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Disturbance Regimes and Management Strategies of Mountain Ash Forest Ecosystems in Victoria, Australia; A Literature Review

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A Master's Paper

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ABSTRACT

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This paper discusses the ecology of mountain ash forests, the disturbances regimes that currently exist in these ecosystems, and finally addresses the current management practices and future management practices. Mountain ash forests are subjected to a wide range of research in the Central Highlands of Victoria, an area approximately 14,000 hectares in range. These forests are dominated by montane ash trees (*Eucalyptus regnans* F. Muell), which are critically endangered and at risk of collapse, attributed to the decline in large hollow-bearing trees throughout the region. Management of these forests are controlled by the Department of Environment, Land, Water, and Planning and primarily carried out by VicForests through clear cut logging and post-fire salvage logging. There are three major disturbance regimes within these forests; fire regimes, silviculture, and climate change. Silviculture has a dominant impact on the forest ecosystems through clear-cut logging, although there have been other methods proposed that are gaining traction that have a primary goal of preserving natural ecosystem functions and composition such as Variable Retention Harvesting System and the Traditional Owners cultural landscape strategy. However, it is becoming important to consider climate change impacts on this ecosystem, with projected increase in temperature and decrease in precipitation. These changes have the potential to cause a significant impact on the ecosystem, via alteration in size, duration, and intensity of wildfires, which has already been observed. This change in wildfire regimes is necessary to consider for future management in Victoria, with an introduction of land ethics into management that extends beyond economic gains.

ACADEMIC HISTORY

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DEDICATION

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Introduction

Overview

Australia is home to mountain forests that are dominated by montane ash (*Eucalyptus regans* F. Muell), which according to the International Union for the Conservation of Nature (ICUN) Red List of Ecosystems is critically endangered and at risk of collapse[1], largely attributed to the decline in large old hollow-bearing trees throughout the mountain ash forest due deforestation[2]. These forests are home to several endangered and vulnerable species such as the Leadbeater's Possum (*Gymnobelideus leadbeateri* McCoy)[3], the yellow-bellied glider (*Petarus australis* Shaw)[4] and the Greater glider (*Petauroides Volans* Kerr)[5], and occur in 3 different Australia states (Victoria, New South Wales, and Tasmania). The tri-state nature of these forests makes the management of these forests difficult due to the need for inter-state cooperation and agreement of governments. These forests are used for recreation, logging, carbon storage and water catchment areas[6], and the decreased production of these forests have a direct impact on these ecosystem services. The land use for these forests is divided between state forests (~92,000 hectare) and national parks (~38,000 hectare)[7]. This paper will focus on approximately 140,000-hectare section of montane ash forest in the Central Highland region of Victoria, primarily due to the breadth of research over four decades in this specific area. The purpose of this review paper is to

[1] VicForests, 2020
[2] Lindenmeyer, Sato, 2018
[3] Lindenmayer et al., 2007
[4] Burns et al., 2014
[5] Bowd et al., 2018
[6] Lindenmayer et al., 2007 & Lindenmayer, Sato, 2018
[7] Lindemayer et al., 2022

discuss the ecology of mountain ash forests, the main disturbances that exist in these ecosystems, climate change in Victoria, and finally to address the current management practices and proposed future management practices. In order to fulfill the purpose of this paper, the underlying question is what does the forest ecosystem currently look like and what could the future look like in this ecosystem?

Victoria is the second-smallest state in Australia at 227,038 square kilometers[8]. Victoria's climate is varied at the state level, having 4 different climate zones; Zone 4 (hot dry summer, cool winter), Zone 6 (mild temperate), Zone 7 (cool temperate), and Zone 8 (alpine) (Figure 1)[9]. Victoria has four distinct seasons, with the average maximum temperature in the winter being 55°F and in the summer 80°F[10]. Unlike the rest of Australia, Victoria's mountain ranges run east-west rather than north-south, causing the climate to be largely influenced by the oceans[11].

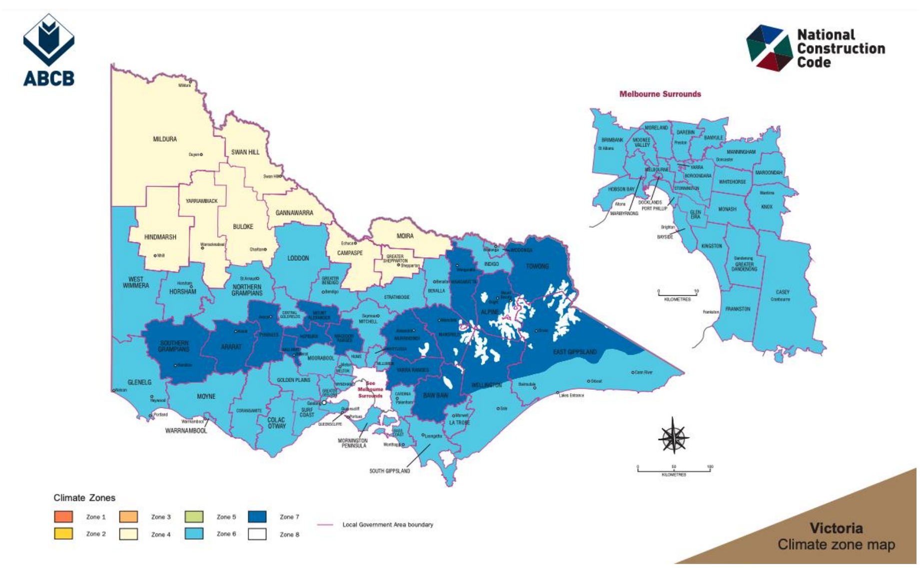

Figure 1. Climate zone map of Victoria. Source: Australia Building Codes Board

[8] Geoscience Australia, 2022
[9] Australian Building Code Board, 2022
[10] Bureau of Meteorology, 1993
[11] Bureau of Meteorology, 1993

Mountain ash forests

Mountain ash forests are present in the Central Highlands of Victoria, Tasmania and New South Wales (Figure 2) and grow between 200-1,100 m above sea level[12]. Mountain ash forests in the Central Highlands have been placed on the IUCN Red List of Ecosystems in the Critically Threatened category, largely due to the decrease in old-growth forests and how future climate change will impact these forests[13]. Mountain ash forests are defined as obligate-seeder forests, which are plants that can only regenerate after fire from seed and are dominated by Mountain ash (*E. regnans*) (Figure 3) and Alpine Ash (*E. delegatensis* R. Baker)[14]. The understory of these forests contains *Acacia* species, Hazel pomaderris (*Pomaderris aspera* Sieber ex DC), *Oleria* species, and tree ferns [(*Cyathea australis* Domin), (*Dicksonia Antarctica* Labill)]. Several of the species in these understories are endemic to Australia, such as Hazel pomaderris, and a number of the flora and fauna within these forests are endangered due to the loss of old-growth portions due to logging or fire[15].

[12] Lindenmayer et al., 2009
[13] Burns et al., 2015
[14] Bowd et al., 2021a
[15] Australian Government Department of the Environment and Energy, 2017

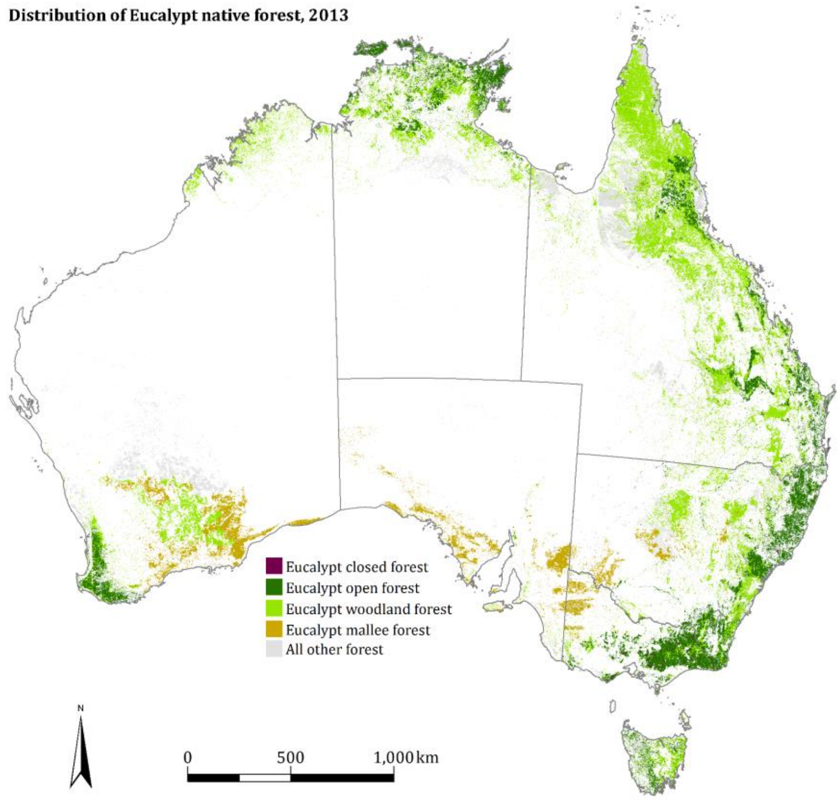

Figure 2: Distribution of Eucalypt native forest, 2013. Source: ABARES 2018

Figure 3. E. regnans and surrounding vegetation. Photo taken by Brian Walters. Australian Native Plants Society 2023

Since the 1960's, the primary management of mountain ash forests have been through clear-cut logging methods[16], where forests at the age of around 80 years between 15-40 acres of single-aged stands have all harvestable trees cut down. Logging slash is then left for 1+ years to dry out and then are burnt to create an ash bed which the mountain ash seed is aerially seeded[17].

