An assessment of the viability of prescribed burning as a management tool under a changing climate: a Tasmanian case study

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ABSTRACT

Fire danger is projected to increase across Tasmania under climate change, with the fire season starting earlier and lasting longer. Prescribed burning is currently the only effective method of managing bushfire risk at the landscape scale in Tasmania. It is generally carried out during autumn and spring, when weather conditions allow low intensity burns to be safely managed. We investigated the changing opportunities for prescribed burning in Tasmania in the near future (2021-2040) and towards the end of the century (2081-2100) under a high emissions scenario (SRES A2[1]). We assessed monthly changes in the climate variables that determine when prescribed burning can be applied, including rainfall, temperature, fuel moisture and atmospheric stability. We found that in the future, weather conditions conducive to safe, low intensity burning may occur less frequently. Increased Drought Factor and Soil Dryness Index in spring and autumn, resulting from rising temperatures and reduced rainfall, may result in increased fuel availability. These trends become evident in the near future (2021-2040), followed by substantial changes by the end of the century (2081-2100). This suggests a significant reduction in the ability to safely conduct and contain prescribed burns in the coming decades. These findings have important consequences for the ability to manage bushfire risk using prescribed burning in the future. The timing and resourcing of prescribed burning may be affected, with a narrower window of suitable weather conditions for burning. Alternative methods to build resilience to bushfire risk may need to be considered.

[1] Scenario A2 described in the Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC).

INTRODUCTION

Recent research suggests that fire danger may increase across much of Tasmania under ongoing climate change, with the fire season starting earlier in the year, and lasting for longer (Fox–Hughes et al. 2015). Changes to fire danger are projected to vary across Tasmania and in different seasons, most notably with an increase in high fire danger days projected to occur in spring. This has important consequences for the ability to manage bushfire risk using prescribed burning, which is currently the only effective method of managing bushfire risk at the landscape scale in Tasmania.

Prescribed burning is extensively used in Tasmania to reduce fuel loads and bushfire risk around human assets, particularly in the peri-urban fringe. It is also used to manage biodiversity and protect fire sensitive habitats in many National Parks and the Tasmanian Wilderness World Heritage Area (TWWHA). Prescribed burning is only carried out when weather conditions and soil moisture are conducive to safe, low intensity burning. These conditions are determined by wind speed and direction (both current and forecasted), fuel moisture, relative humidity, soil moisture and temperature (Marsden-Smedley, 2009).

Historically, most fires in Tasmania have occurred in mid- to late-summer and early-autumn, however significant bushfires can also occur in mid-spring, such as the 2006 Meehan Range fire that occurred on October 12th. The Autumn prescribed burning season therefore typically runs from late March to mid-May, and the Spring season can start as early as October and extend as late as the end of December. Winter burning can also be carried out in some of the drier and more accessible parts of the state, although daylight is a limiting factor in winter. The autumn periods are generally more stable and predictable, whereas spring usually has long periods of unsuitable weather between the 'goldilocks' days. The most appropriate conditions for burning, and thus the annual timing, varies with altitude, rainfall gradients, solar aspect and vegetation type. Both very wet and very dry years tend to curtail the amount of burning that can be done because of inappropriate moisture levels and wind and temperature patterns. During very wet years, moisture levels are too high for fire to carry, while in very dry years the fuel dryness can result in unacceptably high fire intensity even during periods of relatively benign fire danger weather.

If the stable autumn period during which suitable conditions occur becomes narrower under future climate conditions, the viability of prescribed burning as a management tool may be compromised. This study investigates the changing opportunities for prescribed burning in Tasmania under climate change. We use the Climate Futures for Tasmania (CFT) projections to assess changes in the magnitude and seasonality of weather variables that determine when prescribed burning can be applied (rainfall, temperature, fuel moisture and atmospheric stability).

