

Tasmanian Wilderness World Heritage Area Climate Change and Bushfire Research Initiative

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ANTARCTIC CLIMATE & ECOSYSTEMS COOPERATIVE RESEARCH CENTRE

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Cover image: Rob Blakers

1 Executive Summary

Fire managers in the Parks and Wildlife Service Tasmania (PWS) have been provided with new and updated decision making tools to aid in the development of the planned burning strategy for the Tasmanian Wilderness World Heritage Area (TWWHA).

The landscape scale fire regime model FIRESCAPE-SWTAS has been updated to provide an enhanced capability to assess PWS planned burning strategies for the TWWHA. This has been achieved through:

- updates to vegetation data and other spatial input data
- expansion of the model domain to encompass the entire TWWHA and influential adjacent reserves and vegetation westward of the TWWHA
- implementation of a new facility to ingest gridded weather data, such as the new high resolution BARRA products
- implementation of a planned burning strategy currently under development by PWS, as part of the TWWHA Fire Management Plan.

The updates to FIRESCAPE-SWTAS also provide an enhanced capability to assess impacts of climate change on fire regime in TWWHA through the application of Climate Futures for South-East Australia high-resolution regional climate projections.

An assessment of an interim Planned Burning Strategy indicates a significant decrease in the number of unplanned fires in the regions adjacent to planned burn areas. The updated model allows the rapid testing of Planned Burning Scenarios, allowing the optimisation of resource allocation.

This project has produced a tool to calculate climate suitability of a target region. It uses the region defined by an input polygon (such as a shapefile) to subset gridded weather data to define the ‘climate’ of this target region. This can then be compared to the ‘climate’ of every other region (in both space and time) to find regions that are similar. The software developed for this analysis will been made public through The Comprehensive R Archive Network as an open source package for ongoing use and development.

Climate suitability for the historical, mid-century and end-of-century time periods have been provided for 8 broad vegetation types. These indicate a dramatic decrease in the extent of all analogous climates into the future driven by compounding drying and warming trends. Drying trends dominate the mid-century, while warming trends become more important by the end-of-century.

The development process of FIRESCAPE-SWTAS in consultation with PWS identified that certain analyses underpinning model processes would provide useful tools when applied

independently to historical weather observations and climate projection data. Climatologies and future projections of dry lightning occurrence and planned burning opportunity are currently being compiled for delivery to PWS with the following preliminary findings:

- the spatial distribution of dry lightning outbreak probability is unlikely to change significantly into the future
- the number of days each year on which weather conditions are suitable for conducting planned burning in the TWWHA will decrease throughout the century
- the new Climate Futures for South-East Australia regional climate projections, consistent with previous analysis of the Climate Futures for Tasmania projections, show a general decrease in the frequency and extent (but not necessarily intensity) of dry lightning outbreaks. However, this is in the context of a profound drying trend which is already observed to be increasing ignition efficiency. The coincidence of dry surface conditions and the occurrence of dry lightning is being investigated further in a current project, *Modelling coincident extreme weather events under Tasmania's future climate*, funded by the Tasmanian Climate Change Office.

Strong links have been identified between the current project and the Assessment of the Viability of Planned Burning as a Management Tool Under a Changing Climate project, funded by the Tasmanian Bushfire Mitigation Grants Program (TBMGP) recently begun also at ACE CRC. This will provide a continuity of research activities and stakeholder engagement that will substantially enhance the outcomes of the current project through the following activities:

- comprehensive analysis of the effectiveness of PWS planned burning strategies for the TWWHA incorporating different treatment levels, pending the provision of updated input soil productivity mapping and complete data pertaining to the planned burn units from PWS
- application of FIRESCAPE-SWTAS to assess the impact of different planned burning treatment levels to other reserves and wilderness areas across Tasmania
- ongoing FIRESCAPE-SWTAS model development in collaboration with PWS, TFS and UTas including updates to:
    - fire spread algorithms
    - fuel accumulation algorithms
    - vegetation succession pathways
    - user interface and configurability

2 Introduction

2.1 Motivation

The 2015-16 fire season saw the outbreak of many bushfires in Tasmania, including a large number in the Tasmanian Wilderness World Heritage Area (TWWHA). These fires, and the efforts[1] to limit their impacts on the TWWHA drew much interest and public comment, including the establishment of a Senate Inquiry[2].

Across much of Tasmania's wilderness areas, record low spring rainfalls resulted in extremely high vegetation dryness levels. Storms in mid and late January resulted in a number of fires from lightning strikes. Between January and March 2016, bushfires burned approximately 123 000 ha across Tasmania with 20 100 ha (~1.27%) of the TWWHA being affected. Some of the Wilderness areas affected are fire-sensitive and have had a limited exposure to fire in the past.

The recent fires have highlighted the need to consider changing fire risk into the future, and consequently, ways Tasmania could better prepare for, and respond to, bushfires in the TWWHA.

Following the demonstrated benefit to Tasmania of the Climate Futures for Tasmania project outputs (Grose et al., 2010, White et al., 2010) conducted by the ACE CRC, which identified the dual risk of general drying of the Tasmanian landscape along with increasing temperatures, the Tasmanian Government commissioned the Future Fire Danger project in 2010 to increase understanding of bushfire meteorology and fire danger hazards and risks in a changing climate. The project utilised the high quality, fine-scale climate projections generated by Climate Futures for Tasmania, and interpreted the new information to meet the needs of Tasmanian emergency services and fire agencies.

The findings of the Future Fire Danger project were released in December 2015, with publication of the Climate Futures for Tasmania future fire danger - the summary and the technical report (Fox-Hughes et al., 2015), and were further extended by Harris et al. (2017).

While the evidence shows a minor increase in the cumulative Forest Fire Danger Index (FFDI) and severity of high fire danger days in the TWWHA. However, as the study uses the McArthur FFDI, which is based on dry-forest conditions, the predominant vegetation types of the TWWHA are not factored specifically into the indices assessed, and therefore, the FFDI is not really a good measure of fire danger for this region. Further to this, the study's limited ability to project changes in the level of biomass and its flammability in the TWWHA reduce it relevance over the vast important region of Tasmania. Therefore, the actual risk of bushfire in this area over the next century is likely to be greater than what is represented in this study and the future fire risk in this area is therefore underrepresented.

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[1] The firefighting effort involved more than 5 600 Tasmanian volunteer and career firefighters, 1 000 interstate or overseas firefighters, and as many as 40 aircraft assisting each day during the peak. Initial estimates suggest that the cost of fighting the fires will exceed $25m.

[2] Responses to, and lessons learnt from, the January and February 2016 bushfires in remote Tasmanian wilderness, http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/TasmanianBushfires45/

In response to this lack of information for the region, in February 2016, the Premier, Will Hodgman MP, announced the Tasmanian Government's commitment of $250 000 towards a new research initiative to investigate the impact of climate change on bushfire risk in Tasmania's wilderness areas and consider ways to prepare for and respond to bushfires in Tasmania's wilderness areas. This initiative has a specific focus on prevention, predictive modelling, fuel reduction and firefighting strategies in culturally and environmentally sensitive areas. The work is overseen by a high-level Steering Committee with representatives from key Government agencies and an independent chair. A Technical Working Group of experts from research organisations and operational agencies supported the work and a final report, *Tasmanian Wilderness World Heritage Area Bushfire and Climate Change Research Project* (Press, 2016), was provided to the Tasmanian Government in December 2016. Research was undertaken with funds provided through the state government (some research is ongoing).

On the 4th of May 2016, the ACE CRC applied to the NESP Emerging Priorities program for funding to support research directly related and complementary to the state government's Tasmanian Wilderness World Heritage Area Bushfire and Climate Change Research Project. In the application to the NESP, $95,000 cash towards research expertise (contracted to the ACECRC), $30k towards additional expenses (contracted to parties external to the ACECRC) and 1.5FTE in-kind contributions from the state were identified.

An additional $60,500 cash and ~2FTE in-kind contributions, directly related to the scope of the NESP application, have subsequently been committed by the Tasmania State Government.

In late 2016, the NESP approved this project, the Climate Change and Bushfire Research Initiative.

2.2 Findings of preceding sub-projects

There were four separate sub-projects within the overall Tasmanian Wilderness World Heritage Area Climate Change and Bushfire Research initiative:

i. Future Fire Danger in the TWWHA (completed 2017);
ii. Climate change and changes in lightning frequency in the TWWHA (completed 2017);
iii. Examine the use of fire retardants in the TWWHA (completed 2017); and
iv. Further develop and update the FIRESCAPE model.

The scope of the NESP funded portion of this work is sub-project (iv) *Further develop and update the FIRESCAPE model.*

Sub-projects (i), (ii) have been completed and, as noted above,sub-project (iii) was funded with additional resources through the Tasmanian State Government ($60,500 and ~2FTE), the initial stages were completed in 2017, with the work to be extended by other resources. Each of these are discussed below.

i. Future Fire Danger in the TWWHA (completed 2017)

Much of this work was completed by the ACECRC in 2016 with the outputs incorporated into the Tasmanian Wilderness World Heritage Area Bushfire and Climate Change Research Project Report (Press, 2016), through the delivery of interim reports (Love et al., 2016a, Love et al., 2016b). The major findings were:

- Indicators of fire danger relevant to dry eucalypt forest increase significantly with respect to both average conditions and the intensity of extreme events.
- The mean fire danger increases in areas of buttongrass moorlands.
- Increases in fire danger indicators accelerate in the second half of the century.
- The most extreme values of buttongrass moorlands fire danger are projected to remain steady through to the end of the century.
- The number of days per fire season on which the Mount Soil Dryness Index (MSDI) exceeds 50, averaged over the TWWHA, increases by 16 per cent in the near future, 58 per cent by mid-century and 218 per cent by end-of-century.
- The area of the TWWHA over which MSDI exceeds 50 on a given day is projected to increase by similar percentages.
- The number of days per fire season on which 30-day antecedent rainfall is less than 50 mm increases by 8 per cent in the near future, 22 per cent by mid-century and 91 per cent by end-of-century.
- The tendency of dryness indicators is towards longer, more intense summers with more rapid transitions between summer and winter conditions.
- The frequency of occurrence of synoptic weather conditions within an operational classification scheme do not change significantly on an annual basis.

The completed ACE CRC full technical report of research findings is currently going through the peer-review process.

ii. Climate change and changes in lightning frequency in the TWWHA (completed 2017)

The analysis was conducted in two stages. The first stage was an analysis of changes in the Tasmanian region's atmospheric pressure and stability since about 1960. The second stage was an analysis of the Climate Futures data in order to extend the predictions out to 2100.

The information obtained in the analysis of past and future climate change was compared against the fire history of the region since the 1970s in order to provide insights into the likely implications for the management of the region and the impacts on ecological processes. With climate change these changes in the weather are predicted to continue with resultant impacts on ecological processes, in particular due to increases in the impacts of fire.
This work was completed by the ACECRC in 2016 with the outputs incorporated into the Tasmanian Wilderness World Heritage Area Bushfire and Climate Change Research Project Report (Press, 2016), through the delivery of interim reports (Love et al., 2016a, Love et al., 2016b). The major findings were:

- On decadal timescales, widespread lightning outbreaks decrease slightly in frequency and extent (but not necessarily intensity) throughout the current century.
- Average conditions are projected to be less conducive to lightning. Love et al. 2016a note that these findings relating to lightning are consistent with the work of Dowdy and Mills (2012), where instability is projected to decrease with time, over the Australian region during the current century. This does not mean there will be no storms, or indeed a decline in activity levels of storms - it could be that storms may become more intense, just slightly less frequent. This may be possible to establish from a closer examination of the data, which has not been possible within the timeframes of this project.
- The areal extent of the TWWHA subject to dry lightning potential environment decreases across all seasons.
- The most extreme dry lightning potential environment events do not decrease in extent beyond the near future and peak in summer, coinciding with peak increases in dryness indicators.

The completed ACE CRC full technical report of research findings is currently going through the peer-review process.

iii. Examine the use of fire retardants in the TWWHA, including their net environmental impact (completed 2017)

Tasmanian fire-fighting agencies have been using foam suppressants, including in National Parks but excluding the TWWHA, for decades. Long-term retardants were used for the first time in the Tasmanian reserve estate in 2014, and again in the wilderness fires in the TWWHA in 2016. Firefighting chemicals include short term water enhancers (foams and gels) and long term retardants. Short term suppressants extend the efficiency of water as a suppression agent. The foams and gels have a short-term usefulness (less than 4-6 hours), but can provide an effective window for on ground fire crews to extinguish fires, and they can also provide protection for on ground crews. Long term retardants can provide useful chemical fire breaks that last for days to weeks depending on rainfall (which washes it away). These retardants are typically comprised of ammonium phosphate, which is a fertiliser. While these retardants are effective at fire suppression, there are concerns about their environmental impact, especially in the low nutrient environments of western Tasmania, where addition of fertilising agents could alter the natural systems. Studies into the ecological impact of firefighting chemicals have been largely restricted to the northern hemisphere and do not typically include ecosystems such as those of the TWWHA.

Long-term field based trials to assess the impact of the use of foams, gels and long-term retardants on buttongrass moorlands have recently been established. The results of this research will better inform the range of options that are available when responding to fires in these areas.

2.3 Scope of this project

iv. Further develop and update the FIRESCAPE model

Computer simulation modelling provides a useful approach for determining the trade-offs between the extent of planned burning and the long-term impacts of unplanned fires on management values.

In 2006, a study was undertaken by King et al (King et al., 2006), to establish FIRESCAPE-SWTAS, a process-based fire regime and vegetation dynamics model. This model was used in a section of the World Heritage Area of south-west Tasmania, Australia, to investigate the implications of different planned burning treatments on identified management objectives. Treatments included annual planned burning of different proportions of the most flammable vegetation community, buttongrass moorlands.

Additionally, a proposed strategic burning treatment for this landscape was simulated for comparison with these treatments. Simulations identified the nature of the relationships between the planned burn treatment level and the fire size distributions, the mean incidence, and the mean annual areas burnt by unplanned fires, with all three parameters declining with increases in treatment level. The study also indicated that strategically located treatment units were able to enhance the reduction in the fire risk to vegetation species susceptible to fire (fire-intolerant species).

While early work using the FIRESCAPE-SWTAS model was promising in terms of understanding the relationship between different planned burning treatments and fire management objectives, it was identified further resourcing would be required to update this work, with improved fuel layers and other spatial data, future climate projections and expand it to encompass the whole TWWHA. This is the focus of this NESP funded research.

2.4 Objectives

The objective of this project was to update the landscape fire regime model (FIRESCAPE-SWTAS) currently used by Parks and Wildlife Service with improved fuel layers and other spatial data, future climate projections and expand it to encompass the whole TWWHA.

2.5 Outcomes

This has produced an enhanced capability to assess the effectiveness of different planned burning treatment levels and how climate change will impact on the fire regime within the TWWHA, which has improved the ability of the responsible organisation to prepare for, and respond to, bushfires in the TWWHA.

This project has delivered information that allows the relevant authorities to generate or action bushfire mitigation strategies that will have long term protective impacts for target assets.

The project engaged with stakeholders early in the project within a workshop setting to simultaneously inform them of the project objectives and request guidance to ensure the intended outputs are aligned with existing work, is operationally relevant and thus usable.

2.6 Deliverables

The project will deliver an updated version of the FIRESCAPE-SWTAS model that is operating over an expanded domain that includes the entire TWWHA and incorporates PWS planned burning strategies.

The project delivered a tool that can estimate climate suitability layers for an arbitrary definition of a vegetation community. It has used this tool to provide the climate suitability layers for a number of vegetation communities within the TWWHA, but also extended this domain to deliver across all of Tasmania.

In consultation with the stakeholders, regular meetings were conducted in the place of a final workshop, this was more productive way of guiding project outputs and ensured the final outputs matched expectations and were presented in a usable form. However, the project team wishes to present the project outputs (this report, new tools and demonstrate the use of FIRESCAPE) in a future workshop for the key stakeholders.

This project produced a Final Report (this document) that described the findings of the project and the methods used.

3 FIRESCAPE Model Development

3.1 Expanded Model Domain

In previous versions of FIRESCAPE-SWTAS the regions within the TWWHA subject to analysis were limited to those areas south of the Lyell Highway (blue shaded area in Figure 3.1). A rectangular model domain in which the simulations were conducted was defined to encompass this region (blue box in Figure 3.1). While quantitative analysis of the statistical output was carried out only for the TWWHA and adjacent reserves, the inclusion of regions surrounding the TWWHA allowed for fires ignited in surrounding regions to spread into the TWWHA.

The model domain and analysis regions have been expanded in the updated FIRESCAPE-SWTAS (red box and shaded area in Figure 3.1) to include the regions of the TWWHA north of the Lyell Highway, additional areas encompassed by recent TWWHA boundary extensions in 2010, 2012 and 2013, and influential adjacent reserves and vegetation westward of the TWWHA (hereafter Adjacent Areas).

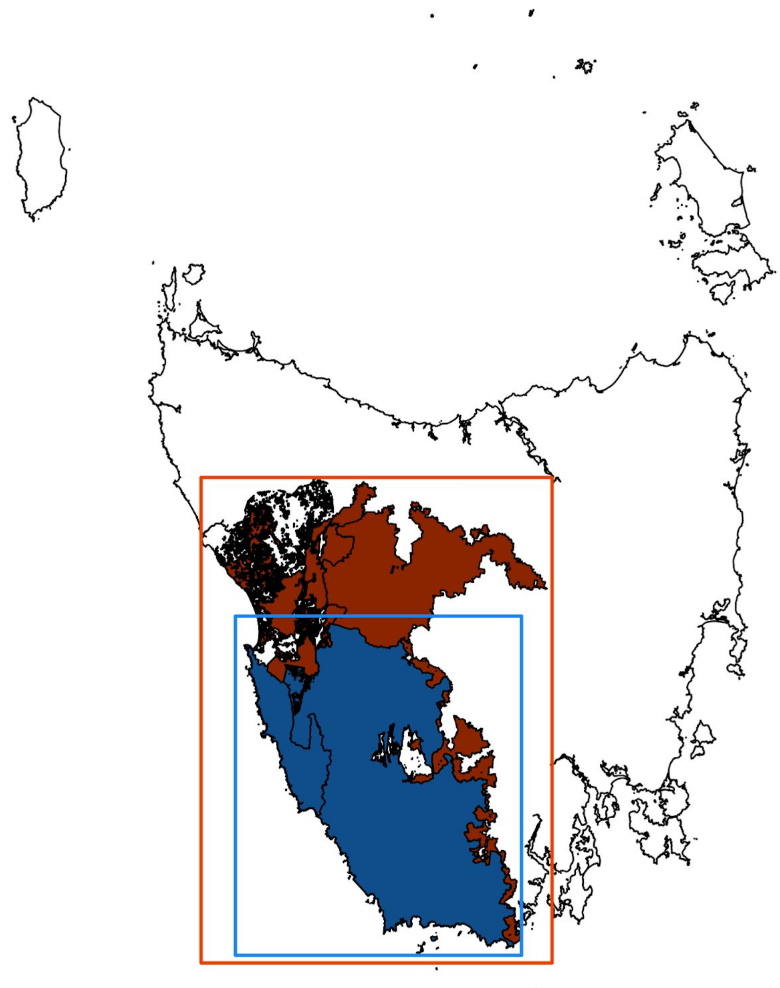

Figure 3.1. FIRESCAPE-SWTAS model original (blue) and expanded (red) domain boundaries (coloured rectangles) and areas within which quantitative analysis is focussed (shaded regions).

3.1.1 Updated Fuel and Other GIS Data

Different priorities have been identified with respect to updating the spatial input data, however, the expansion of the model domain requires that each input layer be expanded in the format appropriate for FIRESCAPE-SWTAS. Since most of the original data sources are no longer available, and those that are available are high priority for updating, it was necessary to source updated data for all layers. In some cases this also provided opportunities to update model processes.

3.1.2 Stochastic Weather Generator and Gridded Weather Data

The stochastic weather generator implemented in the original FIRESCAPE-SWTAS remains available for use in the updated FIRESCAPE-SWTAS over the expanded domain. However, the assumptions made in the implementation of the stochastic weather generator should only be considered valid over the original model domain. No attempt has been made to test the validity of the stochastic weather generator over the additional areas included in the update or to modify the spatial interpolation process using weather stations in the additional areas. Nevertheless, the use of the stochastic weather generator remains valid and merits further use given the updates to the underlying spatial inputs and model processes, provided analysis is restricted to the original model domain.

It is envisaged, however, that the primary use of the model in the future will involve the application of gridded weather data from ensembles of regional climate models (RCMs) and numerical weather prediction (NWP) models. With the modification of FIRESCAPE-SWTAS to take gridded weather data as input, adaptation of this aspect of the model process to different domain extents is trivial given that current and probable future RCM and NWP data typically cover the entire state.