There are alternative management strategies suggested for mountain ash forests that are ecologically sustainable. Ecological sustainability has been defined by Lindenmayer (2022) as 'forest management that places ecosystem intergrity, such as the maintenance of forest structure, species composition, and the create of ecological processes and functions within the typical disturbance regimes'[18]. One proposed method of forest management that would allow for the logging industry to continue in a more ecologically sound manner, is variable retention harvesting system (VRHS). This proposed method would involve selecting the marketable trees for harvesting, whilst keeping a multi-aged ecosystem that allows for biodiversity.

Other forest management methods that can be considered ecologically sustainable must include five things; (i) ecologically sustainable management strategies must account for uncertainty in resources availability, (ii) informed decisions on land management require an understanding of the ecological, economical, and social factors of the target area, (iii) ecologically sustainable management must consider the impacts of disturbance drivers, (iv) wood resource availability assessment must be independent

[16] Lindemayer et al., 2018
[17] Lindenmayer et al., 2022
[18] Lindenmayer et al., 2022

to be considered by land managers, and (v) multi-data and perspectives are needed to guide management decisions[19].

Mountain ash forests are a threatened ecosystem, with a multitude of disturbances that must be tackled at the same time in order to protect this ecosystem. The usage of management strategies that are ecologically sustainable and are able to be implemented quickly by forest managers are the best option for the survival of this ecosystem. With the loss of old growth stands due to a combination of fire and logging, management strategies that can be implemented quickly will assist in increasing the amount of these stands in the Central Highlands, leading to an increase in biodiversity and subsequent protection of other endangered species.

[19] Lindenmayer et al., 2022

Forest Ecology

Mountain ash forests canopies are defined by *E. regnans*, known as Australian-oak, Australian mountain ash, mountain ash, swamp gum, stringy gum, Victorian Ash, or white mountain ash in vernacular[20], however many scientific articles refer to *E. regnans* as mountain ash. The canopy of these forests is also dominated by Alpine ash (*E. delegantensis* subsp *delegantensis* Baker), Mesmate stringybark (*E. oliqua* L"Héritier), and Manna gum (*E. viminalis* subsp. *Viminalis* Labill)[21] [specific species and regions are listed in Table 1].

E. regnans is the main eucalyptus species used by the pulp industry[22] and the timber provided from this species is used in paper and lumber[23]. Growth has a rapid uptick in the second year and grows to be the largest angiosperm in the world, reaching 262 + feet[24]. *E. regnans* is found in wet sclerophyll forests and is highly susceptible to fire, leading to death and the rise of single-ages cohorts[25]. If the fire frequency is shorter than the time it takes the single aged stands to reach reproductive maturity (25-30 years[26]), then the *E. regnans* population are likely to face local collapse and be replaced by species that can regenerate without fire disturbance such as *Acacia*[27].

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[20] Vaughan, 2011
[21] Australian Government Department of the Environment and Energy, 2017
[22] Lindenmayer et al., 2007 & Lindenmayer, Sato, 2018
[23] Britannica 2022
[24] Australian Native Plants Society 2023
[25] Wood, SW et al., 2010
[26] Cawson et al., 2017
[27] Wood,SW et al., 2010 & Bowd et al., 2018

		State Presence					
Common Name	Scientific Name	Tasmania	Victoria	Australian Capital Territory	New South Wales	Queensland	W. Australia
Alpine Ash	*E. delegantensis* subsp *delegantensis*	✓	✓	✓	✓		
Messmate stringybark	*E. oliqua*	✓	✓	✓	✓		
Manna gum	*E. viminalis* subsp *viminalis*	✓	✓	✓	✓		
Blackbutt	*E. pilularis*				✓	✓	
Syndey Blue Gu,	*E. saligna*				✓	✓	
Flooded gum	*E. grandis*				✓	✓	
Tallowood	*E. microcorys*				✓	✓	
Silver-top Stringybacj	*E. laevopinea*				✓	✓	
Turpentine	*Syncarpia glomulifera*				✓	✓	
Brush Box	*Lophostemon confertus*				✓	✓	
Mountain Grey gum	*E. cypellocarpa*		✓		✓		
Brown Barrell	*E. fastigata*		✓		✓		
Narrow-leafed peppermint	*E. radiata*		✓		✓		
White Mahogany	*E. acmenoides*				✓		
Yellow stringybark	*E. muelleriana*				✓		
River peppermint	*E. elata*				✓		
Gully gum	*E. smithii*				✓		
Mountain Blue Gum	*E. deani*				✓		
Karri	*E. diversicolor*						✓
Jarrah	*E. marginata*						✓
Red tingle	*E. jacksonii*						✓
Yellow tingle	*E. guilfoylei*						✓
Rates tingle	*E. brevistylis*						✓
Marri	*Corymbia calophylla*						✓

Table 1: Mountain ash forest Eucalyptus canopy species. Source: Australian Government Department of the Environment and Forestry

E. regnans requires fires that are high intensity (>800kWm^{-1}) for regeneration[28]. It has limited protection from fire like other eucalyptus species. The thin bark and lignotuber, which protects against the destruction of the plant stem from disturbances such as fire, is not present within *E. regnans*[29]. These forests have understory species such as hazel pomaderris (*Pomaderris aspera*), silver wattle (*Acacia dealbata* F. Muell), musk daisy-bush *(Olearia argophylla* F. Muell ex Benth), rough tree fern (*Cyathea australis* R. Brown), and soft tree fern (*Dicksonia Antarctica* Labill)[30]. Understory species are particularly vulnerable to disturbances, largely due to the correlation between the overstory to understory with regard to the light regime[31].

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[28] Wood, SW et al., 2010
[29] Wood, SW et al., 2010
[30] Australian Government Department of the Environment and Energy, 2017& Bowd et al., 2021a
[31] Helm, 2017

The increase of disturbances can cause these species to be replaced by more disturbance resilient species and can change the seed banks, causing a change to the ecosystem. This is known as the 'interval-squeeze' problem[32], where the intervals between disturbances are too short and the disturbances occur before seed crops, causing the replacement of current species with more resilient species[33]. In mountain ash forests, the replacement of *E. regnans* would be acacia species and high elevation mixed species[34], as these species are more fire resilient and reach maturity faster than mountain ash. This replacement of *E. regnans* would cause a shift towards mixed elevation species forest, as seen in the Pacific Northwest's Douglas-fire dominated forests[35]. With the replacement of *E. regnans,* the Central Highlands Mountain Ash forests will collapse, and no longer be present in this area.

[32] Eright et al., 2015
[33] Bowd et al., 2021a
[34] Singh et al., 2021
[35] Halofsky et al., 2020

Disturbances

Fire Regimes

As a continent, Australia is highly flammable with around 7% of the land area being burnt annually[36]. The main natural disturbance of the mountain ash forests are wildfires[37]. Fire season is usually in the summer to early autumn after the drought period[38], and in Victoria typically involve burning fuels that are on or above the ground level[39], referred to as surface type fires[40]. Measuring the fire intensity specifically for mountain ash forests is particularly difficult due to the difficulty in access and terrain, as well as the intensity of the fires being measured above 100,000 kW m^{-1}[41], which is considered a fast-spreading fire with heavy fuel[42]. Aerial photography has become a major component in measuring fire intensity as it removes the concern for human welfare from the situation[43].