METHODS

Climate projections from the CFT project (Corney et al. 2010) were used to provide fine-scaled (10 km) future climate data. The projections were dynamically downscaled using sea surface temperature from six atmosphere-ocean general circulation models from the Coupled Model Intercomparison Project archive (CMIP3) under the A2 emissions scenario as boundary conditions into the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Cubic Conformal Atmospheric Model (CCAM) (McGregor 2005). The host models were ECHAM5/MPI-OM, GFDL-CM2.0, GFDL-CM2.1, MIROC3.2(medres), UKMO-HadCM3 and CSIRO-Mk3.5. These models give slightly different results because they are based on different configurations, but all provide plausible representations of the future climate. Dynamically downscaled climate models represent the climate processes that operate over small distances, so they have the potential to capture regional variation in the climate change signal. This is particularly relevant in Tasmania, which has a complex topography and coastline, and a range of regional climate influences.

The high emissions scenario (A2) is used because global emissions are currently tracking at the higher level of this scenario (Peters et al. 2013). If strong mitigation policies were to achieve reductions in global greenhouse emissions, the pattern of projected changes would be similar, but lower in magnitude.

The projected change in the monthly statistics (mean, and quantiles) for each variable were calculated between the baseline period (1961-1980) and two future time periods, near future (2021-2040) and the end of century (2081-2100). We use two-decade periods to reduce the effect of inter-annual variability and highlight longer-term climate trends.

In addition to daily minimum and maximum temperature and total daily rainfall, several indices were used to indicate weather conditions suitable for prescribed burning. These indices incorporate temperature, rainfall, wind and humidity. Firstly, the Drought Factor (DF, an index scaled between 0 and 10) represents the influence of recent temperatures and rainfall events on fuel availability. It is calculated by combining estimates of the effects of (a) direct wetting from recent 'significant' rainfall (> 2 mm); and (b) wetting from below, which is dependent on the soil moisture content. The latter is calculated as a soil moisture deficit, using the Soil Dryness Index (SDI) (Mount 1972). Secondly, the SDI is used independently as an index of fuel moisture. It is used operationally to help assess the relative flammability of different vegetation types, and therefore the ability to safely conduct a prescribed burn. An overview of the SDI and its strengths and weaknesses can be found in Marsden-Smedley (2009).

Finally, two indices of fire danger were calculated. The Forest Fire Danger Index (FFDI) is used operationally throughout the Tasmanian Fire Service (and other supporting emergency service organisations) to estimate fire danger at a particular location on any given day (initially described as equations by Noble et al. 1980). It incorporates antecedent rainfall conditions (DF), daily soil dryness (SDI), daily temperatures and wind speeds. The Moorland Fire Danger Index (MFDI) is a better representation of fire danger in Buttongrass Moorlands, where soil dryness is less important in determining fire danger than in forests, and is also the most appropriate of the two indices for heathland vegetation types throughout Tasmania (Marsden-Smedley, et al. 1999).

DISCUSSION AND RESULTS

TEMPERATURE

Mean annual temperature increases of approximately 1°C in the near future (2021-2040) and 2.7°C by the end of the century (2081-2100) are projected to occur across Tasmania under the high emissions scenario considered here. This is a gradual acceleration of warming trends observed over recent decades. These increases are consistent across the seasons and are similar in both maximum and minimum daily temperatures (Figure 1A, 1B and 2A, 2B). Trends in the multi-model mean of annual temperature are similar in all regions of Tasmania, demonstrated in Figures 3A and 3B.

Over the next decades, monthly temperatures are projected to move towards temperatures currently experienced in warmer months. For example, by 2081-2100 September may exhibit temperatures more like those currently experienced in October. This effect is amplified in colder months, where July will be more similar to April. During summer, temperatures (both daily minimum and maximum) will exceed those currently experienced in any month.

By the end of the century, days exceeding the 25°C threshold above which prescribed burning cannot be applied (Marsden-Smedley, et al. 1999) are projected to occur regularly in November, becoming more similar to conditions in December, January and February.

RAINFALL

Annual mean rainfall is not projected to change substantially across Tasmania in the future, however, there are strong regional (Figure 3C) and seasonal (Figure 1C and 2C) differences. Summer rainfall is projected to decline in four of the six models, and winter rainfall is projected to increase substantially in all models. There is little change projected in the mean rainfall in autumn. Five of the six models project increased mean monthly rainfall in spring, while one projects reduced rainfall during this season.

The CFT spring rainfall projections should be considered in the context of other available climate projections. A comparison of the CFT projections with a range of CMIP3 models, CMIP5 models, and new downscaling using a more recent version of the CCAM model, suggested they "are at the wetter end of the plausible range of spring rainfall projections" (Grose et al. 2015a; 2015b). The results presented here are therefore likely to be conservative estimates of the drying trends in spring.