3.1.3 Agricultural, Silvicultural and Urban Areas

The expanded domain incorporates larger regions of non-wilderness areas. Consideration was given to modelling human activities that might have a significant influence on fuel loads or fire spread in the vicinity of the TWWHA, such as forestry activities or intensive fire suppression efforts in relation to asset protection. The complexity of modelling these processes in the deterministic framework of FIRESCAPE-SWTAS puts this task beyond the scope of the current update but this should not have a significant impact given that the quantitative analysis is restricted to the area within the TWWHA and Adjacent Areas boundaries, as in previous applications of FIRESCAPE-SWTAS. Assessing anthropogenic changes to the frequency of fire spread from outside of the TWWHA to within the TWWHA would necessarily require an independent study with further model development.

3.2 Updated Fuel and Other GIS Data

FIRESCAPE-SWTAS deterministically simulates the fire regime of southwestern Tasmania on a latitude-longitude grid with a resolution of 100 metres. The gridded input data necessary to simulate fire ignition, spread and impact on ecological drift of vegetation types are summarised in Table 3.1, together with sources of data used in the previous and updated versions of FIRESCAPE-SWTAS. Weather data input and other new spatial input layers associated with gridded weather data input are discussed in Section 3.3.

Parameter	Original Data Source	Updated Data Source
Vegetation Type	TASVEG 2.0	TASVEG 3.0
Digital Elevation Model		Land Tasmania
Macroscale Elevation	Derived from DEM	Derived from DEM
Slope	Derived from DEM	Derived from DEM
Soil Productivity	Mapped from geological maps by A. Pyrke, J. Marsden-Smedley, G. Dixon	Natural and Cultural Heritage Division, DPIPWE
Fire History		Tasmania Parks and Wildlife Service, DPIPWE
Disruption		Tasmania Parks and Wildlife Service, DPIPWE
Human Access		Tasmania Parks and Wildlife Service, DPIPWE
Weather Grid Latitude	N/A	Derived from weather/climate model
Weather Grid Longitude	N/A	Derived from weather/climate model
Weather Model Topography	N/A	Weather/climate model specific (e.g. CCAM (Corney, et al. 2010))

Table 3.1. Gridded input data and sources for FIRESCAPE-SWTAS.

All spatial input data, including planned burning units (Section 3.4), were converted to GeoTIFF format with a common grid prior to being written to the text input format required by FIRESCAPE-SWTAS. Reformatting of raster data to GeoTIFF, rasterisation of vector data to GeoTIFF, and derivation of macroscale elevation and slope data were carried out using ArcMap 10.4. All other formatting tasks were carried out using R (R Core Team, 2018).

3.2.1 Vegetation Communities

The spatial distribution of vegetation communities in FIRESCAPE-SWTAS is provided by "TASVEG - The Digital Vegetation Map of Tasmania", produced by the Tasmanian Vegetation Monitoring and Mapping Program (DPIPWE, 2013). This data set describes the vegetation coverage of the entire state by 155 classifications of vegetation community types. It is derived from aerial photography and field surveys.

FIRESCAPE-SWTAS models vegetation communities in 12 broad vegetation types, listed in Table 3.2. These groupings were chosen based on the representation of vegetation succession pathways implemented in FIRESCAPE-SWTAS. Updating the vegetation succession pathways has been identified as a high priority but is beyond the scope of the current project. A discussion of the ongoing development of this aspect of the model in subsequent projects is presented in section 6.2.

In the previous version of FIRESCAPE-SWTAS, the 129 vegetation communities in TASVEG 2.0 were mapped to the 12 FIRESCAPE-SWTAS types. However, with various changes to the classifications in the major update to TASVEG 3.0 it was necessary to update the mappings based on the TASVEG 3.0 Metadata Statement (TVMMP, 2013) and a recent review of vegetation succession pathways in ecological drift theory (Harris et al., 2018).

Vegetation Code	**Vegetation Type**	**Low Productivity Successor Type**	**Medium Productivity Successor Type**
NV	No Vegetation	Static	Static
BGSPARSE	Sparse Buttongrass Moorlands	Static	Static
BG	Buttongrass Moorlands	Wet Scrub	Wet Scrub
SW	Wet Scrub	Wet Eucalypt Forest	Mature Wet Scrub
WEF	Wet Eucalypt Forest	Mixed Forest	N/A
MF	Mixed Forest	Rainforest	N/A
MATWS	Mature Wet Scrub	N/A	Wet Scrub/Rainforest
WSRF	Wet Scrub/Rainforest	N/A	Rainforest
RF	Rainforest	Climax Type	Climax Type
ALP	Alpine	Static	Static
GRASS	Grassland/Pasture	Static	Static
COAST	Coastal Heath	Static	Static
DSF	Dry Sclerophyll Forest	Static	Static

Table 3.2. Broad vegetation type groupings and succession pathway information.

TASVEG 3.0 is provided as a vector based GIS layer, so it was necessary to rasterise the data for use in FIRESCAPE-SWTAS. TASVEG 3.0 is produced for use at a scale of 1:25 000. Various factors, including data sources and requirements specific to vegetation type result in a range of effective spatial resolution across the TASVEG 3.0 map. Polygons defining patches of homogeneous vegetation are generally larger than 1 ha, however, polygons as small as 0.1 ha are present. Such features are considerably smaller scale than the 100-metre resolution of FIRESCAPE-SWTAS. The rasterisation was therefore carried out using combined maximum area selection where two or more features were present within a grid cell. The digital elevation model raster data provided by PWS were used as a template for the grid of the resulting vegetation raster. The rasterised vegetation type data provided as the updated input to FIRESCAPE-SWTAS are shown in Figure 3.2.

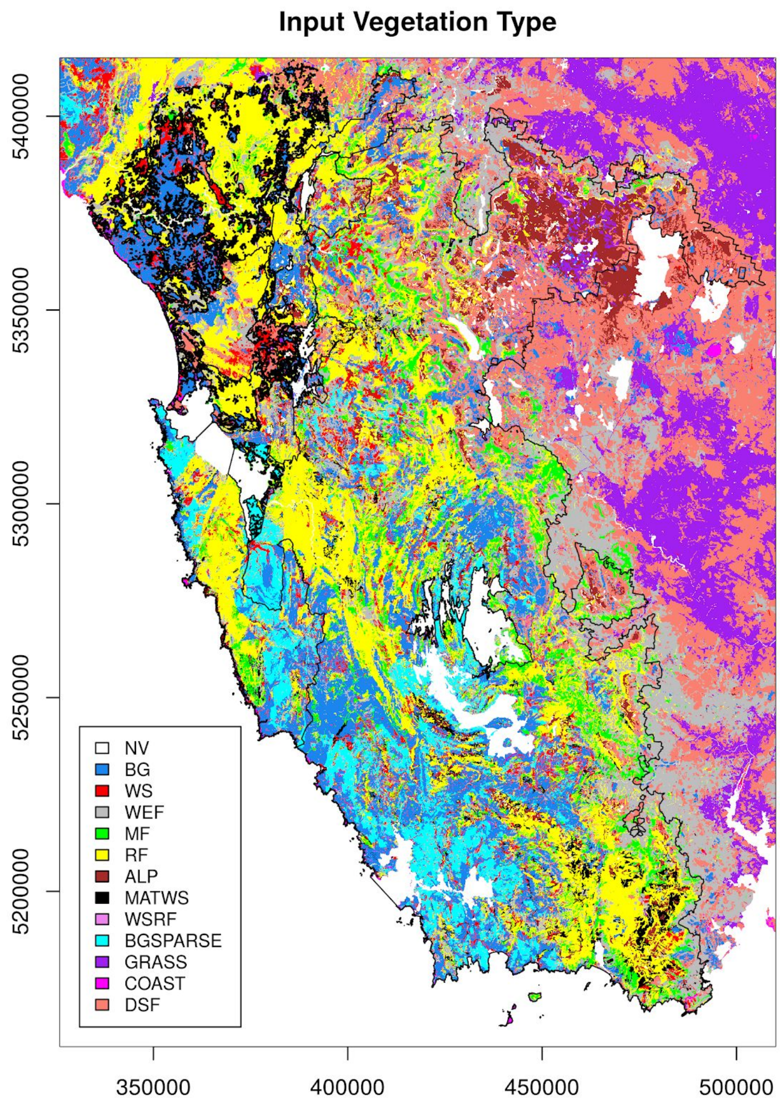

Figure 3.2. Rasterised TASVEG 3.0 vegetation community data grouped into 12 broad vegetation types for input into FIRESCAPE-SWTAS. Vegetation types are described in Table 3.2. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.2 Fire History

3.2.2.1 Fuel age and Fuel Load

One of the primary outputs of FIRESCAPE-SWTAS is the statistics of fire frequency at each grid cell. To compile these statistics, FIRESCAPE-SWTAS keeps track of the time since the most recent fire (TSF) in each grid cell. Each time a fire occurs in a grid cell the statistics are updated and the TSF is reset to zero. TSF is also used to determine the fuel load in a grid cell at the time of a fire according to fuel accumulation functions specific to each vegetation type. Because of this equivalence between fuel age and fuel load, initial values for TSF are necessary inputs so that FIRESCAPE-SWTAS begins with a realistic spatial distribution of fuel load.

To determine the initial values for TSF, a fire history for the region provided by PWS as a vector based GIS stack was utilised. The date and spatial extent of each known fire in the region since 1970 were extracted from the history and rasterised using the digital elevation model as a template for the grid of the resulting TSF raster. In the absence of fire history data prior to 1970, the approach taken in previous applications of FIRESCAPE-SWTAS was to set the TSF for grid cells with no fire history to a common large value of 100. This approach has been maintained initially in the present update of FIRESCAPE-SWTAS, as shown in Figure 3.3, however, assigning values of TSF based on vegetation type would be more appropriate given the implications for vegetation type transitions according to the succession pathways.

Vegetation growth time is another parameter of FIRESCAPE-SWTAS and is derived from TSF. It is used to determine fire ignition thresholds and the occurrence of vegetation type succession and regression. The only processes modelled in FIRESCAPE-SWTAS that affect growth time are the occurrence of fire and vegetation type succession transitions. Within the TWWHA this is a reasonable assumption, however, outside of the TWWHA forestry and agricultural activities have a significant impact on growth times and fuel accumulation independent of fire frequency. This factor can be accommodated into the initial conditions for fuel load (TSF) by assimilating fuel age data provided by PWS into the initial TSF data. In regions where fuel age is less than the time since the most recent fire, due to logging for example, the fuel age is included as TSF since the effect on fuel accumulation will be the similar. This is of importance for the model initial conditions given that areas of recent active forestry now fall within the TWWHA due to the recent boundary extensions. Since forestry and agricultural activities are not modelled, the realism of the fuel age distributions outside of the TWWHA will progressively decline throughout the simulation period. The impact of this on model outputs should not be significant since statistics are determined for areas within the TWWHA boundaries and the only detail of fires outside that is important is whether those fires cross the boundary into the TWWHA.

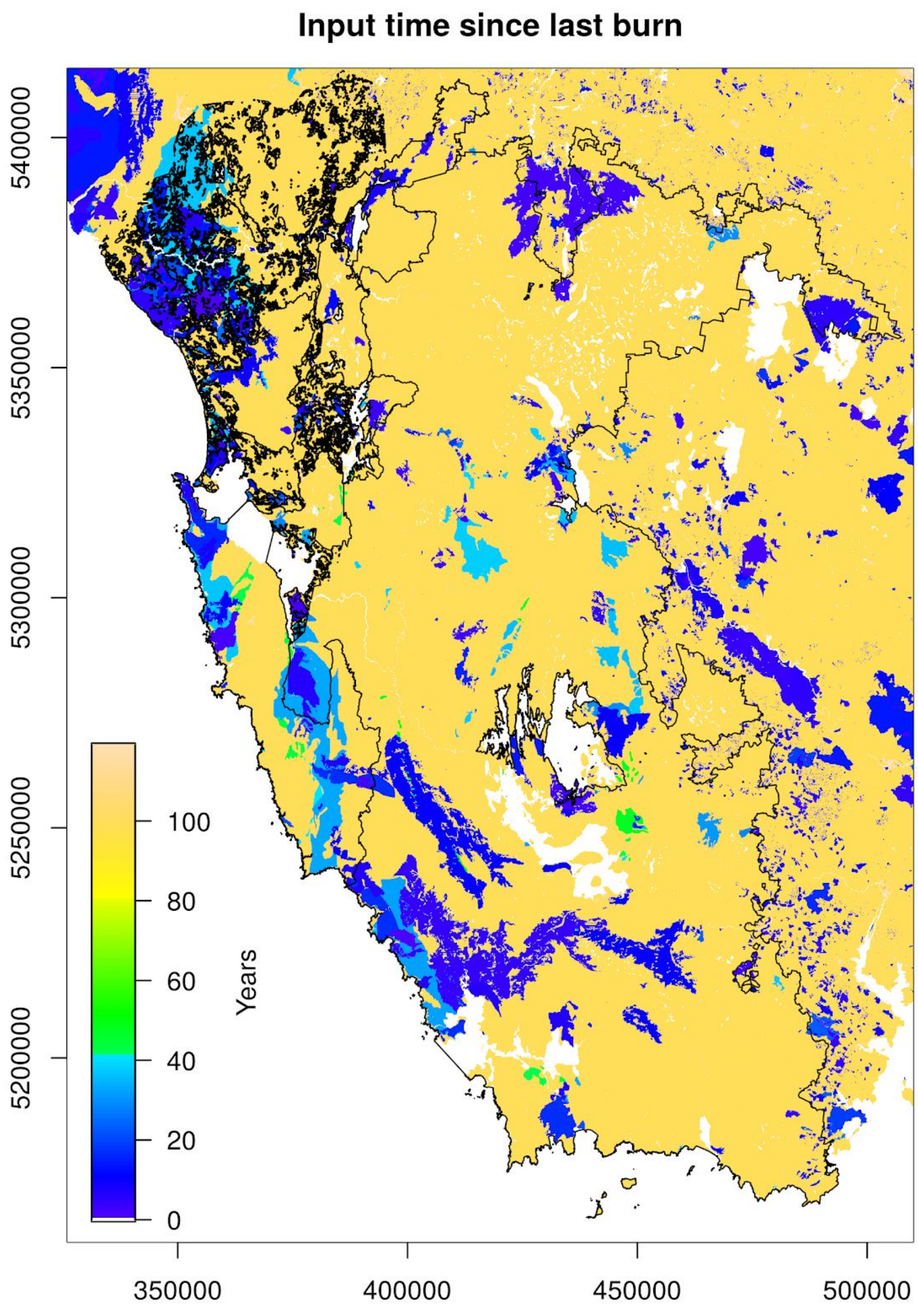

Figure 3.3. Rasterised fire history data denoting the number of years since the most recent fire in each grid cell. Changes in vegetation age due to forestry activities have been incorporated as time since fire. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.2.2 Historical Fire Frequency

Vegetation type regression following fire occurrence as modelled in FIRESCAPE-SWTAS is a function of recent fire frequency. As well as the time since most recent fire (TSF) for each grid cell, the time between the most recent fire and the preceding fire, the inter-fire interval (IFI), is also recorded for each grid cell. Initial values for this parameter are also required as input. As for TSF, these data were obtained where possible from the fire history provided by PWS. Similarly, in the absence of fire history a common large value of 55 was applied, as shown in Figure 3.4, although a vegetation type specific approach would be more appropriate.

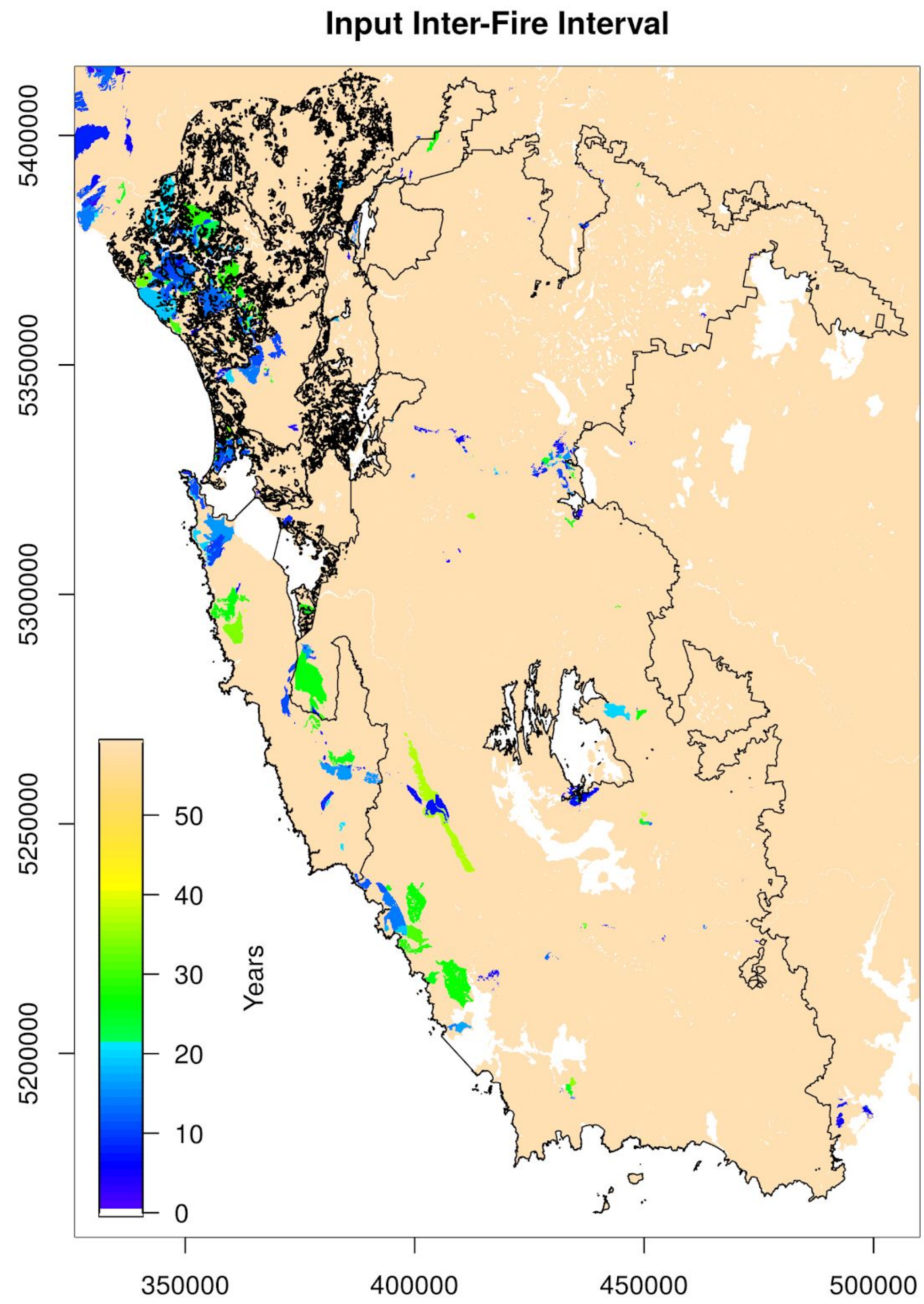

Figure 3.4. Rasterised fire history data denoting the number of years between the most recent fire and the preceding fire in each grid cell. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.3 Site Productivity

Vegetation type succession pathways and in some cases fuel accumulation are determined by the site productivity. Previous versions of FIRESCAPE-SWTAS categorised each grid cell as either low or medium productivity in order to apply the theory described in Marsden-Smedley and Catchpole (1995) and Marsden-Smedley et al. (1999). These categories were mapped from geological data by A. Pyrke, J. Marsden-Smedley and G. Dixon (unpublished). In the absence of any such data for the extended FIRESCAPE-SWTAS domain the Natural and Cultural Heritage Division of DPIPWE agreed to create and provide an updated map of site productivity. This updated map is still in development, so for the purposes of testing the updated version of FIRESCAPE-SWTAS the previous data were applied where available and an arbitrary value of low productivity applied to the extended areas. The resulting interim map of productivity for testing purposes is shown in Figure 3.5.