Victoria has been subjected to intense fire seasons and have been recorded since 1851. Recent memorable wildfires are the 2019-2020 season, 2015, 2012-2013 season, 2009, 2006-2007 season, 2005-2006 season, 2003, and 2002[44]. One of these major wildfires that has been the subject of research in post-fire forest ecosystems is referred to as the 'Black Saturday' fire, which occurred in February 2009 (Figure 5)[45]. The Black

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36 Boer et al., 2016
37 Lindenmayer et al., 2007
38 Ree,s 1984
39 Ashton, 1981
40 Gill, 1975
41 Gill and Moore, 1990
42 Scott et al., 2006
43 Neary et al., 2005
44 State of Victoria (Department of Environment, Land, Water and Planning), 2023
45 Bushfire Royal Commission 2010

Saturday fire was the subject of the 2009 Victorian Bushfire Royal Commission report that was finalized a year and a half later[46]. This fire had a large impact on the stand age and diversity, with an estimated loss of 59,000 hectares[47]. The Black Saturday fire's impacts are still present in the ecosystem, with a decline of old hollow-bearing trees in impacted areas by 96.1%[48]. There has also been a recorded change in age composition in the impacted forests, with the percentage of old-growth forests declining to 1.6% in the Central Highlands, a far cry for the historical typical 30-60% make-up of the area[49].

Figure 4. Location of Black Saturday Fires. Source: Bushfire Royal Commission

[46] Bushfire Royal Commission 2010
[47] Bushfire Royal Commission 2010
[48] Lindenmayer et al., 2021a
[49] Lindenmayer et al., 2021a

The 2019-2020 fire season, dubbed the 'Black Summer', had an absolute fire area of around 1.8 million hectares[50]. This fire season primarily impacted temperate forests and woodland (Figure 6) and lead to 346 species losing 40% of their habitat in Victoria[51]. The severity of this fire season was due to above average temperatures, and the three previous years of rainfall deficit[52], causing an increase in fine fuel load and decreased moisture present in live vegetation. It has been argued that there is a tertiary impact, drawn from the 'landscape trap' hypothesis, in which the regrowth following logging is denser than older stands, causing an increase in flammability in ecosystems[53]. The Forest Fire Danger Index, however, does not show a linear relation of the effect of recent logging on the probability of severe fire[54]. Therefore, this tertiary impact is not a definite attribute to the severity of this fire season[55].

[50] Collins et al. 2021
[51] Geary et al., 2021
[52] Filkov et al., 2020
[53] Bowman et al., 2021
[54] Bowman et al., 2021
[55] Bowman et al., 2021

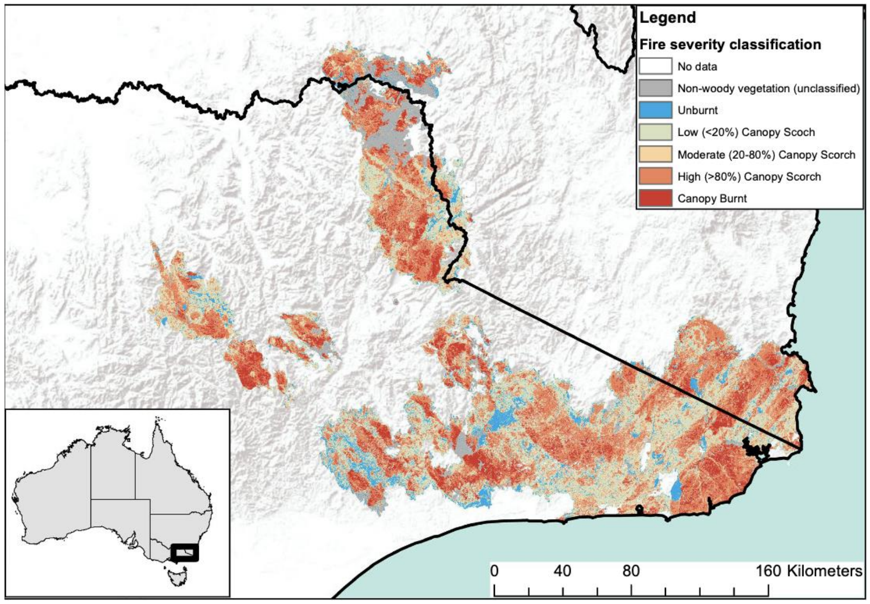

Figure 5. Map of the severity of the 2019/2020 eastern Victorian megafires. Five fire severity classes are mapped based on the horizontal coverage of different fire impacts on plant canopies: unburnt (80% scorch); and canopy burnt (>20% of foliage consumed). Source: Geary et al., 2022

Bushfires are increasing in temporal spatiality and in intensity[56], which is cause for concern with the potential effects of climate change lending itself towards this trend continuing upwards. It is estimated that around 70% of mountain ash forests are either severely disturbed or within 200 meters of a severely disturbance area[57]. High severity wildfires have increased, assumed to be due to the dominance of young stands (the stand age is less than 83 years). This change in stand-age would cause an alteration in the influence of crown burn.[58] (Figure 6). This assumption is due to the probability of a crown burn dramatically decreasing after reaching around 35 years, and logging is suggested to occur at 50 years[59].

[56]Burns, E. et al., 2014
[57] Taylor et al., 2020
[58] Lindenmayer et al., 2022
[59] Lindenmayer et al., 2022

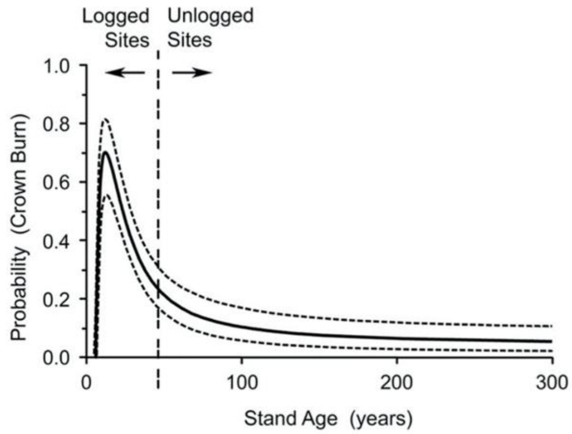

Figure 6. Nonlinear relationship between stand age and the probability of canopy fire or crown burn. The probability of crown burns peaks at ~40 years before declining as stands approach 80-100 years old. Redrawn from Taylor, McCarthy and Lindenmayer. The solid line corresponds to mean response, and the dashed line represents the lower and upper bounds of the 95% confidence interval. Source: Lindenmayer et al., 2022.

In *E. regnans* dominated forests, the fire regime is dominated by high-intensity, infrequent fires on a scale of 75 to 100-year periods between these fires[60]. The Initial Floristic Composition Model[61], proposed by Elger in 1954, describes the pattern of vegetation succession after abandonment. This model shows that the succession pattern will start with grasses and general shrubbery and will end with tree succession. In *E. regnans* forests, the successional pathway differs depending on the disturbance that causes the succession to occur, however the pathway follows similar principles to Elgers proposal[62]. In the presence of multiple disturbances, the species richness will increase, and the composition of that species richness will differ from non-disturbed sites, due to the alteration of ecosystem function via lack of biological legacies[63].

[60] McCarthy et al., 1999
[61] Elger. 1954
[62] Bowd et al., 2021b
[63] Bowd et al., 2021b

Silviculture

The main anthropogenic disturbance to mountain ash forests is the silviculture industry[64]. Logging has been present in these forests since the 1700's[65], and is presently being performed by VicForests, an independent contractor of the state[66]. The current practice of clear-cut logging came about in the 1960's, replacing selective logging practices as the primary system in these forests[67]. These areas can be combined into 120-hectare groups and are typically on an 80-year harvest rotation[68].

Clear cut logging is heralded as the safest method for foresters; however, the ecological impacts of this method are far better documented and studied than salvage logging or selective harvesting (Figure 7)[69]. In comparison to uncut forests, clear-cut areas have an increase in radiation at the surface 10 to 20 times, which can cause a change to soil temperature[70]. This change in soil temperature is dependent on the severity of the clear-cutting and post-harvest site preparation and how that affects understory vegetation and alter soil thermal properties[71]. Increased temperatures at the surface level in clear-cut forests can kill young trees through cambial girdling[72], where the removal of the bark around the entire circumference of the tree cuts off the circulation of water and nutrients. The airflow patterns are extremely variable, and the removal of the canopy creates an increase in windspeed closer to ground, causing a

[64] Lindenmayer et al., 2007
[65] Lindenmayer et al., 2007
[66] Brockington et al., 2018
[67] Lindemayer et al., 2018
[68] Lindenmayer and Ough. 2006
[69] Keenan. 1993
[70] Keenan, Mackey. 1993
[71] Keenan, Mackey. 1993
[72] Keenan, Mackey. 1993

reduction in the 10-20 time increase in temperature due to the radiation[73]. Wind is incredibly effective at dissipating heat from the ground surface, with increase evaporation may decrease soil moisture[74].