When averaged across Tasmania, there is little change projected to occur in monthly rainfall (Figure 1C), although this comes with low confidence due to low agreement between models on the direction of change (increase vs decreased rainfall) and high spatial variability, which is masked by the state-wide averaging (i.e. some districts get wetter, others drier). This degree of uncertainty is common in projections of rainfall (CSIRO and Bureau of Meteorology 2015), because the large-scale storm tracks in the projections are uncertain (Risbey and O'Kane 2011), and it is difficult to fully resolve the many physical processes involved in precipitation or the fine-scale spatial variability (Dowdy et al. 2015).

DROUGHT FACTOR

In the near future period (2021-2040), there is a large range in the annual DF across the climate models, reflecting the greater variation across rainfall projections in the short-term, particularly in summer and autumn (Figure 1E). By the end of the century, however, substantial increases in DF are projected across Tasmania (e.g. up to 100% increase in the monthly mean), with the greatest increases in summer. Large increases in the DF in spring are also projected. There is a wide range in the projections for autumn, reflecting the large range across the models in rainfall for this season.

The projections of DF across Tasmania show gradual drying trends in all months, with increases particularly during summer and early autumn (Figure 2E).

SOIL DRYNESS INDEX

Substantial increases in SDI are projected to occur across Tasmania in the future. In the near future (2021-2040), all models project an increase in SDI in summer, and all but one model project increased soil drying during spring and winter (Figure 1F). There is a greater range across the models in autumn. However, by the end of the century, substantial increases in the SDI are projected by all climate models in all seasons.

Increases in SDI are greatest in the summer and autumn months by the end of the century (2081-2100) (Figure 1F). Smaller increases are projected in late winter and spring months. Increases in the SDI values for both June and November are so substantial that the wettest period for SDI (June to November) is projected to be two months shorter (i.e. July to October) by the end of century (Figure 2F). These changes are projected to occur rapidly over the next decades.

FIRE DANGER INDICES

Substantial increases in annual values of the fire danger indices (FFDI, MFDI) are projected to occur across Tasmania by the end of the century (Figure 1G, 1H). However, the extent to which the indices change across the seasons differs slightly, reflecting the different emphasis on soil dryness and antecedent rainfall in each index. In the near future, increases in the Forest Fire Danger Index are projected by all climate models, for all seasons except autumn (Figure 2G). In contrast, the mean Moorland Forest Danger Index (MFDI) increases in spring and winter (Figure 2H) by the 2021-2040 period, and decreases in autumn and summer. However, this state-wide summary masks substantial regional patterns, with a strong west vs east difference (Figure 3H). Regional differences (for all variables) are outside of the current scope and will be presented in a future publication.

By the end of the century, increases in FFDI are projected for all seasons, with very dramatic increases in spring and summer (Figure 1G). The projected increases in FFDI are lowest during the months April to September (Figure 2G). In the warmer months, there is a shift in FFDI so that by the end of the century, November FFDI is higher than what is currently experienced in December, and future January FFDI values exceed any currently experienced in any month. The MFDI increases substantially in spring and winter, and declines slightly or maintains similar values in autumn (Figures 1H and 2H). The MFDI shows a consistent shift in fire danger indicating higher fire danger values earlier in the year. From June through to December, monthly MFDI by mid-century exceeds the current value for the following (warmer) month. By the end of the century the differences are greatest in late winter and spring. To a large extent, the effects on MFDI of increases (decreases) in winds are offset by increases (decreases) in rainfall.

Wind speed is an important variable in the calculation of FFDI, however, the projections of wind speed for the near-term period are highly variable, with a large range in wind speed across the climate models. In the absence of a gridded wind observations product (see below), the wind output from the regional climate model has not been validated against observations. That said, the model appears to underestimate wind speed, which would contribute to the conservative estimates for FFDI reported here.

WIND SPEED AND DIRECTION

Similar trends in wind speed are projected for all districts (Figure 3D). The projections of wind speed for the near future period are highly variable, with a large range in wind speed across the climate models (Figure 1D). By the end of the century this very large range is reduced, but remains more variable than in the baseline period.