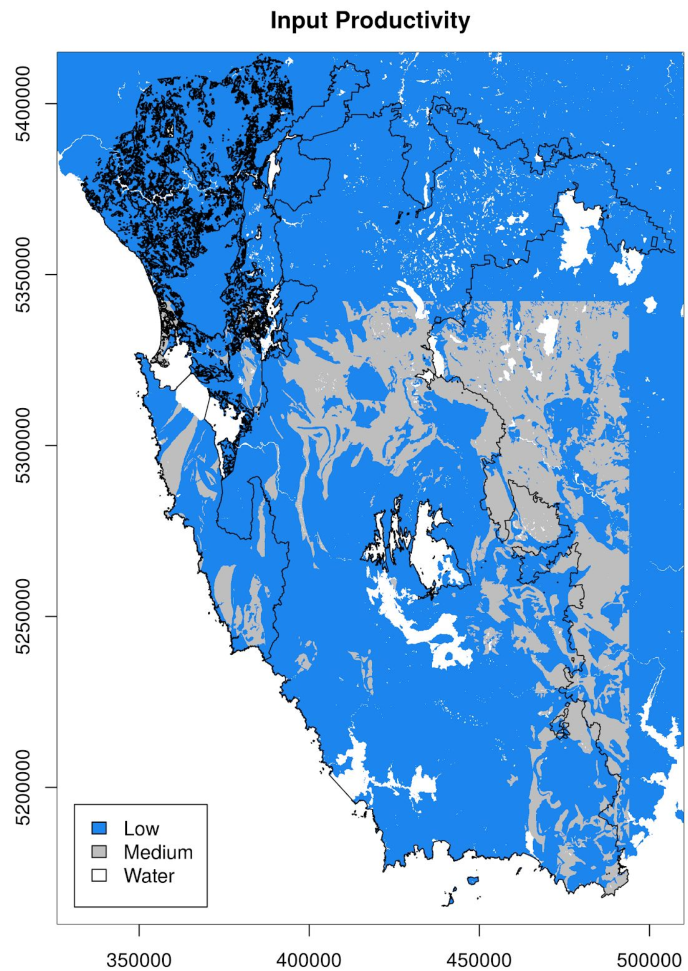

Figure 3.5. Interim site productivity class data incorporating data used in previous FIRESCAPE-SWTAS studies on original domain, and arbitrarily selected low productivity classification for new areas in extended domain. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.4 Digital Elevation Model

3.2.4.1 DEM

In versions of FIRESCAPE-SWTAS in which the stochastic weather generator is applied, the weather parameters are generated for a single grid cell at the location of Strahan and then adjusted for elevation and distance eastward from the west coast. The gridded weather applied in the updated FIRESCAPE-SWTAS accounts for elevation effects but only on a scale of approximately 10 km. Given the highly variable topography of Tasmania it is still necessary to account for discrepancies in elevation between the 10-kilometre and 100-metre grid scales, so an updated DEM data from Land Tasmania were used as input. These elevation data, shown in Figure 3.6, are also the basis for two further input parameters, macroscale elevation and slope, described in the following sections.

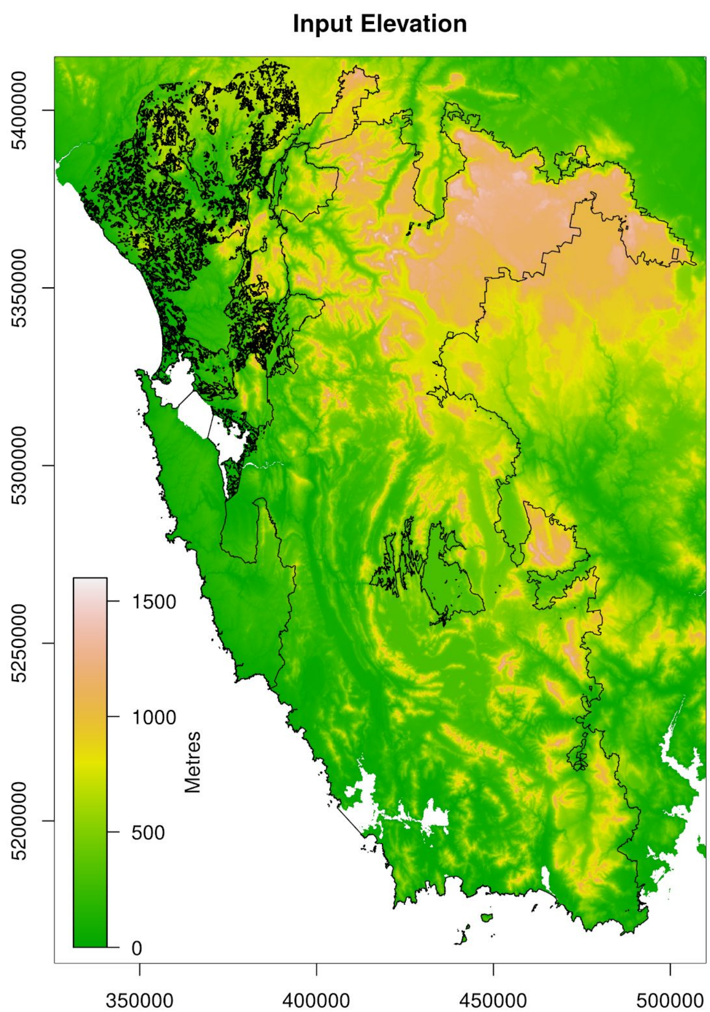

Figure 3.6. Digital elevation model of topography within model domain. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.4.2 Macroscale Elevation

The approximate location of simulated lightning strikes in the original FIRESCAPE-SWTAS is determined by randomly selecting a cell within the model domain while ensuring that the simulated lightning strikes fit the observed probability distribution of lightning as a function of macroscale elevation. The macroscale elevation is defined as the elevation averaged over an area of 1.7 km radius around each grid cell centre. The exact location of each strike is then determined according to the observed probability distribution of lightning strikes as a function of mesoscale elevation residual, the difference between the elevation and the macroscale elevation.

In the updated FIRESCAPE-SWTAS the approximate location of lightning strikes is determined by meteorological parameters at each 10-kilometre grid cell of the gridded weather input, while the exact location remains a function of the mesoscale elevation residual. The mesoscale elevation input data were calculated from the updated digital elevation model and are shown in Figure 3.7.

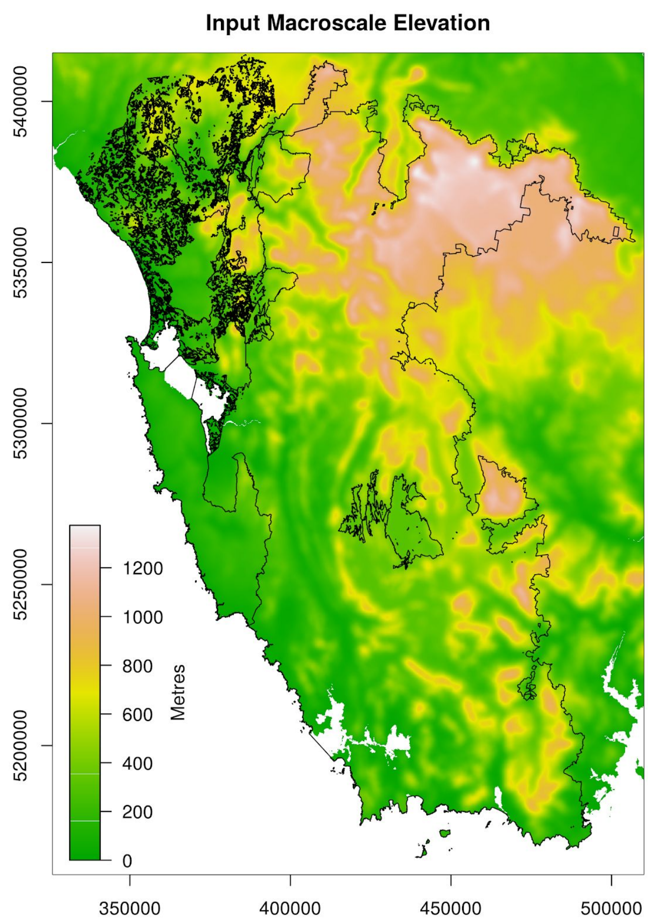

Figure 3.7. Macroscale elevation model derived by averaging the elevation within a radius of 1.8 km of each grid cell. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.4.3 Slope

Slope is a key parameter in the calculation of simulated fire rate of spread. Updated slope input data, shown in Figure 3.8, were calculated from the updated digital elevation model.

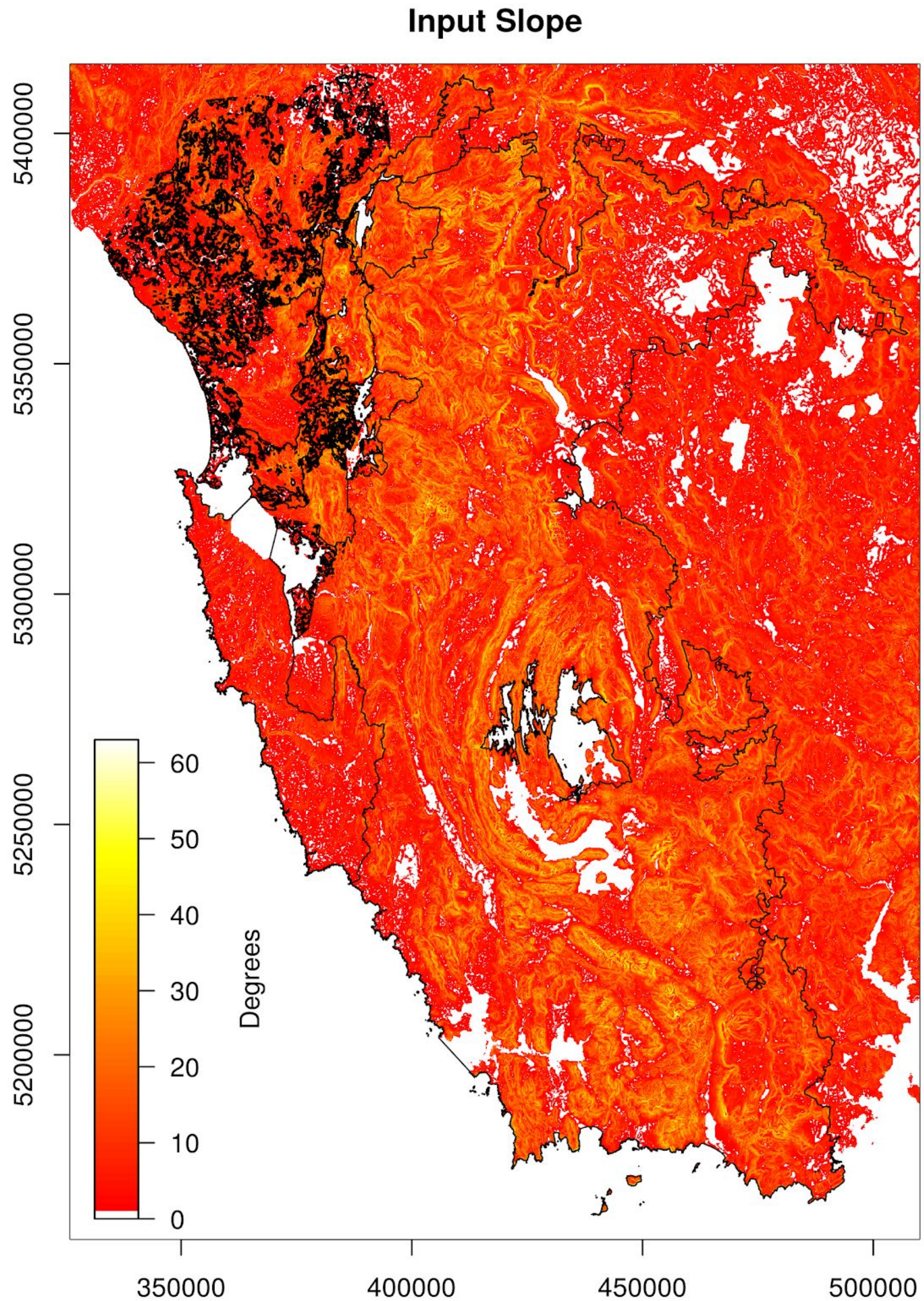

Figure 3.8. Slope of terrain derived from digital elevation model. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.5 Rivers, Roads and Other Disruptions

Simulated fire spread in FIRESCAPE-SWTAS is inhibited by grid cells which contain no vegetation type, such as those representing open water or bare rock. In addition, certain features in the landscape are treated as disruptions to fire spread, primarily these are roads and rivers. In previous versions of FIRESCAPE-SWTAS major roads and most water courses were considered and treated equally. In the updated version of FIRESCAPE-SWTAS distinctions are drawn between different categories of roads, trails, rivers and streams, as well as seasonal variations in streams. Figure 3.9 shows the road, river and other disruption input data used as the basis for fire spread disruption in FIRESCAPE-SWTAS. The data, provided by PWS, are used by PWS in the PHOENIX fire behaviour model. Data were provided in multiple tiled ESRI ASCII rasters, the native format of PHOENIX spatial data, at 25-metre resolution and were aggregated to a single 100-metre resolution GeoTIFF using the DEM raster as a template, prior to conversion to the text input format required by FIRESCAPE-SWTAS. The seasonality data for streams have a different source and are yet to be provided by PWS.

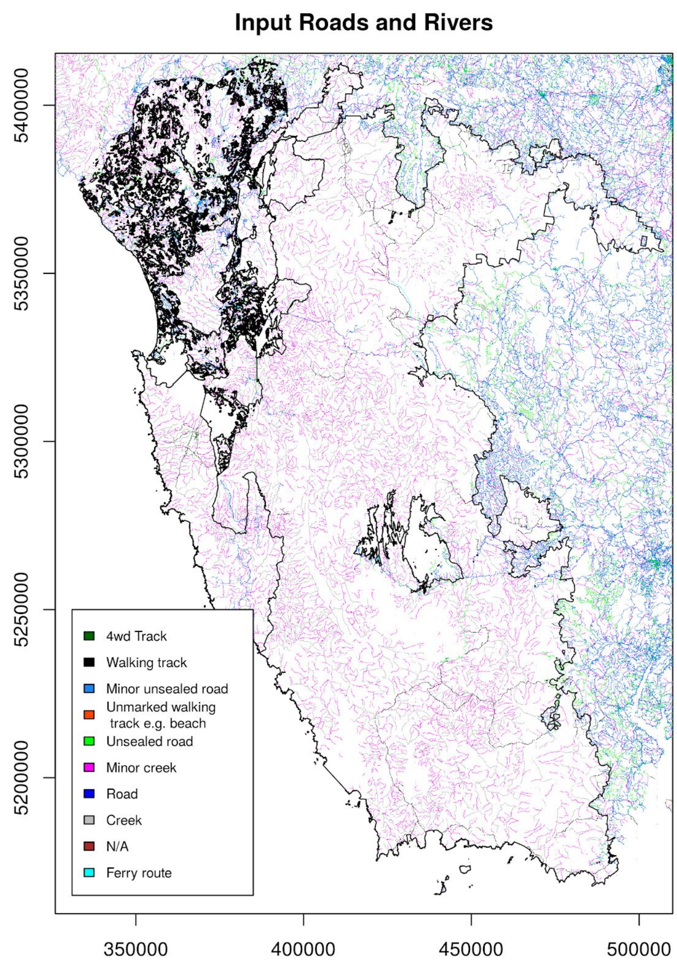

Figure 3.9. Map of locations of roads, rivers and other features that act as disruptions to fire spread. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.2.6 Human Access

Anthropogenic fires other than management fires occurring as a result of accidental ignitions or escaped fires as well as arson are simulated in FIRESCAPE-SWTAS. The locations of simulated ignitions are restricted to the immediate vicinity of roads, trails and coasts that provide ease of human access, consistent with observed patterns. In previous versions of FIRESCAPE-SWTAS human access location data were provided as independent input. In the updated version of FIRESCAPE-SWTAS the more detailed fire spread disruption data described in the previous section also provide human access location data (Figure 3.9).

3.3 Future Climate Projections

3.3.1 Context

King et al. (2013) investigated the combined effects of climate change and planned burning on unplanned fire activity in southwestern Tasmania using FIRESCAPE-SWTAS. In this study, the stochastic weather generator was replaced with multi-year time series of 3-hourly weather observations from Strahan, recorded by the Bureau of Meteorology. To study the effects of climate change, each data point in the observed weather time series was modified according to the median seasonal projected changes for Hobart, determined from a suite of GCMs for low (B1) and high (A1FI) emissions scenarios at 2070 (CSIRO and Bureau of Meteorology, 2007).

The availability of high resolution regional climate model (RCM) projections for Tasmania provides the opportunity for more sophisticated and physically realistic process modelling to be incorporated into FIRESCAPE-SWTAS. The Climate Futures program at ACECRC has recently produced high resolution climate projections for south-eastern Australia (CFSEA) including Tasmania by using the Conformal Cubic Atmospheric Model (CCAM) to dynamically downscale the output of six general circulation models (GCMs) from the Coupled Model Intercomparison Project phase 5 (CMIP5) archive. The RCM data archived from these simulations comprises fundamental meteorological parameters, such as those required by FIRESCAPE for fire behaviour modelling, available at hourly temporal resolution and 10 km spatial resolution for the period of 1980--2100 across Tasmania. This work builds on the original Climate Futures for Tasmania (CFT) project which produced similar climate projections for the Tasmanian region using GCMs from CMIP3 at daily temporal resolution.

The CFSEA data could be applied to FIRESCAPE-SWTAS in a similar manner to application of modified time series weather observations, as in King et al. (2013), by taking the time series of simulated weather from the RCM grid cell corresponding to the location of Strahan. This would offer several distinct improvements over the previous study. The CFSEA data provide climate projections specific to the location of Strahan (as well as every other 10-kilometre grid cell across Tasmania) rather than for Hobart. The CFT projections have shown that there are significant spatial and seasonal variations in the changes to climate across tasmania (Grose et al., 2010), hence the CFSEA projections will provide a much better representation of climate change over the TWWHA. Time series weather from the CFSEA projections captures changes to weather patterns explicitly rather than simply applying statistical offsets on seasonal time scales. With an ensemble of RCM projections derived from different GCMs available, better estimates of the uncertainty in the climate projections can be made.

Rather than apply the single location time series weather from the CFSEA projections, FIRESCAPE-SWTAS has been modified to take gridded weather data as input to take full advantage of the potential improvements outlined. By ingesting 1-hourly, 10-kilometre weather data significant improvements are gained in the physical representation of fine-scale fire behaviour as well as the representation of spatial variations in the simulated fire regime. The enhanced versatility of FIRESCAPE-SWTAS given the ability to ingest gridded weather data is more general than the potential for climate change studies. Data from numerical weather prediction reanalysis based on historical observations can be applied for simulations of historical or present conditions.

3.3.2 Gridded Weather Reanalysis

3.3.2.1 Downscaled ERA Interim and BARRA-TA

The development process for the modifications to ingest gridded weather data into FIRESCAPE-SWTAS was carried out using NWP model reanalysis data products. NWP reanalysis produces gridded weather data representing best estimate of historical weather by taking as much high quality observational data as are available and combining them with standardised versions of NWP (forecast) models. Using reanalysis data for the development process allows changes to FIRESCAPE-SWTAS model processes to be tested against historical observations. Through both case study and long term simulations, empirically determined model parameters such as soil dryness ignition thresholds and extinguishment precipitation thresholds can be adjusted to optimal levels within FIRESCAPE-SWTAS by using reanalysis data and comparing the simulation output to either specific historical fires and weather events, or to long term statistics of, for example, lightning fire ignitions.

The two reanalysis data products most relevant in the current context are the European Reanalysis Interim (ERA-Interim) produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), and the Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia (BARRA) produced by the Australian Bureau of Meteorology.

ERA-Interim is a global reanalysis project producing a continually updated dataset spanning 1979 to the present at 6-hourly temporal and approximately 80 km horizontal spatial resolution. As mandated by the Coordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme (WCRP), the CFSEA ensemble comprises, ERA-Interim for the period 1980-2014, in addition to the 6 CMIP5 GCMs, each subjected to the dynamical downscaling process. This permits an assessment of the downscaling process used in the study as well as an assessment of the behaviour of the individual GCMs in the ensemble for the historical period of the CMIP5 simulations.

BARRA is an Australasian region reanalysis project that is currently in the process of producing a dataset that will span 1990-2016. The primary dataset will have 1-hourly temporal and 12 km horizontal spatial resolution. ACECRC has commissioned a higher resolution downscaled version of the reanalysis for the subdomain of Tasmania which will have approximately 1.5 km horizontal spatial resolution. While some subperiods of this dataset have recently become available, the full dataset will not be available until 2019.

Data presented in the remainder of this section pertain to downscaled ERA-Interim as these data were used primarily for the development due to their ready availability. However, all methods are equivalent for BARRA but at different resolution.

3.3.2.2 Grid Transformation

FIRESCAPE-SWTAS operates on a grid defined in 100-metre steps of eastings and northings of Universal Transverse Mercator zone 55, resulting in grid cells with area of approximately one hectare. Since gridded weather data products are typically provided in spherical latitude-longitude coordinates it is necessary to calculate the coordinate transformation to determine which weather grid cell corresponds to a particular grid cell within FIRESCAPE-SWTAS. The CFSEA data are provided on a 0.1-degree latitude-longitude grid, which corresponds to approximately 10-kilometre grid spacing, so approximately 10,000 FIRESCAPE-SWTAS grid cells fall within each CFSEA grid cell. This is illustrated in Figure 3.10 where the topography used by CCAM has been plotted in greyscale on top of the much higher resolution topography used by FIRESCAPE-SWTAS transformed to rectangular latitude-longitude and plotted in colour.