Variable	Effect	References[a]
General effects		
Air temperature (1.5 m height): diurnal range	2× increase	5
Surface temperature: diurnal range	2.5–3× increase	13
Soil temperature (50 cm depth): summer	5°C increase	3, 7
Soil moisture content: summer	0.5–3× increase	1, 10, 12
Precipitation at the soil surface	15–50% increase	7, 8
Actual evapotranspiration	Large decrease	10
Snow depth	Increase	2, 8, 9
Duration of snow pack	Disappears 1–3 weeks earlier	2, 8, 9
Sunny summer day effects		
Shortwave radiation at surface	10–20× increase	4
Net radiation	0.5× decrease	6
Maximum air temperature (1.5 m)	3–5°C increase	4, 7
Maximum air temperature (seedling height)	Up to 10°C increase	4
Maximum surface temperature (bare soil)	Up to 20°C increase	6, 13
Maximum surface temperature (litter)	Up to 30°C increase	6, 13
Maximum soil temperature (10-cm depth)	5–10°C increase	3, 13
Relative humidity	Small increase	13
Windspeed and turbulence at seedling height	Increase	13
Clear calm night effects		
Net upward radiation at surface	Increase	11
Minimum air temperature (1.5 m)	1–2°C decrease	5
Minimum air temperature (seedling height)	4°C decrease	5, 11
Minimum surface temperature	5°C decrease	7
Minimum soil temperature (10 cm)	2°C decrease	13
Relative humidity	15% increase	13

[a]1, Adams et al. (1991); 2, Berndt (1965); 3, Childs et al. (1985); 4, Fowler and Anderson (1987); 5, Geiger (1957); 6, Holbo and Childs (1987); 7, Hungerford (1979); 8, Jansson (1987); 9, Leaf (1965); 10, McColl (1977); 11, Nunez and Bowman (1986); 12, Smethurst and Nambiar (1989); 13, Spittlehouse and Stathers (1991).

Figure 7. Microclimate effects of clear-cutting compared to the uncut forest. Source: Keenan 1993

Post-fire logging is a secondary form of clear-cutting logging that occurs less than three years after a high-severity bushfire, following the same practices as the clear-cut logging; where all trees are cut, the remaining debris is burnt, and the area is seeded with the dominant surrounding *Eucalyptus* species, with an exception that if there is adequate growth, there will be no slash-and-burn component[75]. This form of logging is done after a disturbance, most often wildfires or insects such as psyllid's[76].

[73] Keenan, Mackey. 1993
[74] Keenan, Mackey. 1993
[75] Blair et al., 2016
[76] Lindenmayer et al., 2006

In the 1980's, Victoria established the Silvicultural Systems Project (SSP) to develop forestry operations that have the ability to replace clearfelling as well as model these alternate systems against clearfelling in regard to a long-term balance between socio-economic and environmental needs[77]. The present thinking and practice in silviculture is moving towards returning to the pre-1960 method of silviculture; selective logging, also known as VRHS[78]. Selective logging method originates in North America and involves four major components; (i) the appropriate retention of structural features to be ecologically effective (ii) retention of stand structural attributes such as large living trees and large dead trees with hollows (iii) a logical spatial distribution of retained structures, and (iv) the retention of structures for at least one logging rotation[79]. This method is designed to be an ecologically sustainable forest management that does not impact species population or diversity of the ecosystem. Selective logging creates a gap that allows for the understory light conditions to increase where the tree was cut, therefore promoting the growth of seedlings and altering the forest composition[80].

Salvage logging is not without fault either. This form of silviculture is understudied, however the few papers that do discuss salvage logging summarize the key impacts into impacts on the stand structure, plants and animals. Primarily, there are three major categories of impacts on a salvage-logged ecosystem; i) the physical structure of the ecosystem ii) the key ecosystem processes, and iii) the individual biota

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[77] Lindenmayer et al., 2007
[78] Lindenmayer. 2007
[79] Lindenmayer. 2007
[80] Qi et al., 2016

and species interactions[81]. Regarding the physical structure of the ecosystem, the patterns of recovery of the ecosystem and biotic elements are largely influence by types, numbers, and spatial arrangements of biological legacies following natural disturbances[82]. Salvage logging removes a number of these biological legacies created by natural disturbances, leading to the altering of biological communities' composition[83]. Key ecosystem processes, such as hydrological regimes, cavity-tree formation, soil profile development, and nutrient cycling are all effected by salvage logging[84]. By introducing anthropological impacts into the ecosystem recovery, there is documented effect on the sediment horizon depth and organic content[85], as well as increasing the compaction and erosion of these soils[86]. Finally, the species interactions and individual biota will be affected by the secondary disturbance of salvage logging compounding the original disturbance. Individual biota is often suited for the historical natural disturbances in the ecosystems, but not for the compounding disturbance[87]. In mountain ash forests, recovery patterns that are affected by salvage logging, such as secondary burns used to promote the growth of commercial tree crops[88], can cause an exhaustion of the seedbanks that were activated after wildfires.

With a clearfelling rotation of 80 years[89], plant species such as slow growing and slow-to-recruit tree ferns are not able to exist and causes a reduction in mammalian

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[81] Lindenmayer et al., 2006 (a)
[82] Lindenmayer et al., 2006 (a)
[83] Morissette et al., 2002
[84] Cooper-Ellis et al., 1999
[85] Hansen 1999
[86] McIver & Starr 2000
[87] Bergeron et al., 1999
[88] Lindenmayer & Ough 2006
[89] Lindenmayer et al., 2006 (b)

foraging sites. The multi-aged stands also provide habitat for species such as the Sooty owl and the yellow-bellied glider[90], and with continued fragmentation of multi-aged stands, the viability of these species into the medium/long-term future is uncertain.

Stand structure impacts from salvage logging can end with the loss of biological legacies, vegetation that are semi resistant to fire, and large living and dead fire-scarred trees with hollow[91]. These impacts could be attributed to its common usage as an action following a disturbance such as wildfire or pests, creating a compounding disturbance on the ecosystem. Salvage logging will have similar impacts to clearfelling logging on plant regrowth, as the mechanistic nature of salvage logging is similar to clearfelling. The young shoots are easily damaged by heavy machinery, causing a decrease in survival[92]. However, this can be mitigated through careful mechanical logging and reduction in clearing burnt understory away[93].

Aboriginal Management Methods

Aboriginals entered the continent at least 65,000 years ago[94], altering the continent with the use of fire for land management. The use of fire became the ultimate tool to maintain resources, both for the health of specific flora and fauna and to prevent large bushfires[95]. Management of the country was done through the frequent ignition of small fires[96], leading to an alteration of herbaceous and woody biomass balance,

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[90] Lindenmayer et al., 2006 (b)
[91] Lindenmayer et al., 2006 (b)
[92] Lindenmayer et al., 2006
[93] Lindenmayer et al., 2006
[94] Clarkson et al. 2017
[95] Gott 2005, Firesticks Alliance Indigenous Corporation 2019
[96] Gott 2005

limitation of density in understory vegetation, and maintenance of open woodlands and savanna landscapes[97,98].

Aboriginal burning practices utilized mosaic burning[99], where fire is manipulated to create a mosaic of small land pieces that represent a range of fire histories[100]. This burning allowed for areas with high tinder amounts to be burnt in a controlled way to prevent larger bushfires, which historical records observed allowed for the movement of people through denser woodland as well as creating a geographic distribution of risk across Aboriginal territory (specifically the Gadubanud people's territory) in case of unexpected wildfire[101].

With European colonization, these Aboriginal practices were ended, and the introduction of mono-crop farms and ill-suited management methods altered the landscape to what we see today. This is not uncommon and is often seen in area's that underwent European colonization. It is also not uncommon, and unfortunately is the case with Aboriginal tribes, that there is a severe lack of management methods that have survived to the 21st century. Methodology has been passed down through different Aboriginal tribes through many ways but have not been implemented into current management systems until very recently. Therefore, there is a loss of endemic knowledge in this ecosystem, and the ecosystem is suffering the consequences of ill-suited management.

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[97] Gott, 2005
[98] Mariani et al. 2022
[99] Lloyd et al., 2005
[100] Parr et al., 2006
[101] Cahir et al., 2021

Observed Climate Change

There has been an increase in climate change impacts on mountain ash forests and is increasingly recognized as a third disturbance to mountain ash forests[102,103]. In order to understand the observed climate change in Victoria, Australia's climate data was accessed from the Climate Change Knowledge Portal (CCKP) for Development of Practitioners and Policy Makers. This resource acts as an aggregation of weather stations monthly climate data and allows for quality-control of the data from the stations. Data was downloaded as observed mean temperature, maximum temperature, minimum temperature, and precipitation in monthly amounts and decadal amounts.