The modelled wind output has not been validated against observations or bias adjusted because gridded observations are not available. However, a comparison with available point observations suggests that the model underestimates wind speed. This would contribute to the conservative estimates for FFDI, since wind is an important component in that calculation. For this reason, we only consider the relative differences between time periods in these variables.

By the end of the century, increased maximum daily winds are projected across Tasmania for spring, and decreased daily winds are projected to occur in autumn. Reductions in maximum daily wind speed are projected for May and June by the end of the century (Figure 2D). From July through to November, maximum daily wind speed increases.

Changes in wind direction were projected and analysed, but these changes were minimal and are not discussed here.

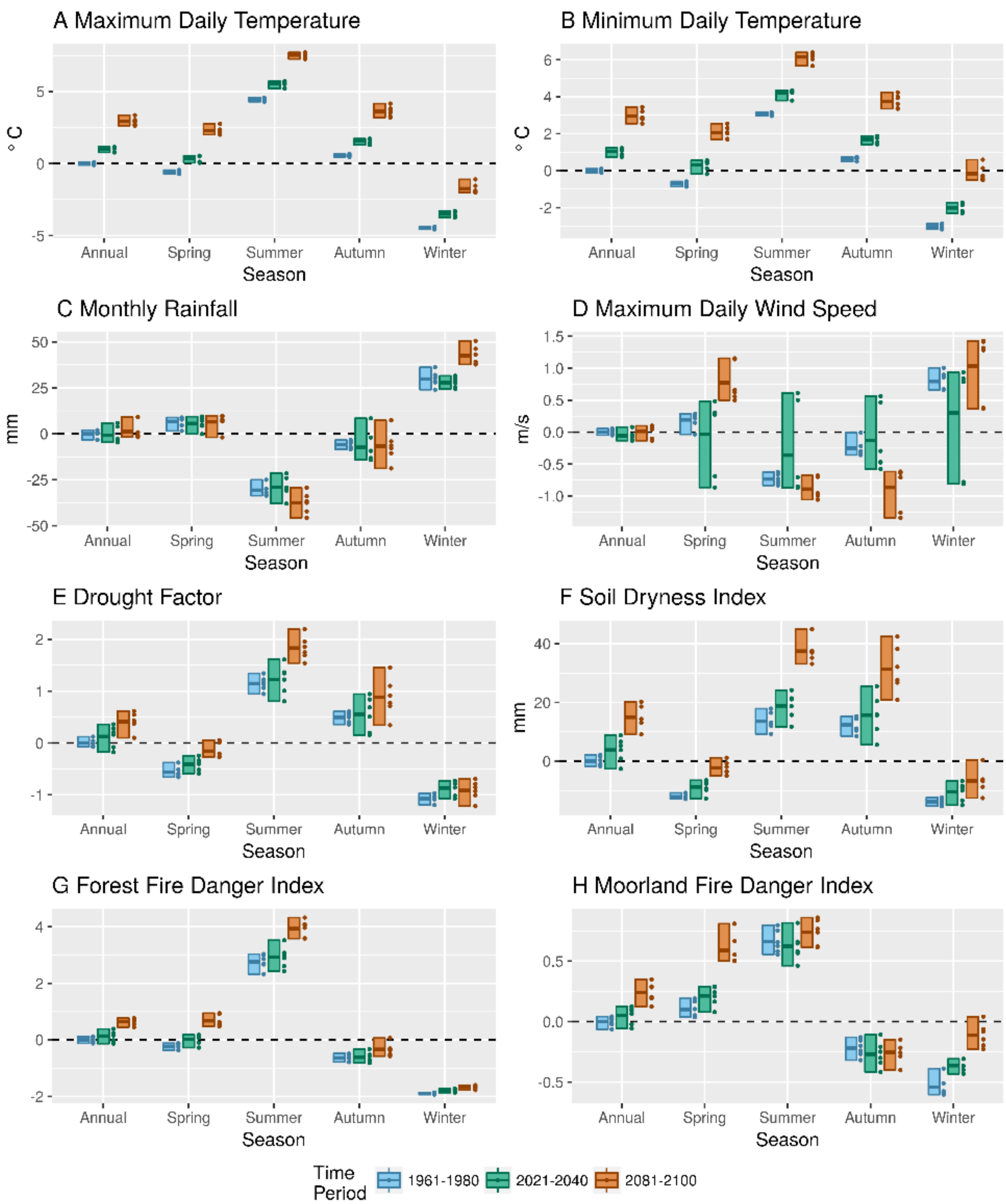

Figure 1: Projected changes in the annual and seasonal values for each variable across Tasmania under the A2 emission scenario. Each season is shown for the baseline (1961-1980), near future (2021-2040) and end of century periods (2081-2100). Values represent change from the multi-model mean annual value for the baseline period, to highlight the real differences of the seasons from the typical annual mean values. The box indicates the multi-model range, the bar shows the multi-model mean, and points indicate the mean for each of the six downscaled climate models, indicating the extent to which the models agree.