Rather than calculate the transformations within FIRESCAPE-SWTAS, the calculations were performed in advance and the results provided to FIRESCAPE-SWTAS as gridded input in the same format as the other input parameters described in Section 3.2. The latitude and longitude of the centre of each grid cell within the FIRESCAPE-SWTAS domain was calculated using the R GDAL package. The latitude and longitude values were then converted into index values for the CFSEA grid and output to text files in the FIRESCAPE-SWTAS format. Figure 3.11 demonstrates the alignment of the different coordinate systems, where each FIRESCAPE-SWTAS grid cell is coloured according to the CFSEA grid cell within which it falls.

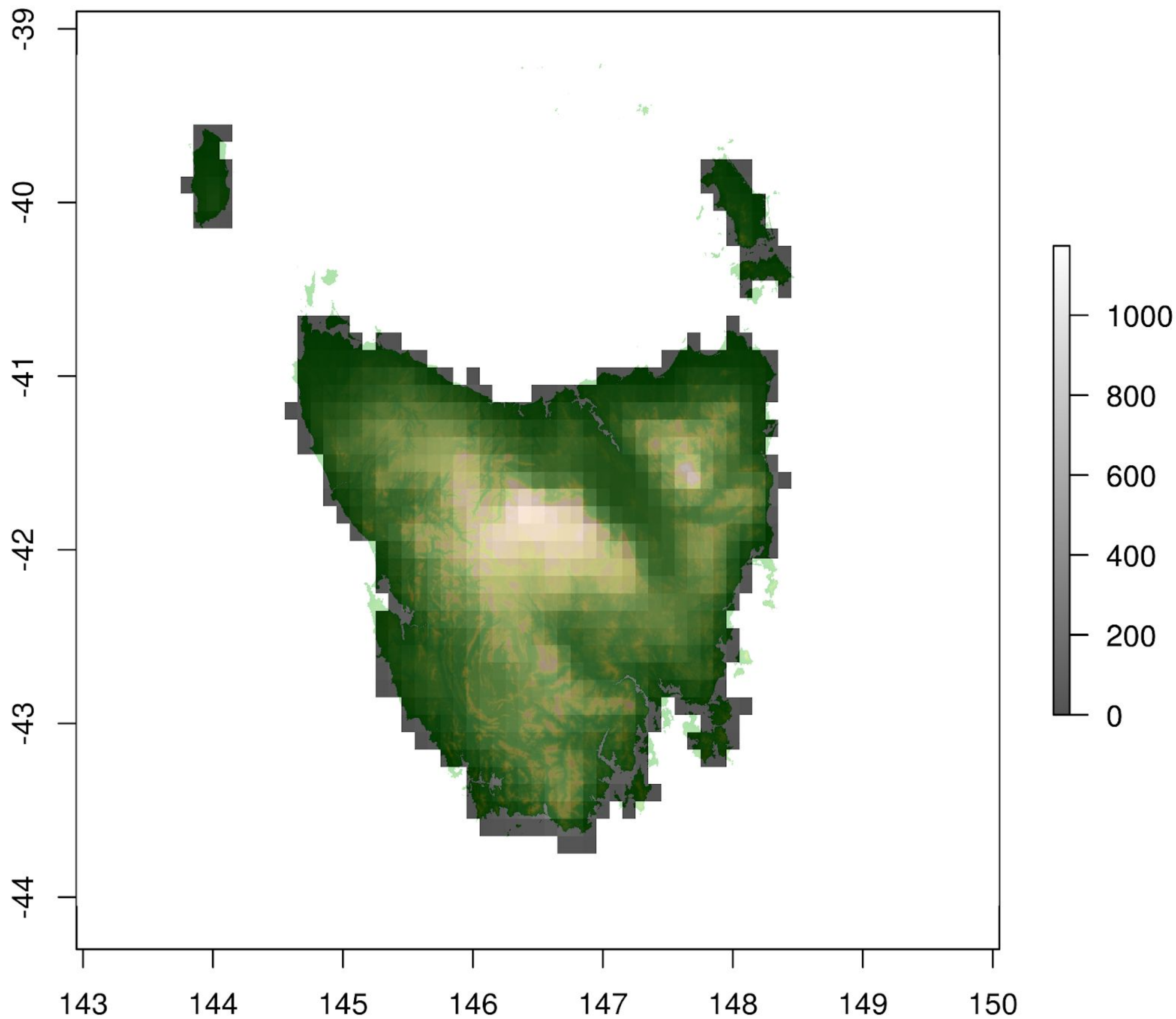

Figure 3.10. Tasmanian topography as represented at two different scales. Digital elevation model from Land Tasmania at 100-metre resolution (in colour). Topography as defined within CCAM at 0.1-degree resolution (overplotted in greyscale). Approximately 10,000 FIRESCAPE-SWTAS grid cells fall within each CFSEA grid cell

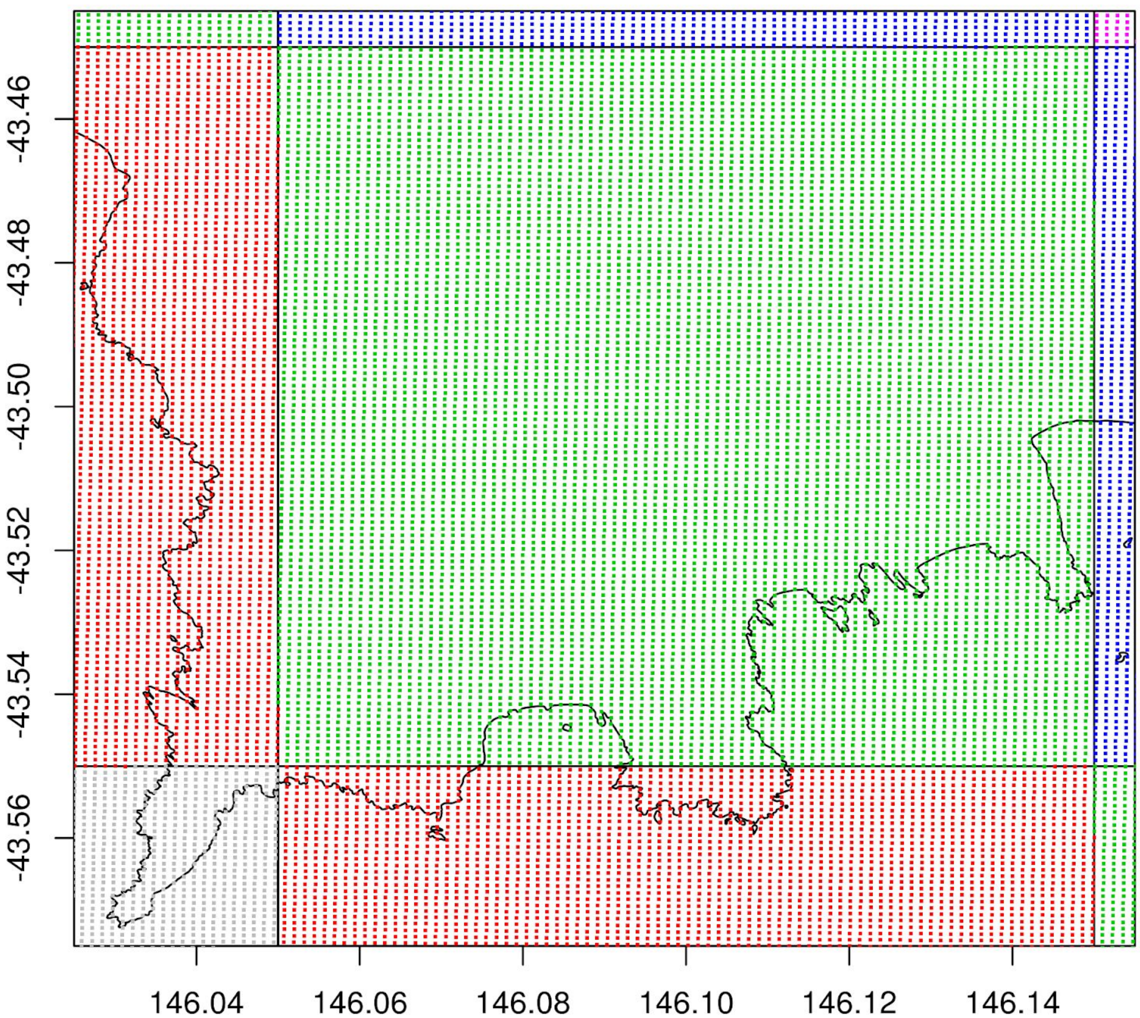

Figure 3.11. FIRESCAPE-SWTAS grid cell central locations transformed to rectangular latitude-longitude (coloured points) in relation to CFSEA grid cell boundaries (black lines) in the vicinity of South West Cape. FIRESCAPE-SWTAS grid cells are coloured according to which CFSEA grid cell they fall within.

3.3.2.3 Weather Parameter Ingestion

The CFSEA data are recorded in netCDF format, the standard for climate model output. The surface meteorological variables require by FIRESCAPE-SWTAS are stored in separate files, each containing a ten year block of data in a 3-dimensional latitude-longitude-time array. New routines were added to FIRESCAPE-SWTAS to read the netCDF files and extract the required subdomain of the arrays. The variables ingested were instantaneous temperature, vapour pressure, zonal and meridional wind speed, dry lightning potential environment and hourly totals of total precipitation. The lightning potential environment variable is a derived variable discussed in Section 3.3.2.5.

Within FIRESCAPE-SWTAS, the vector holding the single location time series weather observations was replaced with the 3-dimensional array of gridded data so that most model processes function as in previous versions by indexing the gridded data using the index values for each cell provided by the new grid transformation inputs in addition to the original time indexing. Gridded weather data are read in 10-year blocks since this is the division of the CFSEA netCDF data files. This value is arbitrary and could be varied if memory constraints require, although the minimum duration time series required at any time is one year for the calculation of MSDI.

3.3.2.4 High Resolution Topographic Effects

FIRESCAPE-SWTAS originally accounted for spatial variations in weather across the model domain by scaling temperature, vapour pressure and rainfall based on the observed effects of elevation. Horizontal spatial variations in rainfall observed at multiple Bureau of Meteorology weather stations were also incorporated as a west to east distance scaling factor. All scaling factors were defined relative to the reference weather station at Strahan, for which the stochastic or observed weather time series were defined.

With the ingestion of gridded weather data the various weather parameters already incorporate the effects of topography and other influences on their spatial heterogeneity at the scale of the underlying model, 10 km in the case of CFSEA. However, with the highly variable topography of Tasmania, significant variations in elevation occur even within a single CFSEA grid cell. Hence, scaling of weather parameters due to the effects of elevation, captured at high-resolution in the input DEM, is retained in the updated FIRESCAPE-SWTAS. Temperature, vapour pressure and precipitation are all scaled by linear functions of elevation based on observed climatologies. In this case the elevation differences are determined relative to the elevation of the CFSEA grid cell within which the FIRESCAPE-SWTAS grid cell falls. This requires CFSEA elevation data within FIRESCAPE-SWTAS, hence a new input layer is required. The difference in elevation between each FIRESCAPE-SWTAS grid cell and the corresponding CFSEA grid cell was calculated externally and written to FIRESCAPE-SWTAS format input file, and the initialisation routines in FIRESCAPE-SWTAS were updated to accommodate their ingestion.

A further enhancement of the representation of precipitation in FIRESCAPE-SWTAS would be to replace the current elevation dependent precipitation adjustment to the more sophisticated precipitation statistical downscaling scheme developed for Tasmania by Matt Webb at DPIPWE. However, while this would be relatively straightforward piece of work it is beyond the scope of any currently funded research.

3.3.2.5 Lightning Parameterisation

The application of gridded weather to FIRESCAPE-SWTAS provides the opportunity for a much more realistic lightning ignition parameterisation. Dry lightning potential environment (DLPE) is an index used operationally by meteorologists to estimate whether forecast meteorological conditions will be favourable for the occurrence of lightning in the absence of significant precipitation. DLPE is defined as either true or false according to the coincidence of three criteria: 850--500 hPa temperature difference in excess of 28 C; difference between 850 hPa dry-bulb and dewpoint temperatures in excess of 10 C; and upward vertical motion in excess of 10 hPa/hr at 850 hPa.

Previous versions of FIRESCAPE-SWTAS determined the occurrence of lightning ignitions by checking if daily values of weather parameters corresponded to those on historically observed days of lightning ignition. Ignition locations were determined randomly but constrained to produce observed distributions of lightning ignitions as a function of broad elevation classifications. Precise location of ignitions were also influenced by observed ignition location distributions as a function of mesoscale elevation residuals, the elevation with respect to a local regional average. Simulated lightning ignitions always occurred at midday local time.

In the updated FIRESCAPE-SWTAS lightning occurrence is determined by DLPE. Hourly values of DLPE were calculated for the full spatio-temporal domain of the CFSEA data. These data were then ingested into FIRESCAPE-SWTAS together with the other meteorological data. The model test of daily weather to determine lightning occurrence was replaced with a test of whether DLPE occurred anywhere within the FIRESCAPE-SWTAS domain during each simulated day. For each positive DLPE grid cell (i.e. 10 km^2) for each hour, a number of lightning strikes is randomly determined from a probability distribution determined from a comparison of DLPE calculations with lightning observations.

3.3.3 Gridded Climate Projections

3.3.3.1 Downscaled CMIP5 GCMs

Wine Australia has commissioned a major project on the future of the wine growing in Australia through the ACE CRC partnering with CSIRO. The project has produced high resolution climate projections for south-eastern Australia.

The new high resolution climate projections have been produced by the CSIRO using their Conformal Cubic Atmospheric Model (CCAM) model to dynamically downscale the output of six general circulation models (GCMs) from the Coupled Model Intercomparison Project phase 5 (CMIP5) archive. CCAM uses a variable grid scale with a high resolution region with approximately 5 km grid spacing centred over and encompassing most of Victoria for the CFSEA simulations. The grid spacing becomes progressively larger moving away from this central region with an average resolution of approximately 10 km over Tasmania. Post-processing of the CCAM simulation output data involves interpolating the data onto a regular latitude-longitude grid for analysis. For the Tasmanian subdomain the post-processed output has 0.1-degree resolution which corresponds to approximately 10 km square grid cells.

The use of simulation output from six different GCMs as input to the CFSEA CCAM simulations allows for more robust estimates of projected changes through the consideration of ensemble means, and gives a better indication of uncertainty in the projections based on the spread of the simulation outputs. The six CMIP5 simulations used for the CFSEA projections all used the RCP 8.5 high emissions scenario, which is consistent with actual recent global emissions trends. CSIRO is currently producing a further set of climate projections for south-eastern Australia using the same configuration as CFSEA but using CMIP5 simulations that used the RCP 4.5 emissions scenario. The availability of these projections will permit the assessment of the range of possible climate change due to variations in anthropogenic forcing.

The use of these high resolution regional climate projection data in FIRESCAPE-SWTAS will permit more realistic assessment of the effects of climate change on the fire regime in the TWWHA than previous studies, also incorporating estimates of uncertainty due to limitations of climate modelling techniques. Further, the effectiveness of planned burning strategies for the TWWHA can be assessed for projected future climates and alternative strategies developed.

3.4 PWS Planned Burning Strategies

3.4.1 Planned Burn Units

The basis for incorporating PWS planned burning strategies into the fire regime simulation within FIRESCAPE-SWTAS is the definition of the regions within the TWWHA that will be subjected to planned burning, the burn units. The interim planned burning strategy (PBS) used for the development process defines 297 regions of buttongrass moorland which fall into one the three planned burning management objective categories. The region boundary data were provided by PWS as vector based GIS layer which was rasterised using the DEM data as a template. The resulting raster was used to create a list of coordinates of each cell within each burn unit. This list was written to a file as required for input to FIRESCAPE-SWTAS. The burn unit grid cell list is plotted in Figure 3.12 where burn units have been coloured according to management objective.

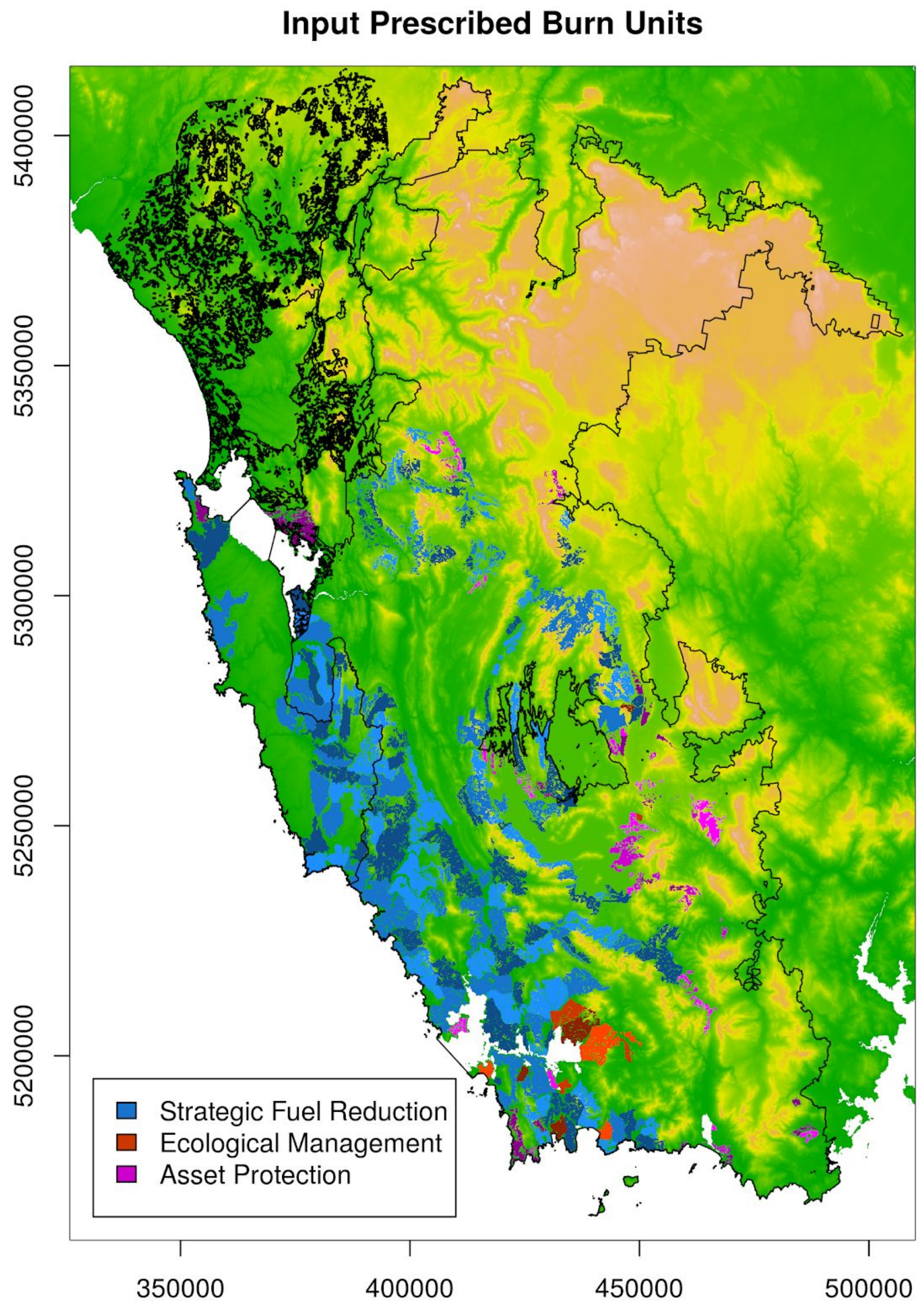

Figure 3.12. Interim rasterised planned burn units categorised by management objectives. Black lines indicate boundaries of TWWHA and Adjacent Areas.

3.4.2 Rotation Strategy

The planned burning strategies currently under development by PWS divide the burn units into regional groups. Within each group, burn units are assigned a range of target years so that each burn unit is scheduled to be subject to a planned burn within the next 10 years. Initial target years reflect the time since each burn unit was subject to either planned or non-management fire. Once the 10-year plan is complete the same schedule is repeated indefinitely.

The ability of the model to carry out the PBS as designed is limited, as in reality, by the constraints imposed by weather and resourcing, discussed in more detail in Section 3.4.3. Within each year burn units are given a priority for treatment. If a burn unit is not able to be treated during its target year the target year is changed to the following year and given high priority. In general, priority can be assigned based on management objective or time since previous fire, although any arbitrary priority is possible. If a significant proportion of the burn unit is burned by an unplanned fire the target year is updated accordingly.

Planned burns can be simulated in the updated FIRESCAPE-SWTAS using two possible methods. For an unbounded planned burn, single or multiple ignition points can be specified using the same mechanisms as for unplanned burns and the spread of fire simulated following the normal model processes. Alternatively, each cell within a burn unit can be treated separately as per the normal model processes but with the possibility of fire spread to adjacent cells removed. This represents an idealised best case simulation of planned burning in burn units with secure boundaries or cases in which sufficient resources are deployed to prevent the spread of fire to areas outside the burn unit, representing highly controlled prescribed burning conditions.