The temperature in Australia has increased from 1901-2021 from 21.41°C to 22.47C, a 1.08°C increase over the 120 years (Figure 9). The temperature growth after 1971 occurred in line with the global temperature increase post 1970, thought to be due to increased aerosol production post World War II[104]. The decrease in temperature that occurred in 2001-2010 has been contributed to the Millennium Drought[105]. This drought has also been contributed to prevailing El Niño conditions reducing the rainfall, intensification of mean sea level pressure[106], as well as potential impacts from the Indian Ocean Dipole and the Southern Annular Mode[107].

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[102] Lindenmayer, Sato. 2018
[103] Lindenmayer et al., 2021 (b)
[104] Henshaw, 2019
[105] Van Dijk et al., 2013
[106] Hope et al., 2010
[107] Van Dijk et al., 2013

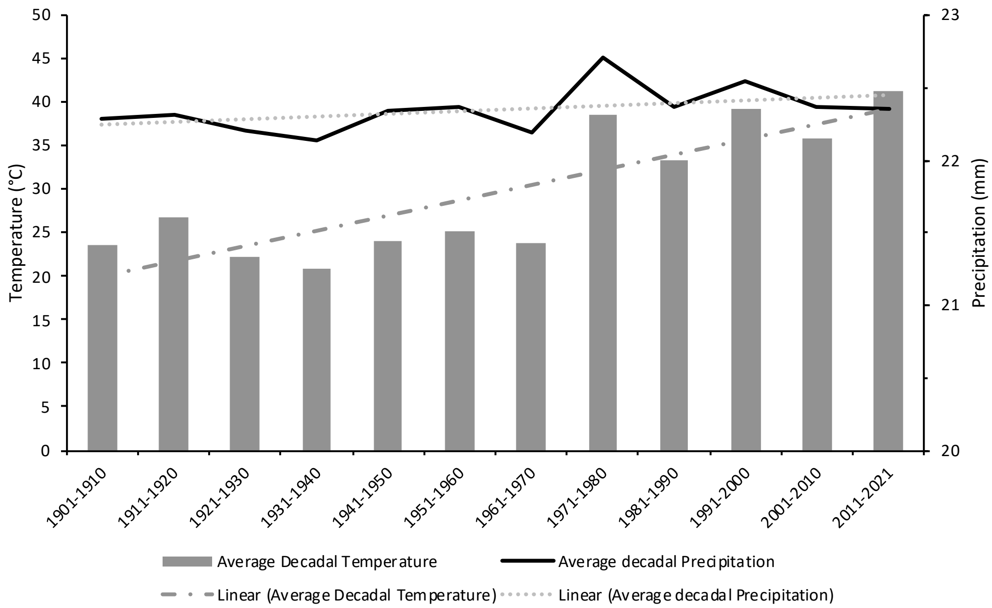

Figure 8. Decadal average temperature and precipitation for Australia (1901-2021). Precipitation is plotted as a line and temperature is plotted as bars

There are no significant trends in precipitation from 1901-2021 (P=.163) (Supplementary Data), which follows the natural variability of precipitation that has been previously documented[108]. Australia commonly experiences precipitation extremes throughout the continent, with the monsoon season that occurs in the north and the subsequent high-pressure system that causes drought in the south. There is a non-linear relationship between Australia's annual rainfall and the Southern Oscillation Index, with Australia having a tendency to dry out during El Niño events, but the degree of the drying is not directly linked to the magnitude of the anomaly event[109]. Precipitation's natural variability caused by atmospheric circulation patterns is comparable to projected anthropogenic forced changes[110]. The comparable effects of

[108] Head et al., 2014
[109] Chung et al., 2017
[110] Watterson et al., 2007

atmospheric circulation patterns and projected anthropogenic forced changes have the ability to mask trends that could be driven by increased greenhouse gas concentrations through anthropogenic actions[111]. However, with the combination of tree ring data, there is an emerging concept that the Southern Annular Mode's (SAM) increasing dominance and frequency could be causing a high summer-autumn precipitation[112]. This increasing dominance could potentially be caused by the impact of anthropogenic-driven greenhouse gas forcing[113]. SAM has experienced an increasing positive phase that has been attributed to ozone depletion[114,115].

In regard to temperature, there is a significant trend showing an increase in temperature from 1901-2021 ($P=.0006$), and significant differences between months (all months were significant $P \leq .00124$) (Supplementary Data). The hottest month on average was January and there was a growth in temperature from 27.724°C in the first decade, to 28.707°C in the last decade studied. The temperature increase has been contributed to greenhouse gas emissions[116]. This increase in temperature can cause an increase in dry period occurrences, such as the Millennium Drought[117] which could contribute to bushfire occurrences and human health risks.

Bushfire's have been increasing since 1950[118], and with the increasing temperature trend there is a high likelihood of the fire season increasing in intensity

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[111] Watterson et al., 2007
[112] O'Donnell et al., 2015
[113] Abram et al., 2014
[114] Perlwitz et al., 2008
[115] Mariani and Fletcher, 2016
[116] Nicholls and Collins 2006
[117] Nicholls and Collins 2006
[118] Lawrence et al., 2022

and length[119]. Van Oldenborgh (2021) reviewed observational data from 1900 and found that the probability of extreme heat has increased by a power of two, and a significant increase of fire weather as severe or worse than 2019/2020 by at least 30%. This increase of fire weather prevents obligate-seeder recruitment which causes a change in vegetation structure[120]. Wet temperate eucalypt forests in southern Australia have experienced a change from alpine ash domination to open forests or shrublands, and this change is projected to continue with the increasing temperature projections under CMIP6[121,122].

[119] Trancoso et al., 2020
[120] Doherty et al., 2017
[121] Doherty et al., 2017
[122] Bowman et al., 2013

Current Management Strategies

All proposed management practices that are being proposed the time frame for the practice to have observable effects. Different sectors have different planning horizons (Figure 12), and therefore the management of these sections must be considering these temporal needs of the sectors. With these planning horizon requirements, forest succession has an 80-year planning horizon, so any policies that are put into effect must be implemented with the acceptance that the results of ecologically sustainable forest management will not be fully seen for 80 years.

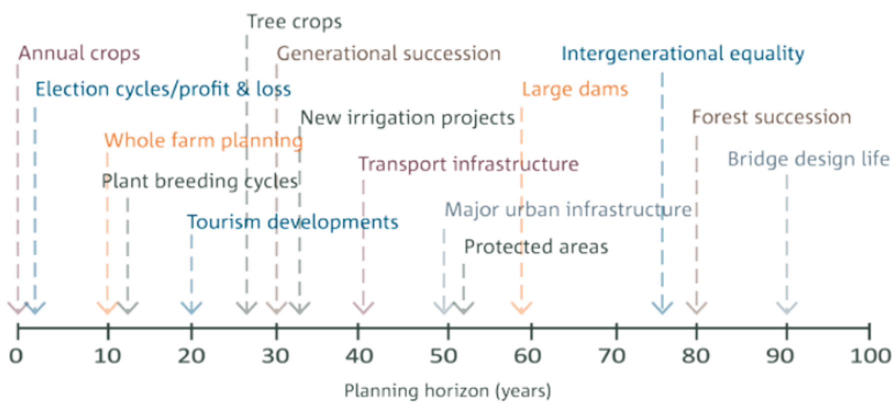

Figure 9. Typical Planning Horizons (years) from different sectors. Source: Climate Change in Australia Projections 2015

Lindenmayer (2007) suggests VRHS should be used in mountain ash forests for four main reasons; the effects of current forms of clearfelling of stand structure and biota, the habitat requirements of biota, the reduction of multi-aged stands by more than 66%, and the importance of maintaining similarities between natural and human disturbances[123]. Selective logging makes up a small portion of the logging that occurs in Victoria but has been stated to have a lesser impact on the forest stands[124] due to the

[123] Lindenmayer et al., 2007
[124] Lindenmayer et al., 2007

ability to keep the older habitat intact whilst harvesting younger, more marketable trees.

The current clearfelling rotation of 50-80 years[125] does not allow for a multi-aged tree stands to occur, and therefore reduces the density of hollows within the stand[126]. Multi-aged stands, and a higher hollow density support high density of native mammals, which in turn supports the health of the ecosystem[127]. Multi-aged stands are important due to the higher diversity of mammals and the potential for some species to have a positive growth response to the combination of old trees and dense understory regrowth typical of multi-aged forests[128].