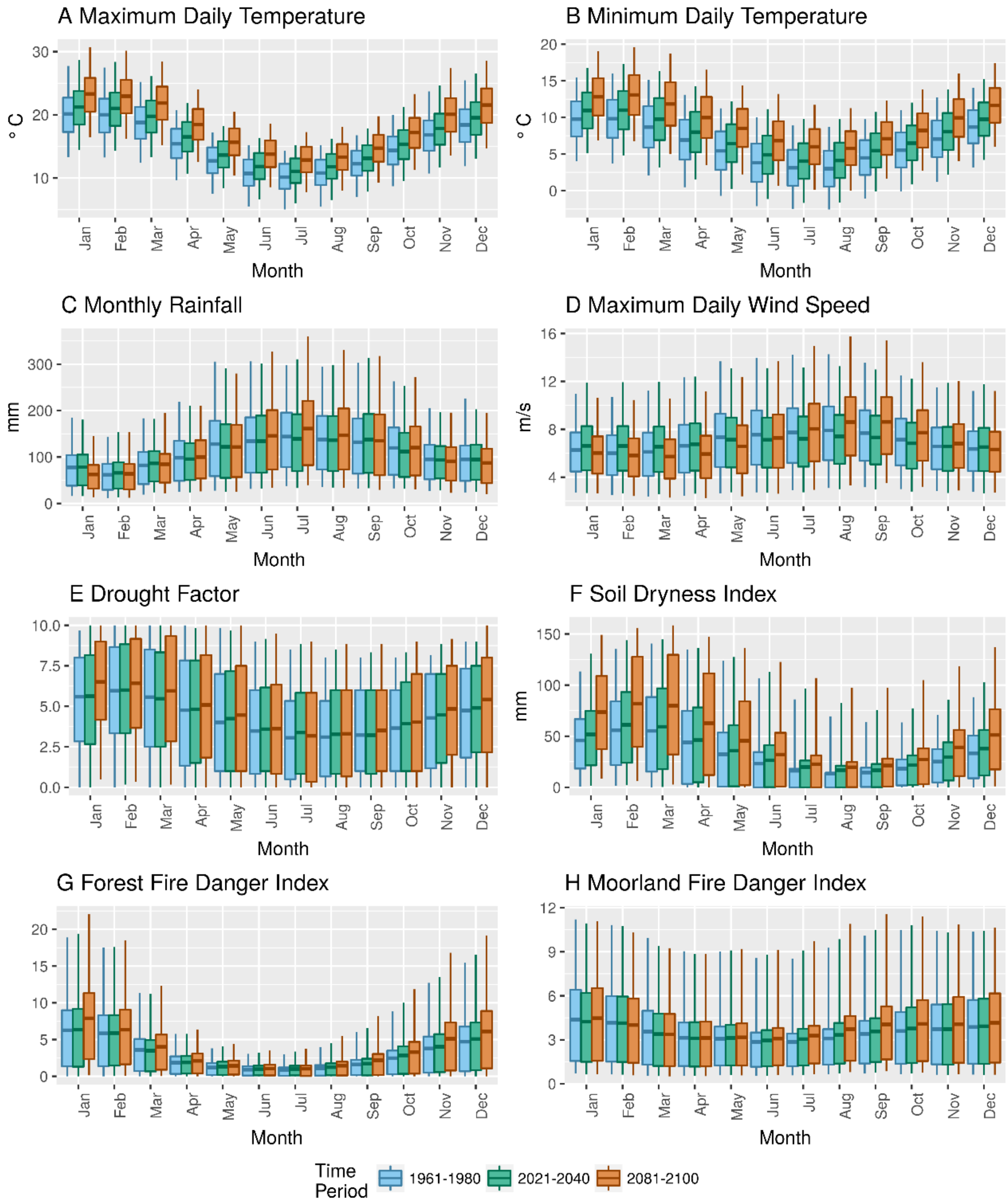

Figure 2: Annual cycle of each variable as projected by the six climate models under the A2 emission scenario for the baseline (1961-1980), near future (2021-2040) and end of century (2081-2100) periods. The box indicates the multi-model interquartile range, the bar shows the multi-model mean, and the whiskers extend from the 5th to the 95th percentile of the multi-model range.