3.4.3 Planned Burning Opportunity

3.4.3.1 Weather Constraints and Planned Burning Index

Weather conditions are a critical constraint on whether planned burning can be carried out while meeting management objectives. Guidelines for conducting planned burning in Tasmania are set out in Marsden-Smedley (2009), including the range of meteorological parameters that define acceptable conditions for different classes of planned burning. The parameters considered are wind speed, temperature, relative humidity, days since rain, MSDI, target inter-fire interval, and MFDI.

Buttongrass moorlands and grasslands are the only vegetation types targeted within the TWWHA by PWS planned burning strategies, although vegetation type boundaries are not always distinct in practice and burning into adjacent heath and scrub will occur incidentally. For buttongrass moorlands four sets of conditions are described in the guidelines. These pertain to fuel management burning when fire spread within a burn unit is secured by natural boundaries such as wet scrub, or by water or mineral earth boundaries, ecological management burning, and unbounded burning where overnight conditions must be sufficient for fires to self-extinguish. The specific conditions are described in Table 2.5 of Marsden-Smedley (2009).

Each burn in the PBS is assigned one of these four classifications based on the associated management objective and the geographical setting. In the updated FIRESCAPE-SWTAS, for each burn unit the meteorological conditions are tested each day in the simulation. Burn units in which the meteorological conditions are acceptable will be treated that day according to the PBS schedule, resources available (see Section 3.4.3.2), and the priorities assigned.

Application of the weather conditions as described can be considered as a simple index indicative of whether any given historically observed or forecast weather is suitable for planned burning at a given location. Statistical analysis of this index based on these four sets of conditions applied to gridded weather data from historical reanalyses and future climate projections is described in Section 5.3 as a tool for assessing potential changes to opportunities for planned burning in the future as a result of climate change.

3.4.3.2 Resourcing Constraints

A further constraint on the number of planned burns that can be conducted in a given period of time is the amount of resources allocated to implementing planned burning operations. Limits exist on the number of crews that can be simultaneously deployed to conduct planned burns, as well as the availability of personnel and equipment throughout any given year. These factors are represented within FIRESCAPE-SWTAS as variables defining the maximum number of planned burns that can be conducted each day and the maximum number of planned burns that can be conducted each year.

4 Changes to Climate Suitability for Iconic Species

4.1 Assessing Climate Suitability of Vegetation Communities

4.1.1 Background

Changing climate suitability under ongoing climate change is expected to lead to shifts in species distributions (Parmesan et al., 2000; Hughes, 2003; Root et al. 2003), causing changes to the composition and structure of natural communities and, potentially, the emergence of novel communities (Hobbs et al., 2006; Williams et al., 2007). This has important consequences for biodiversity conservation and fire management.

Species Distribution Models (SDMs), also known as bioclimatic niche models, habitat suitability models or climate envelope models, are widely used to project current and future distributions of species (Thuiller et al. 2005; Elith & Leathwick, 2009; Zimmermann et al. 2010). SDMs can be grouped into three main types: i) envelope approaches (e.g. BIOCLIM), ii) distance-based measures (e.g. Maxent) and, iii) regression models (eg. generalized linear models (GLM) and generalized additive models (GAM)). All are based on correlations between current environmental or climate conditions and the observed distribution of a species. Assuming that this relationship remains unchanged, the future distribution of the species is then projected according to future climatic conditions.

SDMs are most commonly run on observations of a single species, or group of species. They are often based on bioclimatic parameters (Nix 1986), which represent annual trends (e.g. mean annual temperature, annual precipitation), seasonality (eg. annual range in temperature and precipitation), and extreme or limiting environmental factors (eg., temperature of the coldest and warmest month, precipitation of wet and dry quarters).

We use a climate analogue approach (Williams et al. 2007; Kopf et al., 2008) to assess changing climate suitability for broad vegetation types, for several reasons. The analogue approach provides maps that are easily understandable by a broad audience; it avoids many of the assumptions about the climatic tolerances of target species; it can be readily applied to new regions and it provides information about broad scale change, rather than species specific detail. Bioclimatic modelling remains one of the few methods able to rapidly assess potential broad scale changes in the distributions of multiple species in response to a changing climate (Beaumont and Hughes, 2002; McKenney et al., 2007).

4.1.2 Methods

The climate analogue approach is a climate modelling method that can be used to identify statistically similar climates across space and time. It can therefore identify locations that are climatically similar to a set of reference locations under current and future climates.

ACE CRC has developed a climate analogue tool that captures variability in climate at a fine temporal scale. The tool differs from other available climate analogue tools in two important ways. Firstly, it captures the effects of temperature, precipitation and evaporation, not just temperature. Secondly, it compares the climate on both daily and monthly timescales, to capture differences in extremes and seasonality,as well as mean climate conditions.

The climate analogue approach was used to identify locations that are climatically similar in the future to the climate currently occupied by broad vegetation types in the TWHHA. This enables changing suitability to be tracked under future climates.

4.1.2.1 Broad Vegetation Types

Harris et al. (2018) aggregated the numerous (>100) specific vegetation types described in TASVEG 3.0 into more manageable, landscape level categories. This has been used by the research team in previous projects and was accepted by the stakeholders as a reasonable approach. The members of the vegetation categories are described in Table 4.1.

Table 4.1: Listing of the vegetation types that are members of the Broad Vegetation Types used in this study (adapted from Harris et al., 2018). Use of the term Generic as a descriptor is intended as a catch-all for vegetation types with similar characteristics that do not fit into the other broad types.

Broad Vegetation Type	**TASVEG 3.0 VEGCODE**
Buttongrass	MBE; MBP; MBR; MBS; MBU; MBW; MRR; MSW
Generic	NBA; SAL; SCA; SED; SLS; SMP; SSC; SKA; GCL; GHC; GPH; GPL; GRP; GTL; SCH; SHW; SLG; SRH; SSZ; SCL; DBA; DGW; DMW; DVG; DOW; DKW; DPD; DPO
Eucalypt	DGL; DTO; DAC; DNI; DAM; DSG; DSO; DTD; DTG; DDE; DOV; DPU; DRI; DRO; DAS; DOB; DVC; DSC; DNF; DAD; WDB; WOB; WVI; WDA; WDL; WNL; WOL; WRE; WSU; WDU; WOU; WNU; WBR; WDR; WGK; WNR; WOR
Non-Eucalypt	NRL; NRV; NCR; NRR; NRD; NLM; NRF; NME; NBS; NLA; SBM; NLE; SSK; SWR; SBR; SRE; SLL; SLW; SMM; SMR; SWW
Sphagnum	GSL; MSP
Rainforest	RHP; RKF; RKP; RKX; RMU; RMT; RCO; RFE; RML; RMS; RSH; SRF
Subalpine	DCO; RKS; SHS; RPF; RPP; SSW; DDP; NLN; RPW
Alpine	HUE; HCH; RFS; HCM; HHE; HHW; HSE; HSW; MDS; MGH

An assessment or the appropriate climate envelopes over Tasmania was conducted using the Climate Futures for Tasmania (CFT) projections archive (Corney et al., 2010) as the input climate layers (it is intended to update this using the CFSEA archive in the near future) and TASVEG 3.0 as data input to a process using the R programming language. The method that was developed was applied over all of Tasmania (as opposed to just over the TWWHA).

4.1.2.2 Time periods

The climate projections were split into three periods: Historical, 1961-1990; Mid 2021-2050; and Future 2071-2100. These were used to compare the changes that may be expected in the climate envelopes into the two future periods compared to the current period.

4.1.2.3 Calculating the climate envelopes

Calculating the climate envelopes was a multi-stage process:

1. Determine input climate variables
2. Subset the data based on an input polygon (or shapefile)
3. Calculate statistics for each variable for each period of interest
4. Compare the statistics of each cell in the target region to every other cell in the comparison climate variable grid and return a *climatic difference* value
5. Determine the *climatic difference threshold value* for the variable of interest and use this to determine the spatial extent of 'similarity' for each input variable
6. Overlay each of the input variables to determine the spatial extent of 'multivariate similarity'

Determine input climate variables
A range of climate variables were tested, but those that were considered to be of greatest ecological significance, while also providing the greatest spatial differentiation at the scale of a 10 km grid-cell were temperature, precipitation and evaporation. We also investigated relative humidity and solar radiation but these appeared to be duplicating the influence of at least one of the previous three.

Subset the data based on an input polygon (or shapefile)
Using TASVEG 3.0, the extent of each broad vegetation type was used to define a single polygon. This was used to select the cells used for each comparison. Due to the resolution of the climate data, a decision was made to include (rather than exclude) more cells, to assume the largest domain of each broad vegetation type. Many cells contain more than one broad vegetation type, but this did not impact the analysis.

Calculate statistics for each variable for each period of interest.
The 1st through to the 99th percentiles were used to estimate the range and distribution of values of the input variables within region for the variable of interest. The monthly mean values were used to incorporate the seasonality of the variable.

Compare the statistics of each cell in the target region to every other cell in the comparison climate variable grid and return a *climatic difference* value
The similarity value was determined using this equation:

$$\sqrt{(((\sum |a_p - b_p|) / n_p)^2 + ((\sum |a_m - b_m|) / n_m)^2)}$$

Where:
a_p = array of percentiles of the the target variable in the starting period; b_p = array of percentiles of the variable in the period to which the starting period is to be compared; n_p = number of percentiles being compared; a_m = array of monthly means of the variable in the starting period; b_m = array of monthly means of the variable in the period to which the starting period is to be compared; n_m = number of monthly means being compared. Both a_p and b_p are arrays where the

dimensions are longitude, latitude and percentile. Both a_m and b_m are arrays where dimensions are longitude, latitude and calendar month.

This returns a full grid for every cell within the target polygon. This is summarised into a single layer by calculating the minimum value across all the input layers. This provides the largest (most optimistic) possible extent of the resulting climatic envelope.

Determine the *climatic difference threshold value* for the variable of interest and use this to determine the spatial extent of ‘similarity’ for each input variable.
The *climatic difference threshold* was developed for each of temperature (0.3^{o}C), evaporation (2 mm/day), rainfall (0.2 mm/day). Although the units of this threshold are the same as for each of the variables, they represent the units of the *climatic difference* values.

The *climatic difference threshold* was developed by comparing the historical climate statistics within the target polygon to the entire historical climate grid (including themselves). This allowed an appropriate threshold to be determined that reflects the existing conditions with which to test the impact of future climate conditions (the basic assumption being that the existing climate has some attributes that support the current vegetation). Some flexibility was provided such that each variable could represent a larger domain than that described by the input polygon. In all cases we were surprised to learn the difference required was so small.
A binary (0 or 1) mask was applied such that if the *climatic difference* value was below the *climatic difference threshold* value, the cell was similar (similar = 1), otherwise it was not (dissimilar = 0). This was determined for each of the input variables.

Overlay each of the input variables to determine the spatial extent of *multivariate similarity*.
The similarity masks were then overlaid to determine the *multivariate similarity*. The resulting output for each cell in the grid indicates if it is similar to none, one, many or all of the input variables, labelled as *Consistent Climatic Variables Categories*: none “---”; one “--E”, “-R-” or “T--”; many “-RE”, “T-E” or “TR-”; and all “TRE” (where E=evaporation, R=rainfall, T=temperature). This describes if the cell will have a similar climate, and if only partially the same in which way it will be similar. This helps users identify at risk elements within the landscape.

4.1.2.4 Availability of the method

This process has been written as a package in R which will be submitted and published through CRAN, freely available for anyone to use. There are also plans for an accompanying publication describing the method.

4.1.3 Results and Discussion

Below are the maps that describe the climate envelopes for each of the broad vegetation types. There are differences within the details of each different CMIP3 model projection, however, there are four key points across all models and all broad vegetation types.

The Tasmanian climate becomes dissimilar to the current climate in the mid-term future, mostly driven by moisture balance changes in almost every location across Tasmania. The similarities decrease dramatically into the far future, driven by warming temperatures. There are very few, if any climate analogues in adjacent or alternative regions, even in the near-future, providing little opportunity for climate-sensitive species to disperse into more suitable climates in nearby regions. This dramatic climate pressure is due to the change of multiple variables simultaneously, in non-complementary directions. Increasing heat is compounding a drying trend in most areas. This is particularly evident when comparing those broad vegetation types that are present over almost all of Tasmania, where the size of the historical extent is not limiting, yet they have almost no climate analogues by the end of century.

Temperature is the least sensitive variable to climate change. Evaporation and rainfall appear to have greater influence than temperature on the extent of the climate envelope, especially in the near future (although this could be a function of the thresholds used and requires further investigation).

Buttongrass, eucalypt, non-eucalypt and generic broad vegetation types are not expected to be limited in extent by climate related variables due to their wide distribution across multiple climate regimes. Although the climate envelopes they currently inhabit are expected to decrease in size and change in shape (quite dramatically), as they do not appear to be particularly sensitive to climatic factors, it is expected other ecological factors will drive changes in these communities (e.g. the occurrence, or frequency of fire).

In contrast, alpine, subalpine, sphagnum and rainforest broad vegetation types are likely to be more susceptible to changes in climate, and their extent is projected to decrease dramatically over the coming 20-50 years. It must be noted, the resolution of the climate projections is a significant drawback of this method. It is clear it does not capture the vegetation communities at the resolution that is relevant to them. However, the trend across the Tasmanian Landscape is clear. Although the number of refugia will no doubt be larger and more distributed than presented here, they will be of significantly reduced extent than the existing domains.

The method highlights some small locations that may offer longer term refugia for the current vegetation communities, especially in the far south, and the high elevation regions of the south-east. These regions are distributed across high elevation and long elevation regions and are worth further investigation. Further investigation using climate data at higher spatial resolution (possibly by taking advantage of the new statistical downscaling techniques developed by Matt Webb at DPIPWE), and using targeted TASVEG3.0 vegetation communities (rather than aggregations) would provide much more useful information for land managers.

4.1.3.1 Buttongrass

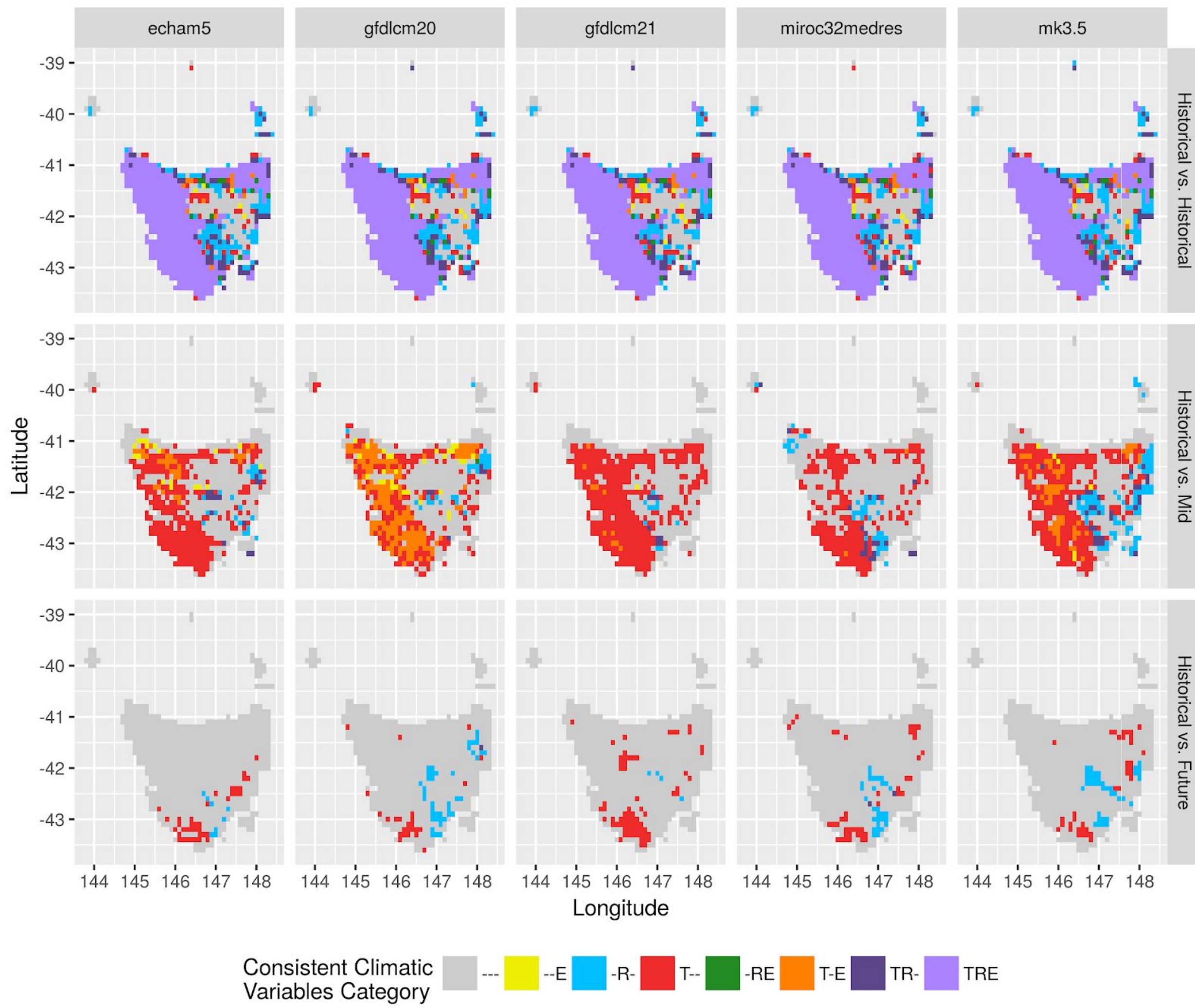

Figure 4.1: Buttongrass climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The buttongrass vegetation type is not expected to be limited by climate, as its members occupy a broad range of climates at present, thus it is expected to be limited by other ecological factors.

4.1.3.2 Generic

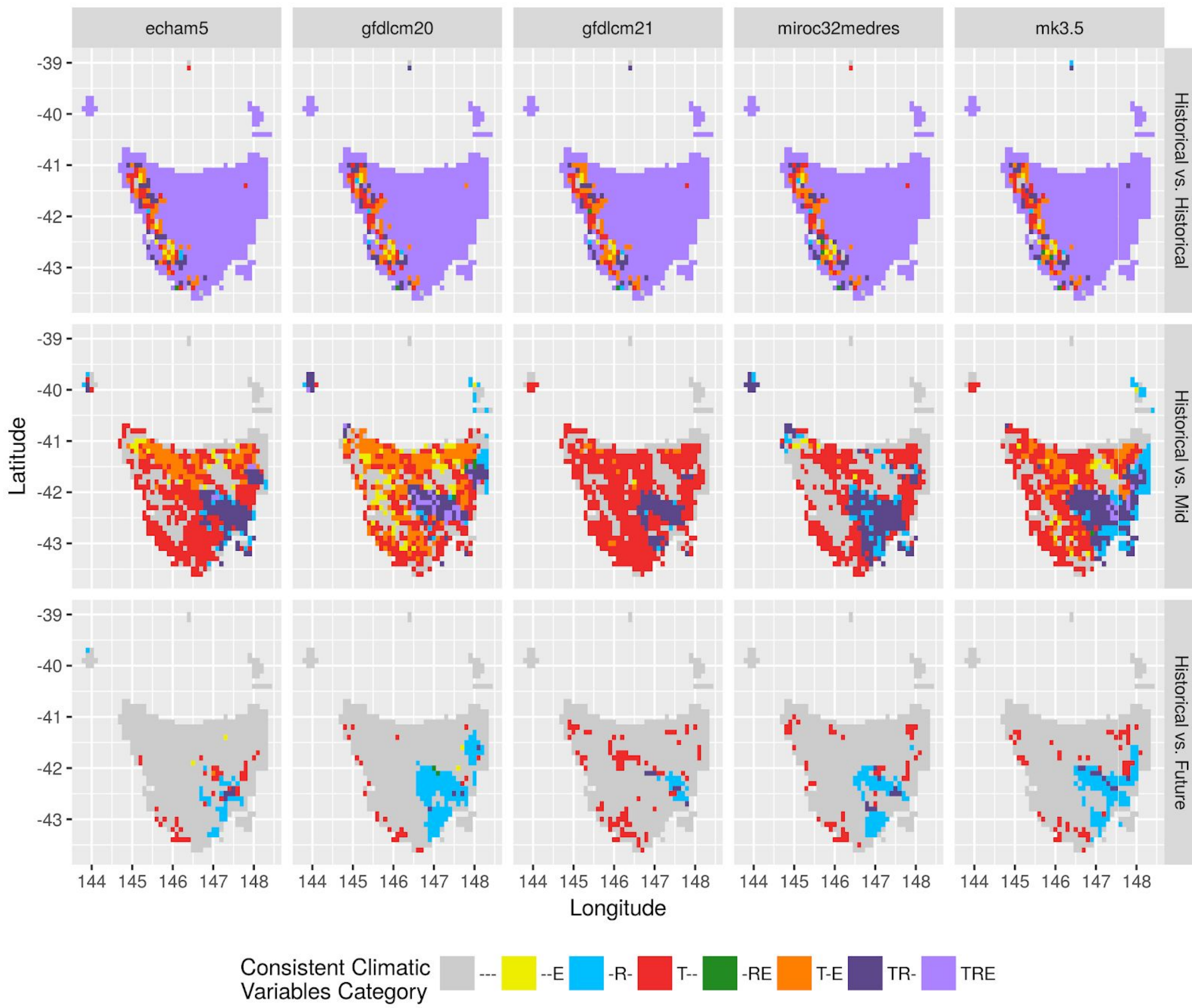

Figure 4.2: Generic climate envelope as described by each model within the CFT archive projections, for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The generic broad vegetation type is not expected to be limited by climate as the members are a diverse range of vegetation communities found across a broad range of climates in the present. Although some of the members may be limited by climatic factors, it is expected these communities are limited by other ecological factors, not strongly linked to climate.