Bushfire Management Code (2012, amended 2022)

The current bushfire management code was created in 2012 and was recently amended in 2022. This code has been created to plan and implement strategies and actions to reduce the impact of bushfires on primarily human life and property[129]. The first section of this code of practice is 'Risk-based bushfire management and planning', where in this code discusses the risk analysis framework consistent with the Australian Standard for risk management (Figure 10). This sections objectives are twofold; i) to minimize the impact of major bushfires on human life, communities, and the economy and environment whilst placing human life as a priority over other considerations and ii) to maintain/improve the resilience of natural ecosystems and their ability to provide

[125] Lindenmayer et al., 2007
[126] Lindenmayer et al., 2007
[127] Lindenmayer et al., 2007
[128] Lindenmayer et al., 2006
[129] Code of Practice 2022

ecosystem services such as biodiversity, water, carbon storage and forest products[130]. In order to fulfill these two objectives, the risk management measures will be done at three separate levels; strategic (identification and evaluation of strategies that are able to meet the objectives), operational (implementation of a 3 year forward-look to planned works and prioritization of annual implementation of these actions), and tactical (community engagement, planned burns, and fuel breaks)[131].

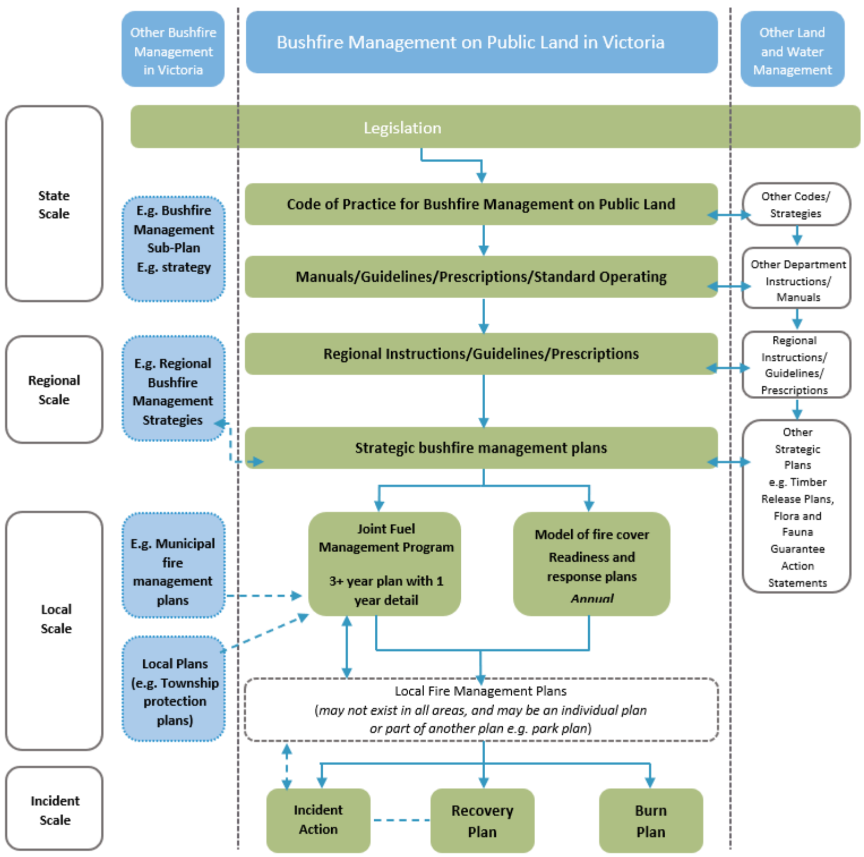

Figure 10. Bushfire management code Risk Analysis framework. Source: Code of Practice 2022

The second section pertains to prevention, due to the *Forests Act of 1958* requiring the carrying out work on State forests, national parks, and protected public

130 Code of Practice 2022
131 Code of Practice 2022

land to prevent and suppress bushfires[132]. This same act lays the foundation for the third section of the code; preparedness. To fulfill this section, there are four main outcomes; i) effective and appropriate allocation of staff capabilities and resources for bushfire management ii) effective and appropriate allocation of non-staff capabilities and resources for bushfire management iii) risk analysis informs capability and resource allocation according to existing and forecast risk across Victoria and iv) improved interoperability with other fire and emergency management agencies[133].

Fuel management including planned burning makes up the fourth section. There are three outcomes of this section; i) reduced impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment, with human life a priority above all else ii)resilient natural ecosystems, which can deliver services such as biodiversity, water, carbon storage and forest products and iii) the roles of bushfire in the Victorian landscape is well understood by informed stakeholders and the broader community.

The fifth section of the bushfire code is response. This section has one outcome, to suppress and manage bushfires in the aim to reduce the risk to human life, communities, essential and community infrastructure, industries, the economy, and the environment. This outcome is expected to be meet through four strategies; i) response to bushfires on or threatening public lands in a safe, efficient, and planned manner ii) work towards development and maintenance of a messaging system capable of delivering advice and warnings to communities iii) identify and mitigate risks to and on

[132] Code of Practice 2022
[133] Code of Practice 2022

public land and adjoining properties iv) rehabilitation of bushfire suppression works post-bushfire response.

Next, the sixth section is recovery. This section has two desired outcomes; i) risks to human life, communities, essential and community infrastructure, industries, the economy and the environment are mitigated following damage caused by bushfires and ii) fire-impacted communities are supported by re-establishing safe access to public land impacted by bushfire.

The final section is monitoring, evaluation and reporting, which has three outcomes. They are i) continual learning of bushfires and bushfire management ii) improved bushfire management strategies and actions iii) transparent implementation of bushfire management strategies and actions on public land. In order to support these outcomes, there are several strategies that have been listed, such as undertaking management to agreed standards, refine scientific models that support decision making using new knowledge from science, and providing the results of management strategies and the impacts on outcomes and objectives readily available.

Leadbeater's Possum

Within the conservation strategies for mountain ash forests, extant biota such as the Leadbeater's possum conservation has a large conservation impact on these forests. Leadbeater's possum's distribution is located in a small area in the Victorian Central Highlands (Figure 13)[134]. Leadbeater's possum only exist in the Central Highlands of Victoria and rely heavily on the presence of old-growth stands. They also act as a

[134] Edge 2022

'flagship species', acting as a symbol for the Central Highlands forest. As they live only in the Central Highlands, bushfires pose a significant threat to the species, as seen in the Black Saturday fire which caused around a 50% population loss[135].

Conservation strategies targeted towards Leadbeater's possum's have a dual purpose of protecting possum's and old-growth/multi-aged stands from silviculture, largely due to the possum's habitat requirement of needing hollows within old-growth trees as well as their dietary requirements of tree exudates[136]. These hollows are formed by termites, microbes, and fungi as there is no cavity-creating vertebrates (e.g. woodpeckers) in Australia[137]. With the lack of cavity-creating vertebrates, the cavities that are necessary for habitat requirements of many vertebrates are not large enough until the tree is 120-150 years old[138].

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[135] Friends of Leadbeater's Possum (2020)
[136] Lindenmayer et al., 2010
[137] Lindenmayer et al., 1997
[138] Lindenmayer et al., 1997

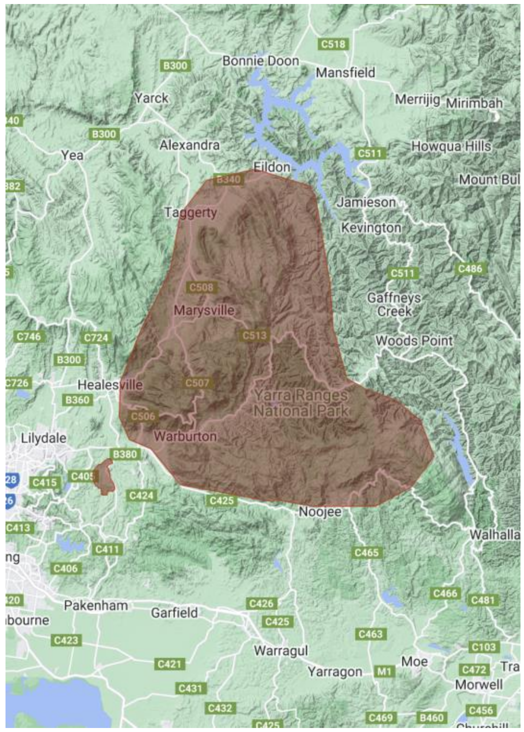

Figure 11. Leadbeater Possum Habitat Range. Source: Edge of Existence, Zoological Society of London

Maintaining a similar disturbance regime as naturally occurs in these forests is important to ecosystem function. Natural disturbance regimes in these mountain ash forests are primarily fire related and typically occur at 75 to 100-year intervals[139]. These fires allow for multi-aged stands and encourage understory development. The anthropogenic disturbance regimes such as silviculture have changed the forest stand structure through both the creation of single-aged stands and the disturbance in understory development through machineries impact soil impaction and shoot destruction[140].