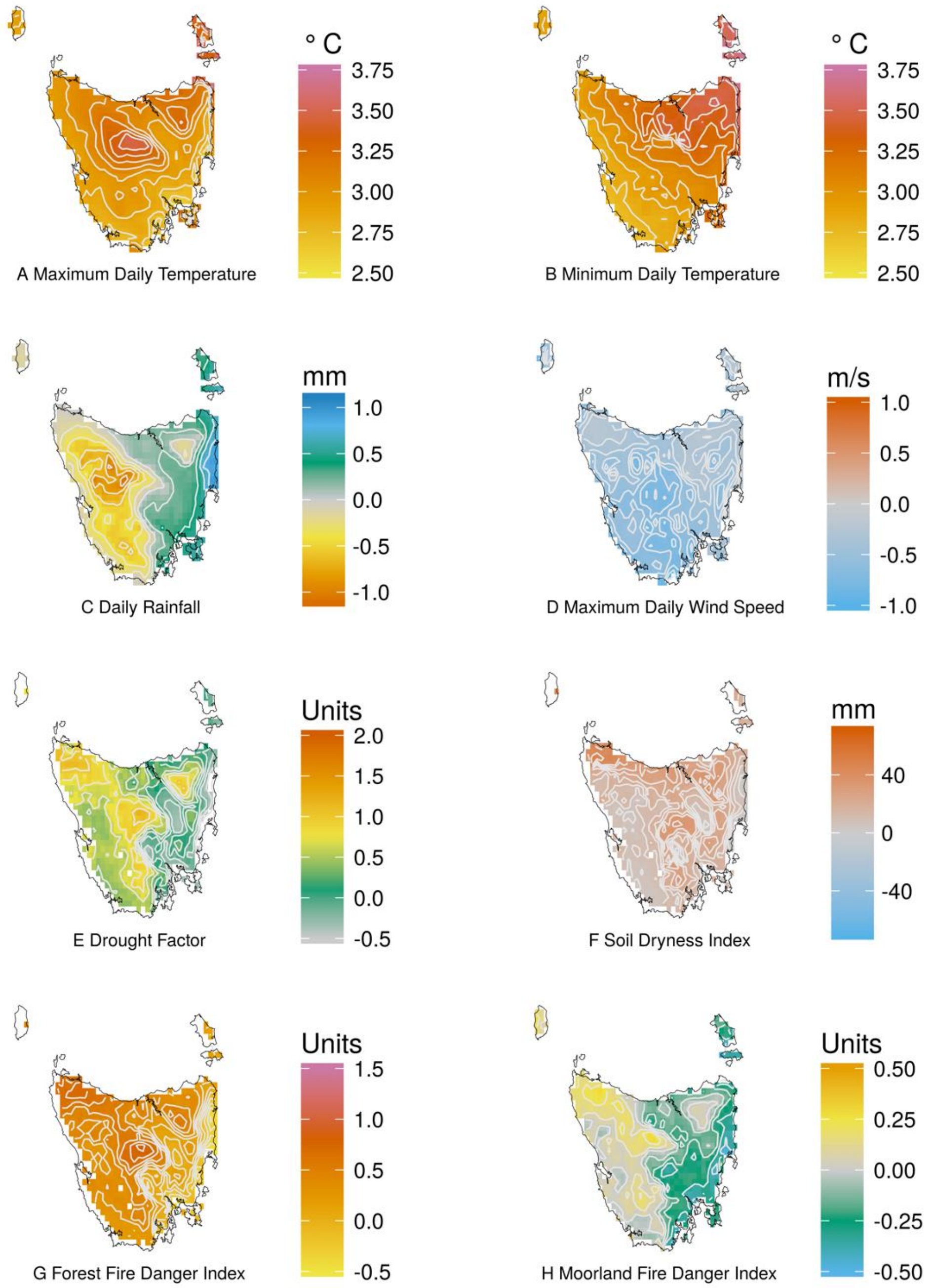

Figure 3: Change in climate variables for the autumn period (March, April, May) by 2081-2100, relative to the baseline period (1961-1980). These maps highlight the regional differences projected across the state, particularly the West to East gradient of moisture related variables (i.e. Daily Rainfall, DF, SDI, MFDI).

IMPLICATIONS FOR PRESCRIBED BURNING AS A MANAGEMENT TOOL IN THE FUTURE

The strong warming and drying trends projected for autumn and spring suggests that it will become more challenging to safely conduct and contain prescribed burns in these seasons. These trends become evident in the near future (2021-2040), and represent substantial changes (relative to the baseline) by the end of the century (2081-2100).

Wind speed and direction are not projected to change substantially in autumn and spring, but increased temperatures are projected to occur across Tasmania (up to 2.7°C by the end of century under the high emissions scenario), contributing to increases in Soil Dryness Index, Drought Factor and subsequently Forest Fire Danger Index and Moorland Fire Danger Index values. These changes are projected to occur rapidly over the next decades. In the near future (2021-2040), all models project an increase in SDI in summer, and there is high model agreement that there will be increased SDI during spring and winter. By the end of the century, substantial increases in the SDI are projected by all climate models in all seasons.

By the end of the century, very large increases in both FFDI and MFDI are projected for spring. The FFDI also increases dramatically in summer (discussed in detail in Fox-Hughes et al. 2014), while the MFDI increases substantially in winter. These changes have important implications for the ability to apply prescribed burns (following current protocols) in spring and winter to mitigate the increased fire danger that is projected to occur in summer. Over time, the burning period may move towards the winter and early spring months, as opportunities for safe burning decline in the autumn months.

There is general agreement across all models for increased SDI and DF as rainfall is projected to be less than evaporation as temperatures warm. However, as this ensemble of projections represents a slightly wetter future when compared to other available future model projections (Grose et al. 2015a), the results presented in this study may be a conservative estimate of the drying trends in spring. If so, spring may become drier and more prone to fire more quickly than shown here.