4.1.3.3 Eucalypt

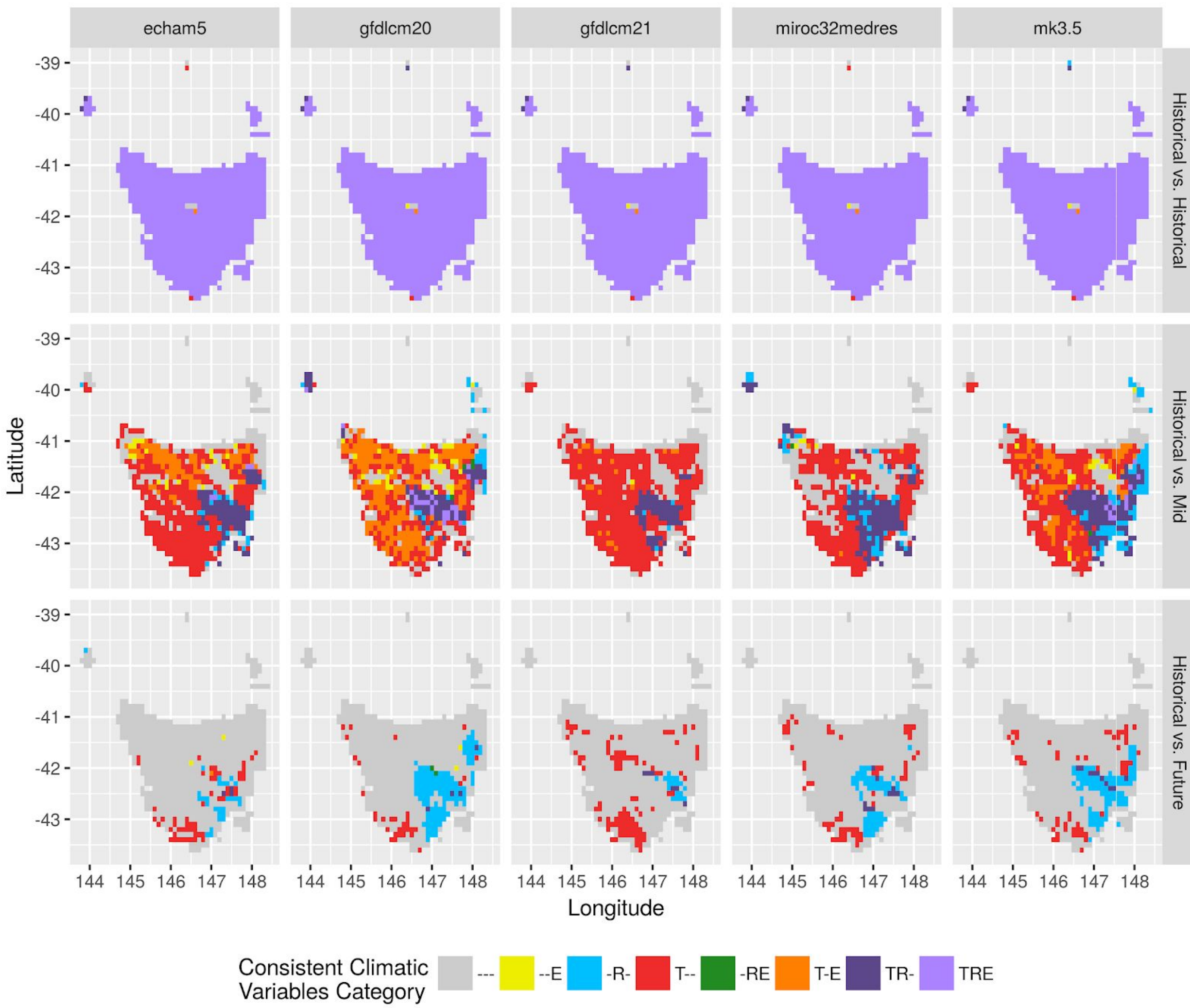

Figure 4.3: The eucalypt climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The eucalypt broad vegetation type is the most widely distributed, covering all of Tasmania. It is not expected to be limited by climate given the wide range of climate these communities inhabit across Australia at present, thus it is expected to be limited by other ecological factors.

4.1.3.4 Non-Eucalypt

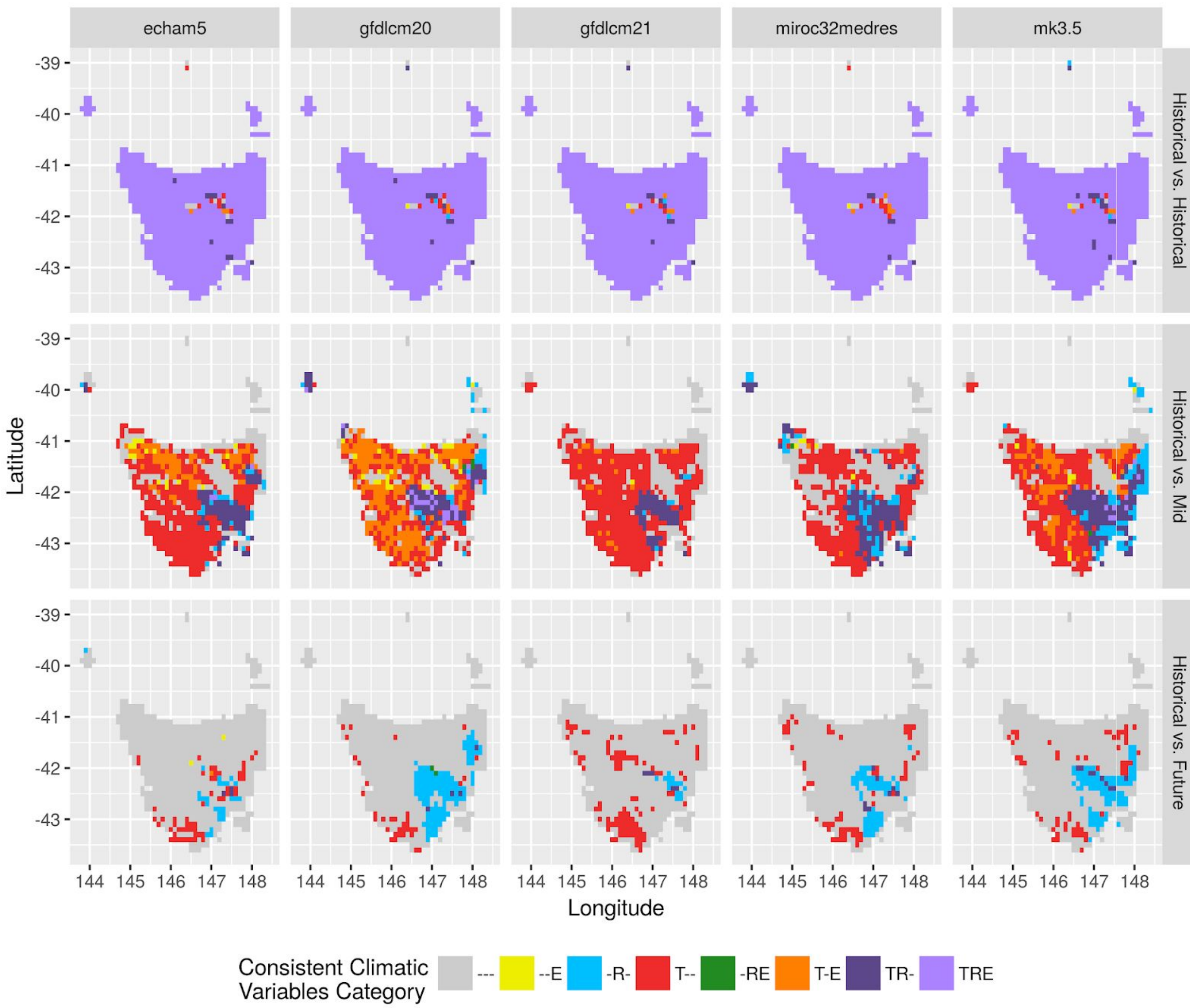

Figure 4.4: The non-eucalypt climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The non-eucalypt broad vegetation type is widely distributed, covering all of Tasmania. It is not expected to be limited by climate given the wide range of climate these communities inhabit across Australia at present, thus it is expected to be limited by other ecological factors.

4.1.3.5 Sphagnum

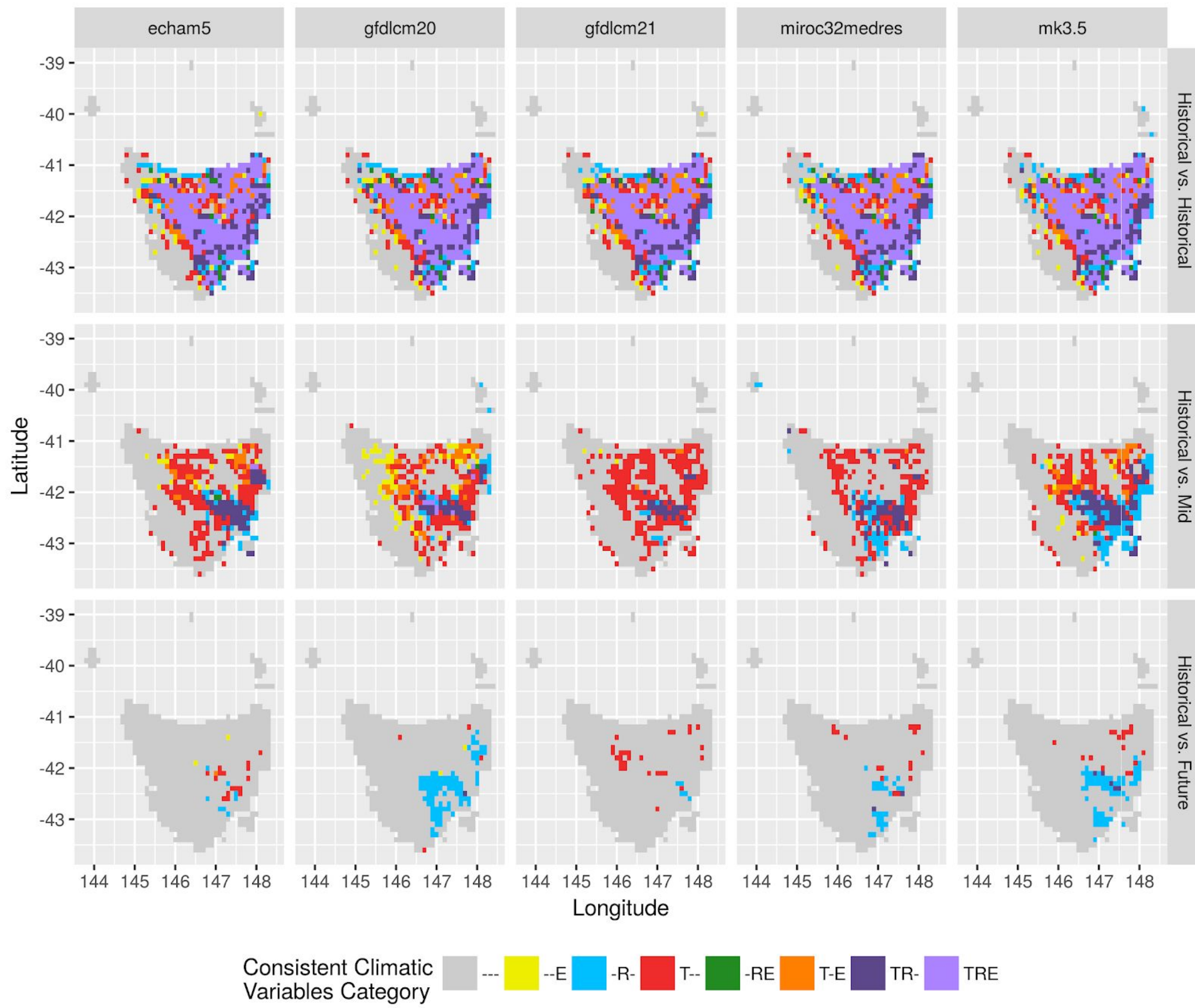

Figure 4.5: The sphagnum climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The sphagnum broad vegetation type is widely distributed across the central highlands. Given its apparent dependence on low temperatures and high moisture levels, the projected reduction in the extent of the climate envelope may place pressure on these communities. This study suggests it is a change in each of temperature, rainfall and evaporation that may influence the sphagnum vegetation type.

4.1.3.6 Rainforest

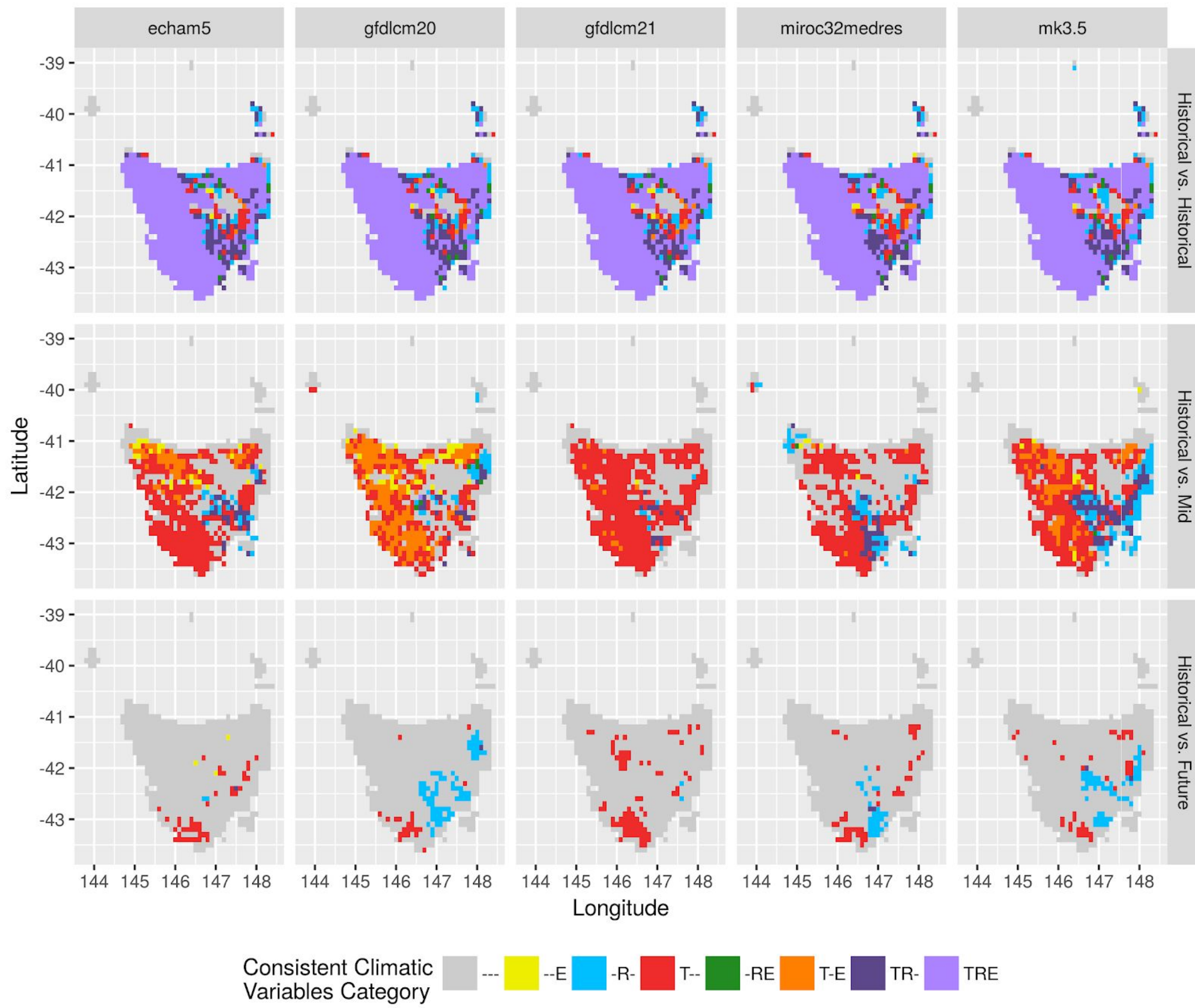

Figure 4.6: The rainforest climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

The rainforest broad vegetation type is the widely distributed across the western half of Tasmania. Given its dependence on high moisture levels, the projected reduction in the extent of the climate envelope may place pressure on these communities. Any climatic threat to these communities will be through a reduction in rainfall and increase evaporation, rather than an increase in temperature (as described by this approach).

4.1.3.7 Subalpine

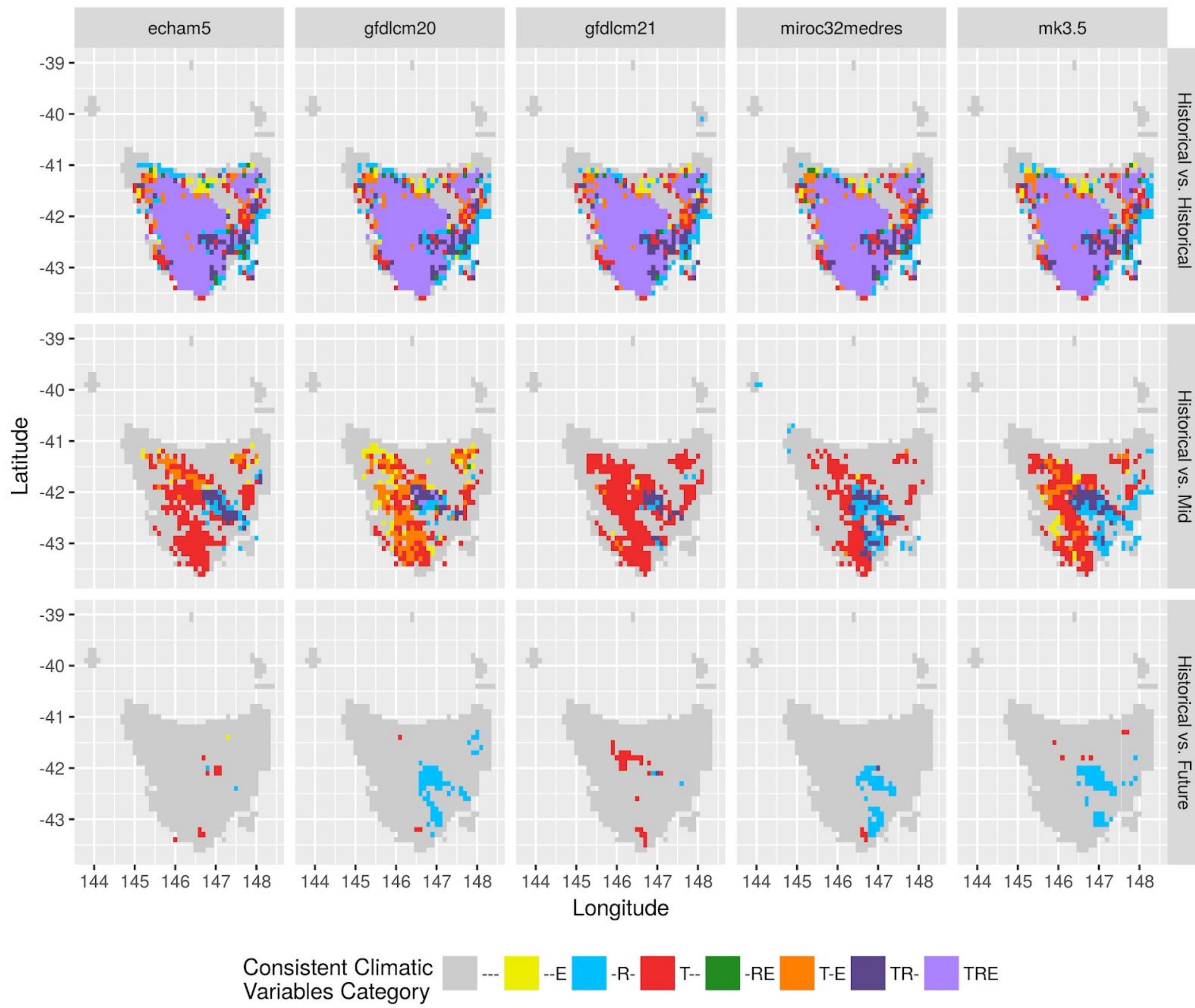

Figure 4.7: The subalpine climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

This approach grossly overestimates the current extent of the subalpine broad vegetation type, as it is only a very small percentage of each of the cells it is found within. Regardless of this unavoidable error, given its dependence on relatively low temperatures and high moisture levels, the projected reduction in the extent of the climate envelope is expected to place pressure on these communities. However, the greatest climatic threat to these communities is projected to be through a reduction in rainfall and increase in evaporation, rather than increasing temperature (as described by this approach).