[139] McCarthy et al., 1999
[140] Van Nieuwstadt et al., 2001

Governmental Challenges to Timber Harvesting

The Secretary of the Department of Environment, Land, Water, and Planning (DELWP) requested an independent review into timber harvesting regulations following a 2018 unsuccessful prosecution of VicForests, for a breach of the 2004 Sustainable Forests Timber Act. The Sustainable Forests Timber Act was created to; (i) provide a framework for sustainable forest management and sustainable timber harvesting in state forests, (ii) guarantee long-term access to timber resources in state forests, (ii) foster investments and returns from timber resources in state forests, (iii) establish timber harvesting safety zones to reduce risks to public safety and disruption of timber harvesting operations, (iv) deter activities that create risks to public safety and that cause disruption of timber harvesting operations, and (v) amend the Forests Act 1958 and the Conservation, Forests and Lands Act 1987[141].

The two main concerns that arose from this independent review was firstly the essential self-regulation of VicForests and additionally the usage of regulatory tools is both inadequate and underused. This review suggests alterations to the framework in use that specifically address (i) the lack of internal guidance, policies and procedures on regulation and compliance leading to delays and inconsistencies in the use of regulatory tools and decision-making, (ii) the prosecution policy need for quicker endorsement and implementation, (iii) strengthen the governance and organizational arrangement, (iv) the impartiality of the timber harvesting regulator, (v) timeliness, responsiveness and transparency of the organization, (vi) DELWP compliance activity should shift its role

[141] Sustainable Forests (Timber) Act 2004

from reactive and post-harm to planning, (vii) better defining DEWLP role as a regulator, (viii) defining a single regulator, (ix) the creation of a deliberate strategy to strengthen organizational regulatory ability, (x) updating the regulatory framework to best practice methods, (xi) updating the regulatory tools for regulation, (xii) utilization of investigation and compliance tools, (xiii) increase of information about forest and timber harvesting plans, and finally (xiv) increasing policy position clarity on the trade-offs between environmental and native timber harvesting values[142].

The independent review suggests that the best way to move forward within timber harvesting and silviculture is to move the regulations to a proactive standpoint rather than reactive, as well as moving the regulation framework to more specific standards that encompass better timber harvesting practices[143]. Clarification of roles, or consolidation of roles, would also be beneficial as there are 4 different organizations that have responsibilities in managing forestry operations (Figure 14).

[142] Brockington et al., 2018
[143] Brockington et al., 2018

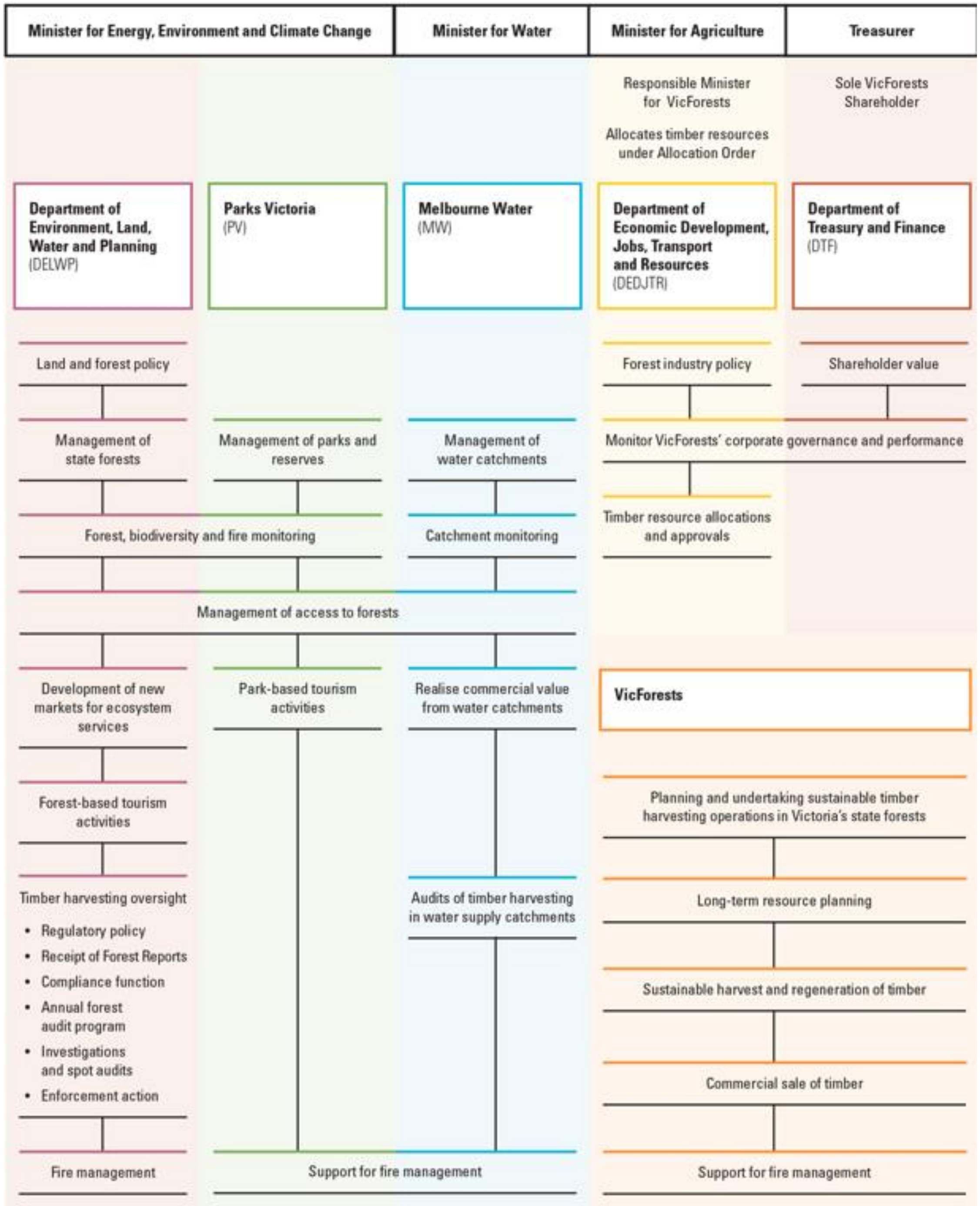

Figure 12. Victorian Government roles and responsibilities in timber harvesting. Source: Brockington et al., 2018

An Outlook to the Future

Projected Climate Change

Since 1910, Australia has warmed 1.44°C, with the majority of warming occurring after 1950[144]. There has been an increase in daily heat wave extremes and overall temperature, which can have large impacts on ecosystems. This increase is necessary to include in climate impact and risk assessments as there will be an impact on ecosystems. Risk assessments also need to include the influence that atmospheric circulation patterns such as El Niño, La Niña, the Indian Ocean Dipole, and the Southern Annular Mode has on rainfall trends[145]. The nature of these atmospheric circulation patterns on the precipitation are affected by both decadal variability and the increase of greenhouse gas emissions and cause a decrease in precipitation in southern Australia and increase in northern Australia[146].

Data analysis was achieved by using data from the CCKP. Whilst CMIP6 model output is similar to CMIP5 model output, CMIP6 implements new set of emissions and land use scenarios based on the future pathways of societal development[147]. Climate data for this study was downloaded from the CCKP multi-model ensemble for mean temperature and precipitation annual projections from 2015-2100.

Victoria's temperature under the SSP projections is expected to increase under all scenarios. SSP 1-1.9 projects a slight increase from 14.26°C to 14.82°C, whilst SSP 5-8.5 projects an increase of 3.756°C from 2019 to 2100. As this state is closer to the

[144] State of the Climate 2020
[145] Van Dijk et al., 2013
[146] State of the Climate 2020
[147] Eyring V. et al., 2016

Antarctic, is it is projected that the temperature projections for this state would be lower than the countries overall temperature projections (Figure 13).

