. & Marsden-Smedley,

- J.B.** 2013: Contrasting fire responses to climate and management: insights from two Australian ecosystems. *Global Change Biology* **19**: 1223–1235.
- Kirkpatrick, J.B.** 1977: Native vegetation of the west coast region of Tasmania. In Banks, M.R. & Kirkpatrick, J.B. (eds): *Landscape and Man*. Geography Department, University of Tasmania, Hobart: 55–80.
- Kirkpatrick, J.B.** 1984: Altitudinal and successional variation in the vegetation of the West Coast Range, Tasmania. *Australian Journal of Ecology* **9**: 81–91.
- Kirkpatrick, J.B. & Balmer, J.** 1991: The vegetation and flora of the Cradle Mountain-Pencil Pine area, Tasmania. In Banks, M.R. (ed.): *Aspects of Tasmanian Botany: a tribute to Winifred Curtis*. Royal Society of Tasmania: Hobart: 119–148.
- Kirkpatrick, J.B. & Bridle, K.L.** 2013: Natural and cultural histories of fire differ between Tasmanian and mainland alpine vegetation. *Australian Journal of Botany* **61**: 465–474.
- Kirkpatrick, J.B., Bridle, K.L. & Dickinson, K.J.M.** 2010: Decades-scale vegetation change in burned and unburned alpine coniferous heath. *Australian Journal of Botany* **58**: 453–462.
- Kirkpatrick, J.B., Bridle, K.L. & Wild, A.S.** 2002: Succession after fire in alpine vegetation on Mount Wellington, Tasmania. *Australian Journal of Botany* **50**: 145–154.
- Kirkpatrick, J.B. & Dickinson, K.J.M.** 1984: Impact of fire on Tasmanian alpine vegetation and soils. *Australian Journal of Botany* **32**: 613–629.
- Kirkpatrick, J.B., Green, K., Bridle, K.L. & Venn, S.** 2014: Patterns of variation in Australian alpine soils and their relationships to parent material, vegetation formation, climate and topography. *Catena* **121**: 186–194.
- Kirkpatrick, J.B., Marsden-Smedley, J.B. & Leonard, S.W.J.** 2011: Influence of grazing and vegetation type on post-fire flammability. *Journal of Applied Ecology* **48**: 642–649.
- Love, P.T., Fox-Hughes, P., Harris, R., Remenyi, T. & Bindoff, N.** 2016: Impact of climate change on weather-related fire risk factors in the TWWHA. Interim Report. Tasmanian Government, Hobart: 11 pp.
- Marsden-Smedley, J.B.** 1998: Changes in the fire regime of southwest Tasmania over the last 200 years. *Papers and Proceedings of the Royal Society of Tasmania* **132**: 15–29.
- Marsden-Smedley, J.B.** 2009: Planned burning in Tasmania: operational guidelines and review of current knowledge. Fire Management Section, Parks and Wildlife Service, Hobart: 93 pp.
- Marsden-Smedley, J.B. & Catchpole, W.R.** 1995: Fire modelling in Tasmanian buttongrass moorlands II. Fire behaviour. *International Journal of Wildland Fire* **5**: 215–228.
- Marsden-Smedley, J.B. & Kirkpatrick, J.B.** 2000: Fire management in Tasmania's Wilderness World Heritage Area: ecosystem restoration using Indigenous-style fire regimes? *Ecological Management and Restoration* **1**: 195–203.
- Peterson, M.** 1990: Distribution and conservation of Huon Pine. Forestry Commission, Hobart: 15 pp.
- Parks and Wildlife Service unpublished fire history database.** Parks and Wildlife Service, Department of Primary Industries Parks Water and Environment: Hobart.
- Read, J.** 2005: Tasmanian rainforest ecology. In Reid, J.B., Hill, R.S., Brown M.J. & Hovenden, M.J. (eds): *Vegetation of Tasmania*. Biological Resources Study, Canberra: 160–197.
- Robertson, D.I. & Duncan, F.** 1991: Distribution and conservation of deciduous beech. Forestry Commission Tasmania and Department of Parks, Wildlife and Heritage, Hobart: 9 pp.
- Styger, J. & Kirkpatrick, J.B.** 2015: Less than 50 millimetres of rainfall in the previous month predicts fire in Tasmanian rainforest. *Papers and Proceedings of the Royal Society of Tasmania* **149**: 1–5.
- Styger, J.K., Kirkpatrick, J.B., Marsden-Smedley, J.B. & Leonard, S.W.J.** 2011: Fire incidence, but not fire size, affects macropod densities. *Austral Ecology* **36**: 679–686.
- Turner, P.A.M., Balmer, J. & Kirkpatrick, J.B.** 2009: Stand replacing wildfires? The incidence of multi-cohort and single-cohort *Eucalyptus regnans* and *E. obliqua* forests in southern Tasmania. *Forest Ecology and Management* **258**: 366–375.
- TWWHA Management Plan** 2016: Parks and Wildlife Service, Department of Primary Industries Parks Water and Environment, Hobart: 230 pp.
- Wood, S.W., Hua, Q., Allen, K.J. & Bowman, D.M.J.S.** 2010: Age and growth of a fire prone Tasmanian temperate old-growth forest stand dominated by *Eucalyptus regnans*, the world's tallest angiosperm. *Forest Ecology and Management* **260**: 438–447.
- Wood, S.W., Ward, C. & Bowman, D.M.J.S.** 2017: Substrate controls growth rates of the woody pioneer *Leptospermum lanigerum* colonising montane grasslands in northern Tasmania. *Austral Ecology* **42**: 9–119.
- Wood, S.W. & Bowman, D.M.J.S.** 2012: Alternative stable states and the role of fire–vegetation–soil feedbacks in the temperate wilderness of southwest Tasmania. *Landscape Ecology* **27**: 13–28.
- Zylstra, P.J.** 2018: Flammability dynamics in the Australian Alps. *Austral Ecology* **43**: 578–591.

(accepted 6 November 2018)