4.1.3.8 Alpine

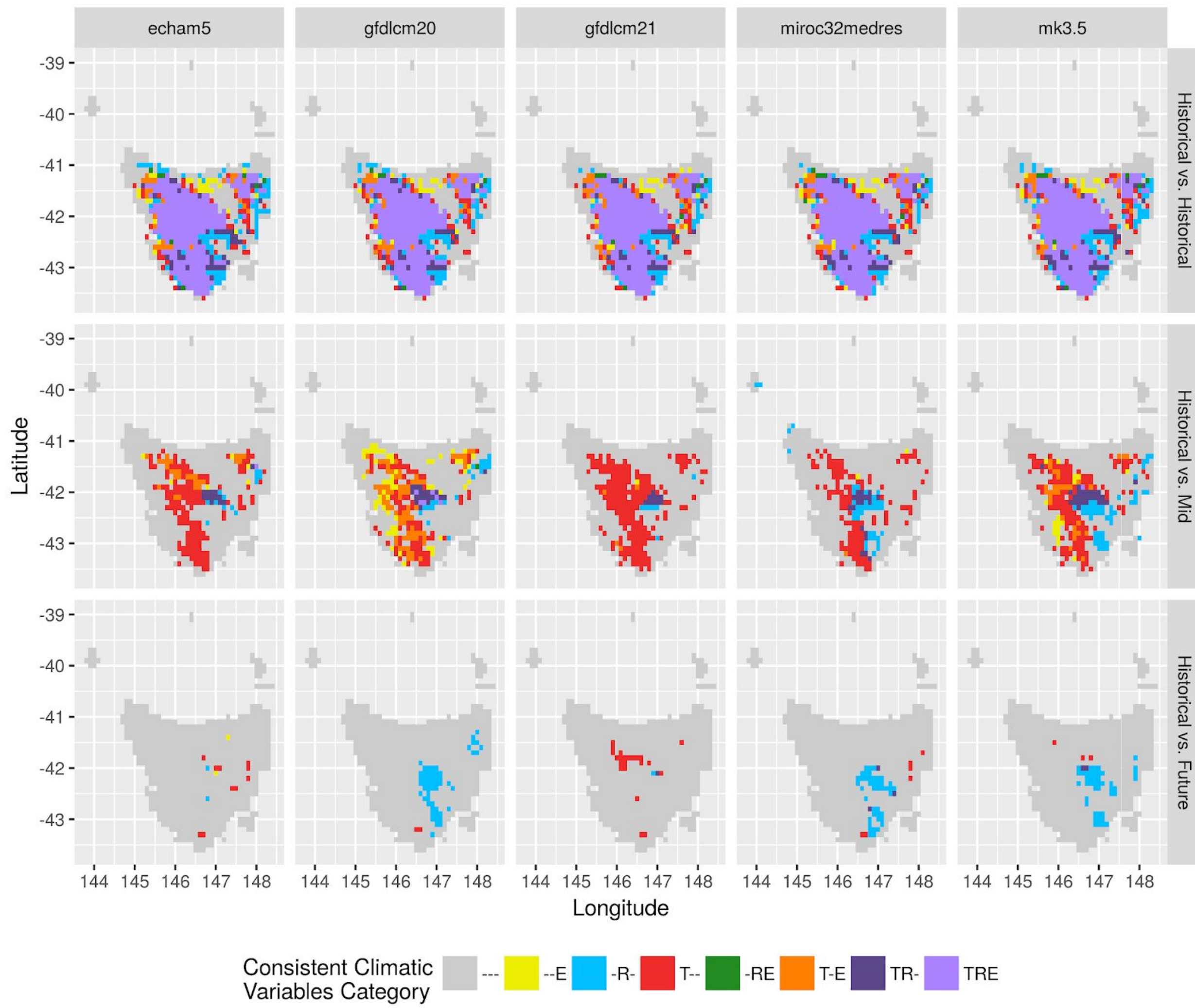

Figure 4.8: The alpine climate envelope as described by the CFT archive models for each of the three time period comparisons: historical vs. historical (itself); historical vs. mid and historical vs. future.

This approach grossly overestimates the current extent of the alpine broad vegetation type, as it is only a very small percentage of each of the cells it is found within. Regardless of this unavoidable error, given its dependence on the lowest temperatures anywhere in the state, along with high moisture levels, the projected reduction in the extent of the climate envelope is expected to be real, with a climate pressure expected on these communities into the future. However, the greatest climatic threat to these communities is projected to be through a reduction in rainfall and increase in evaporation, rather than increasing temperature (as described by this approach).

4.2 Prioritisation of Natural Assets as Targets for Hazard Reduction by Planned Burning

This study indicates the climate envelopes of all species, communities and landscapes is going to dramatically change into the future. Any specific areas of refugia, such as valleys and gullies (not captured in this study) are likely to become more important as climate change accelerates. The results here are indicative only, but present managers with an improved understanding of the magnitude of change that may be expected in the future.

An assessment of current natural assets and the identification of those that are ecologically at risk of dramatic climate change may assist managers to identify the best spread of resource allocation. As mentioned, this would be further assisted by applying this methodology at a finer spatial resolution.

5 Project Outputs

5.1 Updated and Expanded FIRESCAPE-SWTAS Model

FIRESCAPE-SWTAS has been updated in accordance with the project objectives. Three main changes from previous versions of FIRESCAPE-SWTAS are the expansion of the model domain to include the entire TWWHA, updating all input GIS data, and application of gridded weather data from regional historical weather reanalysis and regional climate models. In order for FIRESCAPE-SWTAS to be a useful tool for TWWHA fire managers the current developmental PWS planned burning strategy has been incorporated into the model. FIRESCAPE-SWTAS will assist in the development of planned burning strategies by simulations testing the relative effectiveness of variations to treatment levels, resourcing, burn units and rotation schedules. Analysis will be based on model output statistics, examples of which are described in the following sections.

5.1.1 Protection of Built, Natural and Cultural Heritage Assets Within TWWHA

For each simulation FIRESCAPE-SWTAS outputs detailed summaries of each fire. In addition several statistical summaries are computed for each cell in the domain and output as gridded data. The most fundamental of these statistics is the number of fires occurring within the duration of the simulation. An example of the gridded fire count statistics is given in Figure 5.1 for a 200 year simulation under current climate conditions. In this simulation no planned burning has been included and fires are attributable to only lightning ignitions. The related statistic of average fire frequency is shown in Figure 5.2.

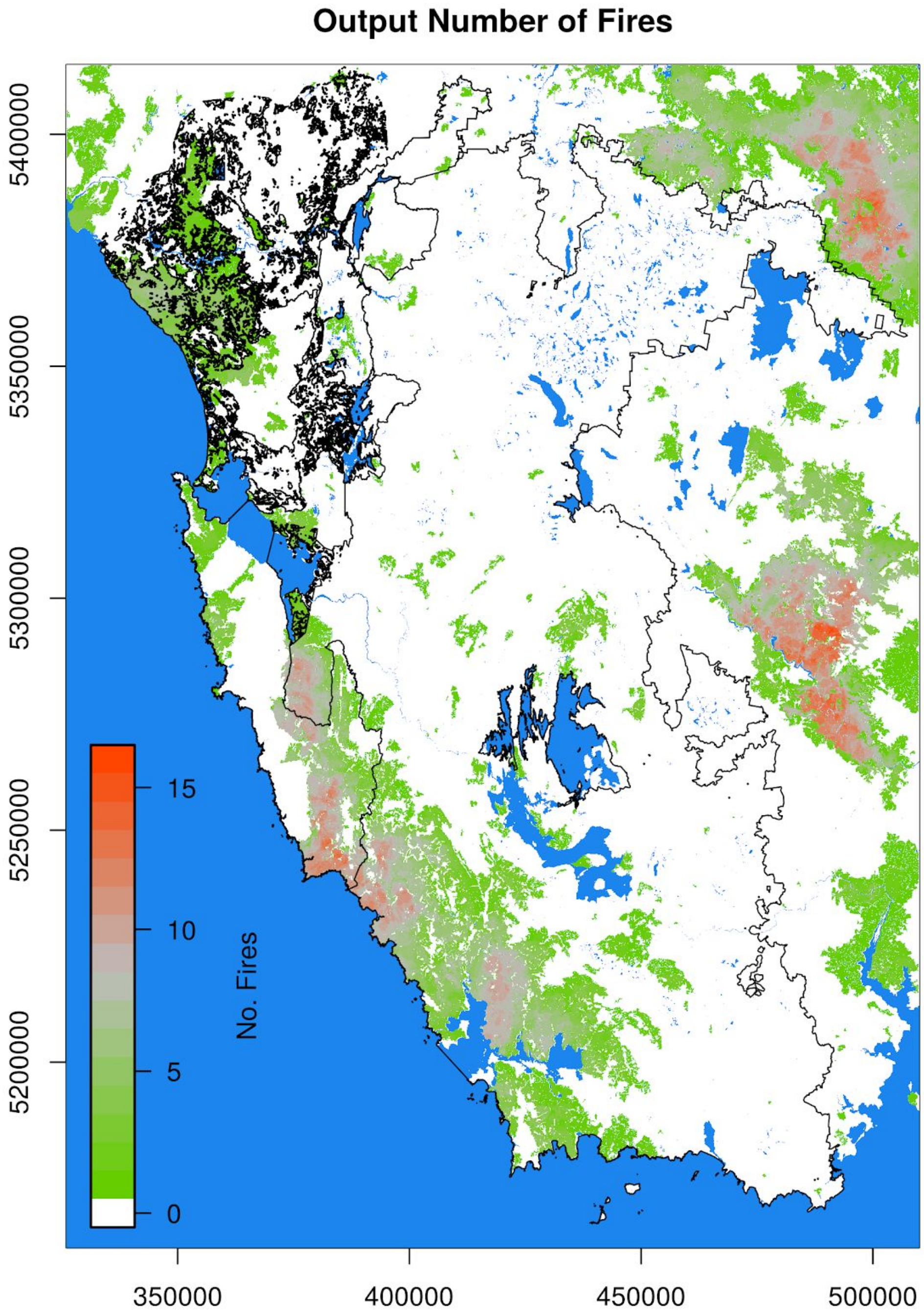

Figure 5.1. Model output data indicating the number of lightning ignited fires that occurred in each grid cell during a simulation.

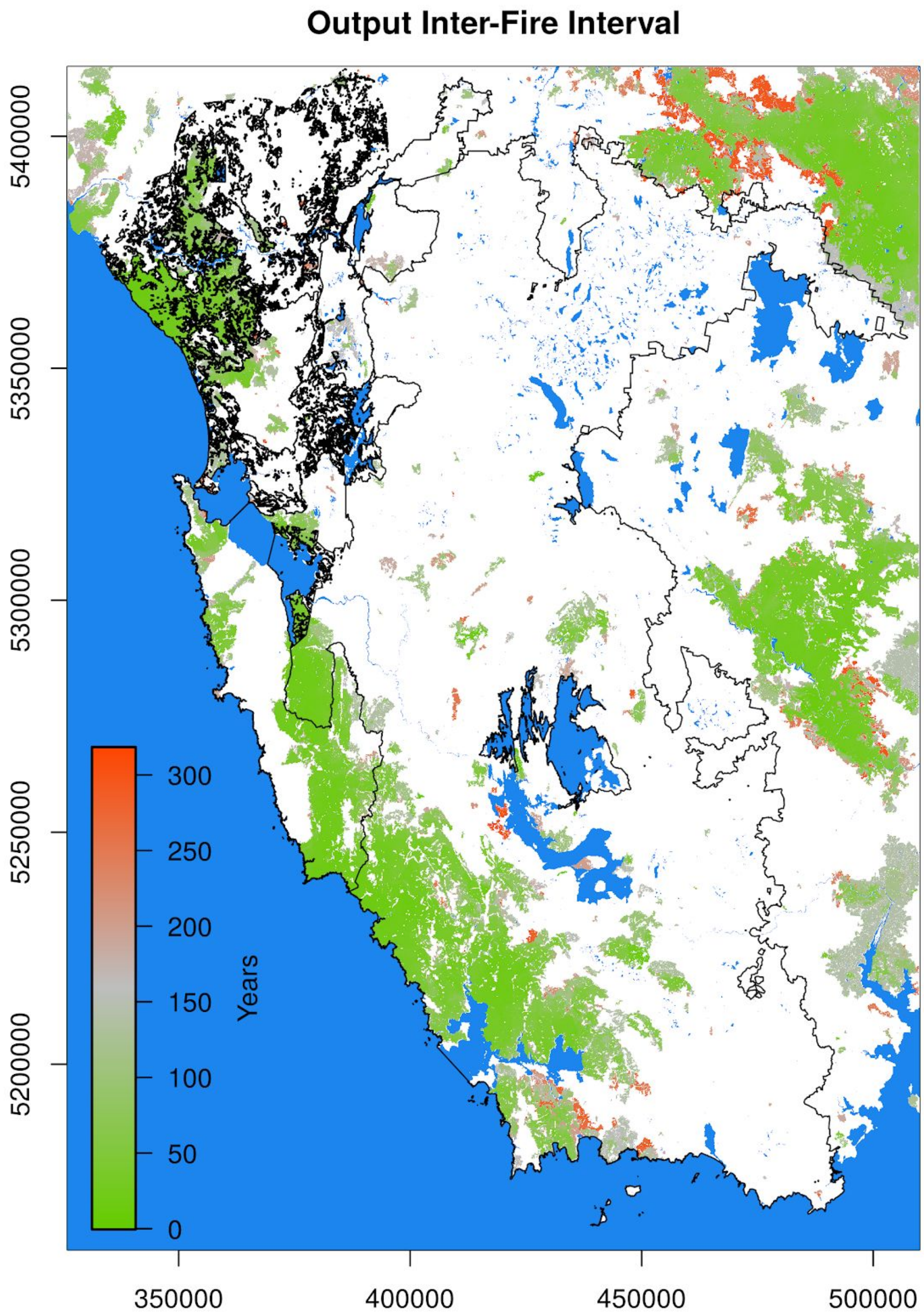

Figure 5.2. Model output data indicating the average number of years between fires (inter-fire interval) in each grid cell during a simulation.

The distribution of simulated fires within the TWWHA and Adjacent Areas, mostly occurring in buttongrass moorlands, is fairly consistent with the observed fire history input to FIRESCAPE-SWTAS (Figures 3.3 and 3.4) noting the different time periods and difficulties in collating an accurate fire history for such a remote area with limited recorded history.

When the simulation is repeated with the same parameters and the PBS implemented the gridded outputs can be compared. Figure 5.3 shows the difference between the number of fires in each grid cell simulated in the lightning ignition only simulation (Figure 5.1) and number for the same simulation repeated with the PBS implemented. Red regions indicate areas where more fires occur due to the implementation of the PBS while blue areas indicate a reduction. The figure depicts a small subdomain located along the boundary of the TWWHA and Adjacent Areas to highlight some of the differences on the scales as small as individual grid cells. Burn unit boundaries are indicated by black lines.

As expected, significant changes to the fire regime are effected by the PBS. In burn units incorporating significant or fortuitously located portions of wet scrub or other potential disruption that frequently limit the spread of naturally occurring fires, treatment by planned burning increases the fire frequency. In some other burn units planned burning decreases the fire frequency, while in others there is little change. The predominant effect on fire occurrence outside of the burn units is to significantly reduce the frequency of fire in regions adjacent to burn unit boundaries. Restricting the analysis to the incidence of unplanned fires gives a measure of the effectiveness of the PBS.

Similar gridded statistics for average and maximum fire intensities are output by FIRESCAPE-SWTAS for comparative analysis in a similar manner. In this way ensembles of simulations can provide estimates of probability of fire and potential fire intensity in asset zones. Systematic intercomparison of other simulations implementing variations of the PBS can be used to identify treatment levels and other characteristics of the PBS necessary to meet the management objective of safeguarding built, natural and cultural heritage assets.

Assessment of the effectiveness of the ecological management burns at meeting the objective of maintaining biodiversity and special habitats for fauna and regenerating plants can be made by analysis of model outputs relating to fuel age and vegetation type. While impacts on fauna cannot be directly assessed, the simulated mosaic of vegetation age can be tested against the range defined by the ecological requirements of both flora and fauna in relevant areas. Simulated changes to the proportion and distribution of vegetation types as a result of succession pathway transitions can be used to assess how well different variations of the PBS maintain the range of vegetation communities and successional stages within communities.

Distributions of simulated unplanned fire size and intensity can be compared between variations of the PBS to assess the effectiveness of strategic fuel reduction at meeting the objective of minimising the risk of unplanned fires reaching large sizes.

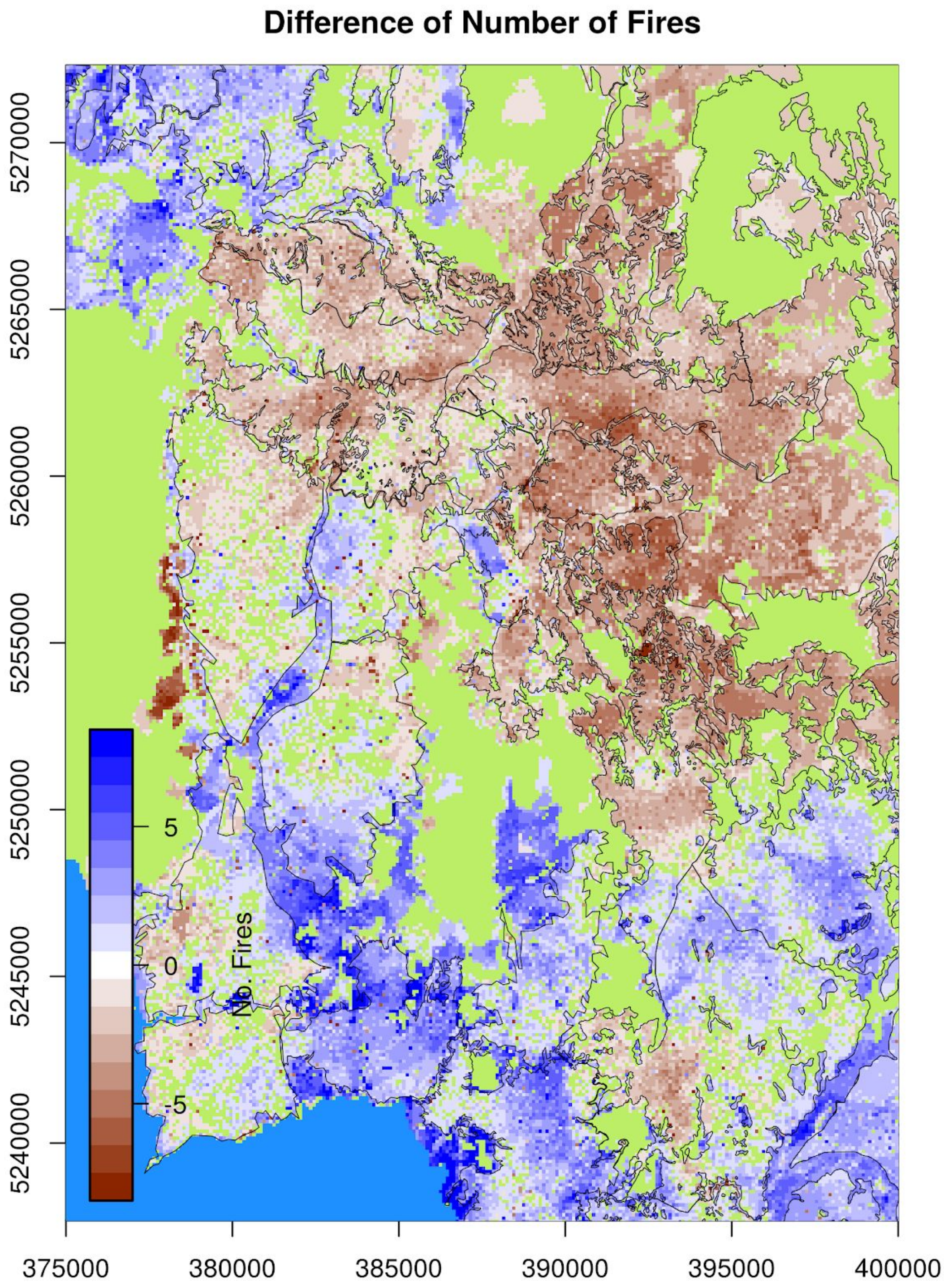

Figure 5.3. Difference between the number of fires occurring in simulations with and without the planned burning strategy in place. Red regions indicate increased number of fires with planned burning, blue regions indicate a reduction. Black lines mark the boundaries of the planned burn units. Significant areas outside of but adjacent to burn unit boundaries show a strong reduction in fire numbers.