As the frequency of warmer and drier conditions increases in autumn and spring across Tasmania, the likelihood of all variables coinciding at their maximum values (e.g. maximum wind speed, lowest relative humidity, highest temperature, SDI and DF) can be expected to increase. This increases the likelihood that fires will burn with faster rates of spread, higher intensities and a higher risk of escape than under current conditions (Marsden-Smedley 2009). This higher risk will constrain the application of prescribed burning, as the number of available periods decreases, particularly in the autumn months, when the majority of prescribed burns are currently carried out. There are indications that these windows of opportunity for burning may move to the winter and early spring months.

Strategies that improve the capacity of fire agencies to take advantage of suitable conditions will always be of great value, and these projections support future research into a range of areas, such as improving the understanding of fire behavior during prescribed burning (including the differences between vegetation types); investigating different prescribed burning practices, and utilizing finer scale weather forecasting to support operational activities.

Further to this, other tools for reducing fuel loads may need to be considered, such as mechanical removal of fuels and the maintenance of fire breaks by grazing. Research into the impacts of such approaches is still needed. Since these approaches are not yet widely accepted in the community, consultation and education will be an important aspect of the move to alternative fuel reduction techniques. Prescribed burning will always play an important role in fire management, but it is likely that it will need to be supplemented by other fuel reduction techniques under future climate conditions.

CONCLUSION

The results suggest that there will be a narrower window of suitable conditions for prescribed burning across Tasmania in the future. The trends become evident in the near future (2021-2040), and represent substantial changes (relative to the past) by the end of the century (2081-2100). This has important consequences for the ability to manage bushfire risk using prescribed burning in the coming decades. Fire managers will need to reconsider the timing and resourcing of prescribed burning and build capacity to mobilise rapidly when weather conditions are suitable during autumn and winter.

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