5.1.2 Effectiveness of Planned Burning Strategy Under Projected Climate Change Scenarios

Previous analyses utilising FIRESCAPE-SWTAS of the effects of climate change on the fire regime in south-western Tasmania have employed long duration simulations in contrasting steady state climates. The long duration simulations were achieved by looping time series of observed weather. In the simulations of future climate, observed weather time series were adjusted by statistical estimates of changes to the distributions of daily weather parameters.

Long duration steady state climate simulations can be undertaken with the updated FIRESCAPE-SWTAS configuration with the significant improvement of utilising gridded weather time series observations and most significantly gridded time series projections of future weather under different climate change scenarios. In addition to running steady state simulations by looping historical or projected weather, the climate projections provide long continuous weather time series from historical periods through to the end of the current century capturing the progressive alteration of weather projected through this period. Running FIRESCAPE-SWTAS simulations with these data will similarly capture progressive changes to the fire regime in the TWWHA and Adjacent Areas. Robust statistics can be derived by repeating simulations across the ensemble of RCM simulation outputs.

5.2 Climate Suitability Layers

Climate suitability envelopes have been calculated with complete coverage across Tasmania for broad vegetation groups. These have been presented as maps for each group depicting the suitability of the climate at each CFT grid cell with respect to climate difference thresholds of temperature, evaporation and rainfall. Maps are presented for suitability under current historical conditions and projected mid-century and end-of-century climate.

The software developed for this analysis will been made public through CRAN as an open source package for ongoing use and development.

5.3 Planned Burning Index - Climatology and Projections

In the development of the model implementation of the PWS planned burning strategy an opportunity was identified to provide a quantitative assessment of the projected changes to the number of days per year that are suitable for executing planned burns. As noted in Section 3.4.3, the weather criteria listed in Marsden-Smedley (2009) defining conditions appropriate for the various classifications of planned burning can be applied to gridded weather reanalyses and climate projections. In this way gridded statistics can be generated of the theoretical number of days suitable for planned burning under recent climate conditions and under different climate change scenarios.

For each day in the gridded weather data being analysed, each criteria is tested at each grid cell and assigned a true or false result. If all of the criteria for a given grid cell are true then that grid cell is assigned a value of true for that day, otherwise a value of false is assigned. This true/false assignment for each grid cell for each day of observed or projected weather data is referred to here as the prescribed burning index (PBI). Counting the number of days on which the PBI is true at each cell within a given period, e.g., decadal, will permit comparative analysis of present versus future planned burning opportunity. Other PBI statistics, such as the interannual variability in planned burning opportunity, could also be useful for fire management planning.

The weather criteria defined in Marsden-Smedley (2009) are guidelines only and the implementation of each planned burn is subject to specific management objectives and expert knowledge. However, on a statistical basis the quantitative changes to the PBI will be a good indication of changes to opportunities for planned burning in the future. The calculation of these gridded data for buttongrass moorlands using the CFSEA climate projections is underway and will be delivered to PWS fire managers upon completion. Preliminary results indicate a decrease in the number of days per year on which the weather is suitable for planned burns decreases throughout the century.

5.4 Dry Lightning Occurrence - Climatology and Projections

Similar to the PBI, in the development of the lightning parameterisation for FIRESCAPE-SWTAS it became evident that a climatology of dry lightning occurrence and projections of how that climatology would change under different climate change scenarios, would be a useful stand alone tool for PWS fire managers. Love et al., (2017) calculated projections of lightning potential environment using the CMIP3 based CFT climate projection data, finding that the frequency of DLPE is in general projected to steadily decrease in the future. The analysis was carried out at six-hourly temporal resolution as TWWHA averaged statistics. The calculation of DLPE using the CMIP5 based CFSEA climate projections and BARRA reanalysis at hourly time steps is currently underway. A climatology of the spatial distribution of DLPE and projected changes under different climate change scenarios will be delivered to PWS fire managers on completion. Preliminary results indicate that the spatial distribution of dry lightning occurrence probability is not projected to change significantly in the future as shown in Figure 5.4. The general frequency of dry lightning occurrence based on CFSEA data is projected to decrease, consistent with the CFT projections.

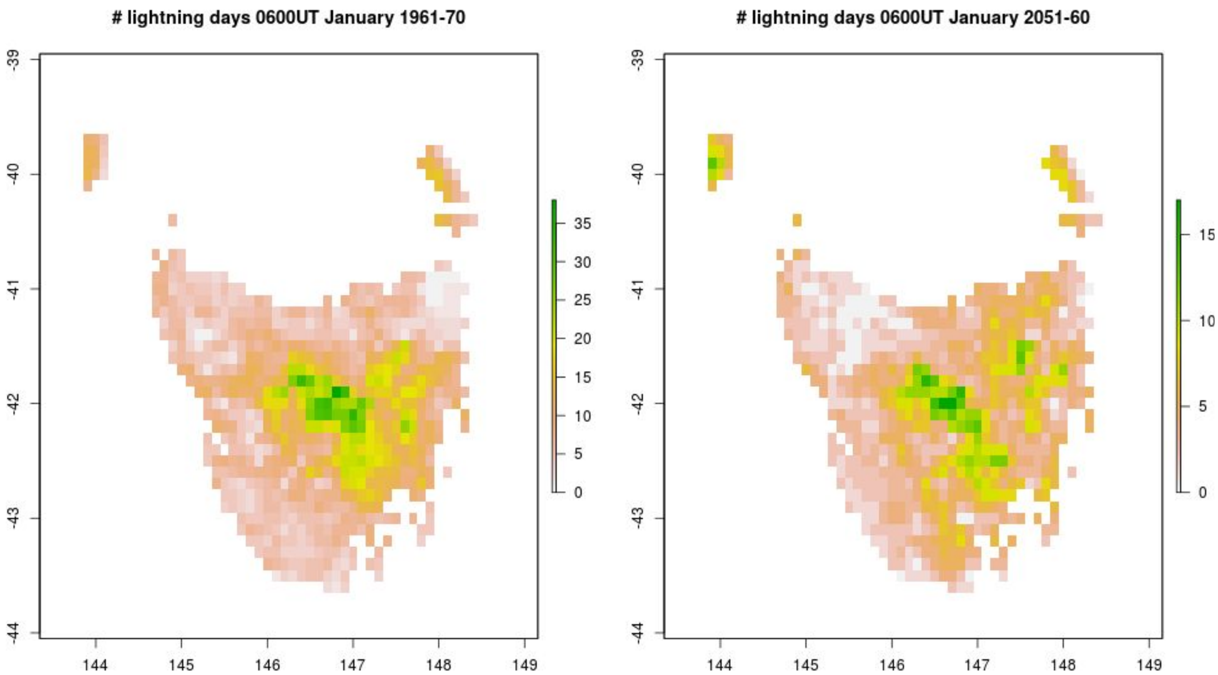

Figure 5.4. Number of January days per decade on which lightning could occur as determined by the dry lightning potential environment index based on climate projection data from historical (left) and mid-century (right) time periods. Spatial patterns are quite similar but note the different scales.

5.5 Soil Productivity Map

The production of a soil productivity map by DPIPWE Natural and Cultural Heritage Division as an input layer for FIRESCAPE-SWTAS is an incidental but important project output. Given that no such digital data set is currently available this is an important addition to fire regime and ecosystems data available for modelling and other analytical studies.

6 Ongoing Model Development

6.1 Context

The objectives and activities of the Climate Change and Bushfire Research Initiative have been identified as having strong links with those of the Assessment of the Viability of Planned Burning as a Management Tool Under a Changing Climate project, funded by the Tasmanian Bushfire Mitigation Grants Program (TBMGP), which recently commenced, also at ACE CRC. With PWS a key stakeholder in both projects and FIRESCAPE-SWTAS a necessary tool for both projects, it is anticipated that there will be a near seamless continuity of both research activities and stakeholder engagement. The outcomes of the CCBRI will be enhanced as the TBMGP funded project builds directly on the achievements documented in this report. This will involve the comprehensive application of FIRESCAPE-SWTAS to simulate and assess the effectiveness of PWS planned burning strategies together with further development of the FIRESCAPE-SWTAS model itself. Ongoing development activities are discussed in detail in the following sections.

6.2 Vegetation Succession Pathways

During the time since the vegetation succession pathways were implemented in the original FIRESCAPE-SWTAS, the growing body of observational data and theoretical interpretations has increasingly demanded an update to this aspect of the model. As in previous applications of FIRESCAPE-SWTAS the model itself can be used as a tool to investigate different variations of vegetation succession theory.

A relatively simple adaptation of the existing scheme has been provided by J. Marsden-Smedley (personal communication, 2018) and is presented in figures 6.1, 6.2 and table 6.1.

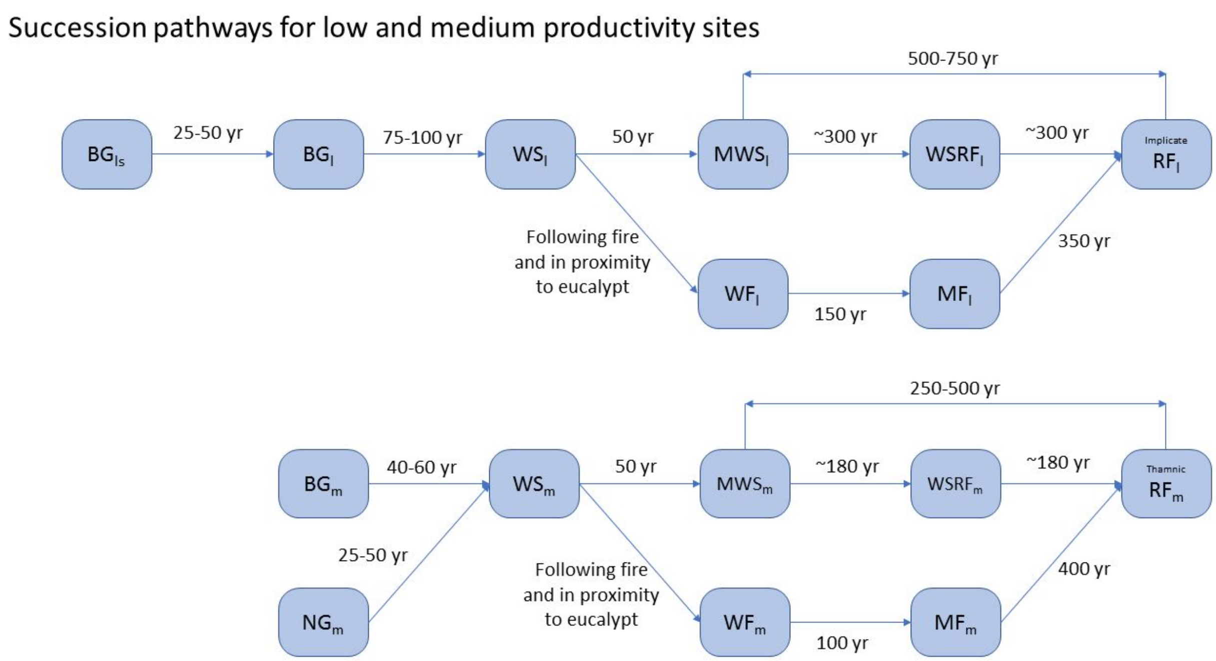

Figure 6.1. Succession pathways for low and medium productivity sites. Subscript l denotes low productivity, subscript m denotes medium productivity, and subscript s denotes sparse.

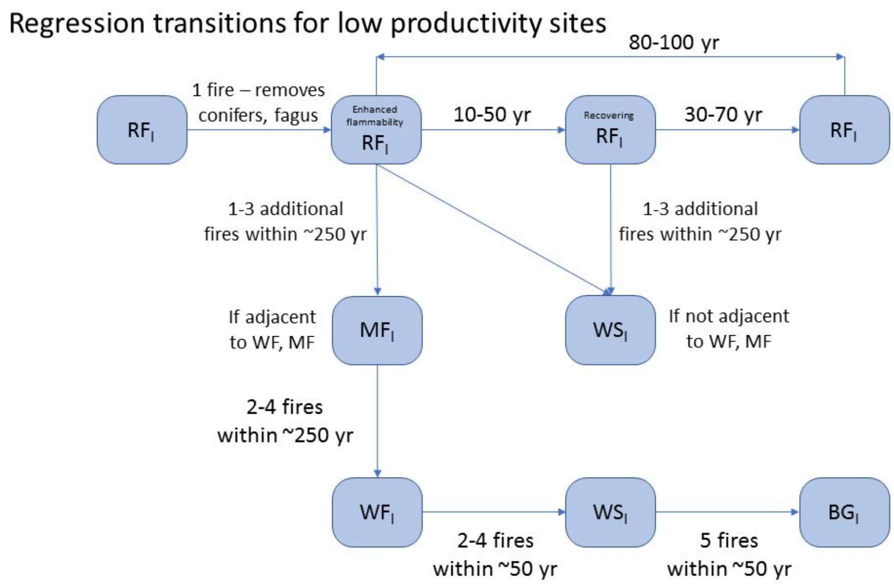

Figure 6.2 Regression transitions in response to fire for low productivity sites.

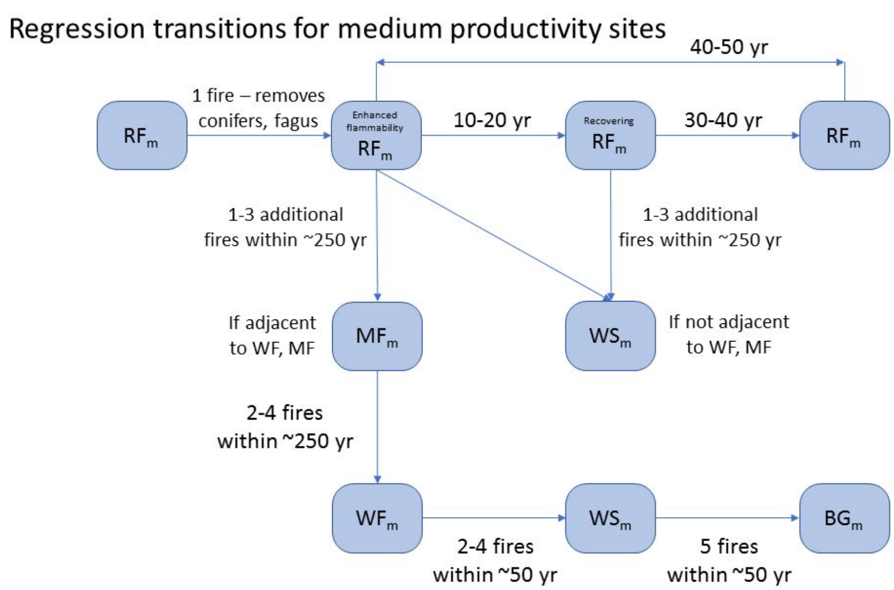

Figure 6.2 (cont.) Regression transitions in response to fire for medium productivity sites.

Table 6.1 Abbreviations used in vegetation succession/regression diagrams in figures 6.1 and 6.2.

Abbreviation	Veg type	Abbreviation	Veg type
BG	Buttongrass	NG	Native Grassland
WS	Wet Scrub	WF	Wet Forest
MWS	Mature Wet Scrub	MF	Mixed Forest
WSRF	Wet Scrub/Rainforest	RF	Rainforest

The first phase of the Assessment of the Viability of Planned Burning as a Management Tool Under a Changing Climate project (now completed, funded by the National Bushfire Mitigation - Tasmanian Grants Program) developed a vegetation model (hereafter VM) for Tasmania to investigate the changes to broad vegetation types that may result from the interaction between climate change and frequency of burning. The VM incorporates separate vegetation succession/regression pathways for eight broad vegetation groups, determined from a review of the literature (Harris et al., 2018).

FIRESCAPE-SWTAS has been identified as a possible alternative or supplement to the VM in achieving the objectives of the current phase of the (TBMGP funded) project. To this end, the more detailed succession model will be implemented in FIRESCAPE-SWTAS, replacing the current scheme. This will involve changing the 12 vegetation types currently implemented to the 63 vegetation types that make up the 8 broad groups in the VM.

Ongoing refinement and testing of these groupings and pathways is likely to continue in the near future in order to achieve consensus. For example it has been suggested that grouping GSL into Sphagnum communities could be misleading since it has a much broader climatic distribution. Questions such as this will be discussed at a workshop on the topic that is due to be held in Hobart in 2019.

6.3 Model Domain

The updated inputs described in Section 3.2 have all been sourced from GIS data layers with coverage of the entire state of Tasmania. Together with the ingestion of gridded weather data, this yields the possibility of running FIRESCAPE-SWTAS over any arbitrary domain within the state. While simulations in agricultural, silvicultural and urban areas would require significant additional model development, the potential exists for fire regime simulation and prescribed burning impact analysis in other parks and wilderness areas across the state. The model domain boundaries can become a user configurable parameter under the modifications described in Section 6.6.

6.4 Fire Spread Algorithms

FIRESCAPE-SWTAS has a modular system for calculating the rate of spread within different vegetation types. Whenever fire spread calculations are necessary within a given grid cell the vegetation type for that cell is used to determine which of three fire spread routines currently implemented is called to execute the calculations. Work is under way to update or replace the existing modules, and to add new modules to improve the specificity of the fire spread calculations.

Considerable work has been done on fire rate of spread models for different vegetation types across Australia since development of FIRESCAPE-SWTAS. A recent review of fire spread models by Cruz et al. (2015) also included evaluations of each model and recommendations on which models represent the best science available and which are outdated. Among the recommendations are the results of Vesta project, conducted by CSIRO and the Western Australian Department of Parks and Wildlife. This project determined new fire spread equations for dry eucalypt forests to replace those of McArthur, the latter currently being used in FIRESCAPE-SWTAS. Corrections for these are also available so that they are applicable to tall wet eucalypt forests which can be included in FIRESCAPE-SWTAS as a new module for this vegetation type which currently relies on the McArthur fire spread model. The heathland and wet scrub fire behaviour model of Catchpole et al. (1998) and Marsden-Smedley (2002) has been superseded by Anderson et al. (2015). The New Zealand Fire Behaviour Prediction System, which is based on the Canadian Forest Fire Behaviour System, includes a fire spread model for podocarp forest that can be adapted to Tasmanian rainforest.

An alternative approach (beyond the scope of any currently funded research) would be to replace the modular fire spread system currently implemented by integrating a more sophisticated fire behaviour model such as Spark into the FIRESCAPE-SWTAS framework. While the computational demands would be significantly higher, the necessary resources are available and the level of realism in the model and therefore the confidence in the results from FIRESCAPE-SWTAS would be greatly enhanced, while also providing an alternative way to use Spark.

6.5 Fuel Accumulation

The fuel accumulation algorithms and parameter values specific to each vegetation type are currently under review based on recent research since the development of FIRESCAPE-SWTAS. Further changes will be dictated to some extent by other aspects of FIRESCAPE-SWTAS development described in the preceding sections.

Implementing the succession pathways of the VM (Section 6.2) will require the implementation of the fuel accumulation parameters relevant to the updated vegetation types. Since these parameters were determined for the VM as part of the recent review, the adaptation would be very simple. Improvement to the continuity of fuel accumulation across transitions in vegetation type based on the vegetation succession pathways should also be undertaken.

The implementation of new rate of spread algorithms will in some cases require the implementation of corresponding fuel accumulation algorithms. For example, the Vesta fire behaviour model for dry eucalypt forest is based on fuel hazard ratings for surface, near-surface, elevated and bark fuel accumulation.

6.6 Configuration

FIRESCAPE-SWTAS has some capacity for post-compilation configurability of model parameters. This is implemented by a user-interactive phase at the beginning of execution in which the user is queried to specify parameters relating to succession modelling, ignition thresholds, simulation outputs and other factors. Work is ongoing in the updated FIRESCAPE-SWTAS to remove this interactive phase of execution in favour of a configuration input file incorporating many of the current post-compilation configuration options and adding additional configurability of further model parameters currently embedded in the source code. This will further enhance the utility of FIRESCAPE-SWTAS as a tool for testing and refining the various theories underpinning the model.

A further improvement to workflow efficiency currently being implemented is the automated visualisation of model outputs. Scripts, currently written in R, to produce plots from the various standard model outputs are incorporated into execution of each FIRESCAPE-SWTAS simulation so that a suite of image files summarising the simulation results is produced along with the numerical model outputs.

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