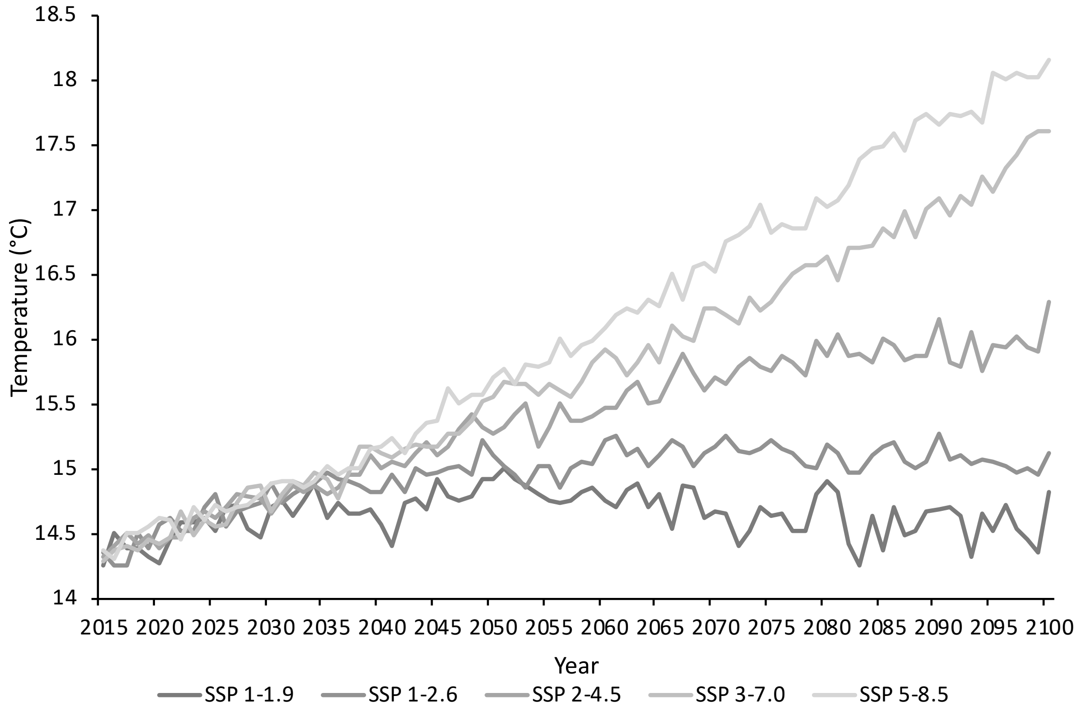

Figure 13. Temperature Projections for Victoria under 5 main SSP Scenarios

Precipitation in Victoria is projected to have varying trends, with SSP 1-1.9 projecting a slight annual increase of 0.0061mm and SSP 2-4.5, SSP 3-7.0, SSP 5-8.5 projecting a decrease in precipitation (0.3671, 0.698, 0.9603mm per year respectively) (Figure 14). However, precipitation projections have a high uncertainty resulting from imperfect representation of the climate system, assumed greenhouse gas emission scenarios, limited spatial and temporal resolution, and errors in forcing data[148]. Therefore, drawing conclusions regarding precipitations future projections should be done with caution.

[148] Kim et al., 2020

Figure 14. Precipitation projections for Victoria under 5 main SSP scenario's using a 5-year running average

Both temperature and precipitation projections show a deviation from the norm. The projected increase of temperature has been attributed to both anthropogenic increase in emissions, and a change in atmospheric patterns. As Victoria's climate is controlled by atmospheric circulations, such as the Hadley Cell, any changes in these patterns can contribute to changes in temperature and precipitation. Therefore, modelling must take into account the future changes to atmospheric circulation patterns.

Projected Landscape Changes

Anthropogenic pressure on climate dynamics will continue to cause ecosystem changes throughout Australia. 47% of ecosystems in Australia have plant species at the higher end of their climatic tolerances for temperature and expect these plants to no longer be functional in their region by 2070[149]. The Southwest Australian Floristic Region of Western Australia is the only area that had vegetation identified as at risk due to precipitation decrease by 2070[150]. Changing ecosystem make-up can also change the plant nutrient availability, with changing temperatures and increasing carbon dioxide causing an increase of phosphate in phosphate-limited soils[151]. These soils, with the effect of accelerated organic matter decomposition and increased nutrient availability, have the potential to promote plant growth through future projected increases in carbon dioxide concentrations[152,153]. The change in soil chemical composition can create an unsuitable environment to *E. regnans* and promote plant growth of non-native plants to the region. This has not been studied nor documented in this region, which has been suggested as a possible outcome to the intensive logging that Victoria experiences in relation to other Australian states[154].

Paradigm Shift in Management

Considering the management methods currently being used, ecosystems are valued for the economic services provided, rather than valuing in ecosystem for the non-economic services. There is a direct benefit to shifting the paradigm from an ecosystem is only as good as the services it provides to an ecosystem is good as an ecosystem. This is not a novel approach to thinking about ecosystems, with Aldo Leopold's *A Sand County Almanac* (1949) presenting the concept of 'land ethic' through

[149] Gallagher et al., 2019
[150] Gallagher et al., 2019
[151] Hasegawa et al., 2015
[152] Hasegawa et al., 2015
[153] Ochoa-Hueso et al., 2017
[154] Bradshaw, 2012

the statement, "Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise"[155] (Leopold, 224). Implementing this land ethic concept into future management would require a paradigm shift towards ethics that are unmotivated by economic gains.

Forests provide a wide range of values beyond the economic gains from its services. Manning et al. (1999) suggests values such as aesthetic, ecological, recreational, educational, moral, historical, therapeutic, scientific, intellectual, and spiritual[156]. Each of these values allow the surrounding cultures to connect with the land, benefitting from the connection to ancestors, connect with the natural world, and to plainly enjoy the beauty of the ecosystem[157]. The economic benefits that come from forests, in this case through lumber, are outweighed by the importance of the other values that forests provide[158].

Even if this paradigm shift away from economic gains is discounted, there are more ecosystem services that forests provide that the current forestry actions in the Central Highlands do not take into account, such as climate regulation, soil fertility maintenance, and protection of watersheds[159]. These are especially important to this region, as these forests hold 56% of the water for Melbourne[160]. The increasing need

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[155] Leopold, 1949
[156] Manning et al., 1999
[157] Manning et al., 1999
[158] Manning et al., 1999
[159] Chasek et al., 2017
[160] Taylor et al., 2018

for climate change mitigation strategies lends itself towards protection of multi-aged forest stands, as they are able to sequester more carbon than single-aged forests[161].

Management in the Face of Increasing Wildfires

Following the 2019-2020 fire season, there has been an increase of research into fire regimes and potential management methods to decrease the intensity of fire seasons. One proposed management method is forest thinning, a wide-spread practice in the Western United States to reduce the fire impacts and associated risks[162]. This practice has been studied in Victoria, of particular application to this paper is a study conducted in higher altitude *E. delegatensis* forests where the surface fuel hazards, and fuel loads decreased eight years post-thinning but no significant impact on coarse woody fuel loads[163]. Implementing thinning into future management actions would benefit both the timber industry, through growth concentration of trees to reach a valuable size faster[164], and the ecological structure of the forest, through increased stand health via removal of invasive shrubs and smaller trees[165].

Thinning also mimics traditional practices of Aboriginal people. In 2021, Victoria's State Government released the Cultural Landscapes Strategy in conjunction with Aboriginal groups, creating the base for Traditional Owner groups to be engaged in Department of Land, Water, and Planning actions regarding public forest management[166]. There are eight enabling principles in this document, which are

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[161] Yao et al., 2017
[162] Keenan et al., 2021
[163] Volkova et al., 2017
[164] Kennan et al., 2017
[165] Kennan et al., 2017
[166] Victorian Traditional Owners et al., 2021

designed to guide partnerships operations; i) traditional owners leading management, ii) traditional owners working together, iii) monitoring and evaluation supporting traditional owners, iv) manage the country holistically, v) managing country is healing, vi) traditional owner centered governance vii) agency partnership and viii) agency resourcing[167]. With the guidance from these principles, there is a direct benefit to forest management.

Similar to Western United States, the Aboriginal populations were managing wildfires in a way that supported the ecosystem and their respective communities well before the introduction of European settlers[168]. Their management strategies were able to prevent larger bushfires which became more common with European colonization stopping the use of controlled burns, as well as creating landscapes that were seen as parks by European settlers[169]. Discussions regarding the re-implementation of Aboriginal management practices have increased with the growing amount of research that current European management strategies are no longer effective and will not be effective in future climatic conditions.

[167] Victorian Traditional Owners et al., 2021
[168] Gott, 2005
[169] Cahir et al., 2021

Conclusion

Montane ash forests provide numerous ecosystem services to Melbourne and in turn Victoria. They provide water catchment services, carbon sequestration, public enjoyment, and lumber. However, their management and disturbance regimes have differed from the natural regimes, through both stand dynamics and fire temporality. The decreasing time between bush fires is both to do with anthropogenic causes of these fires as well as the increase in single aged stands, below the threshold for a decrease crown burn risk (Figure 6). With a decrease in overall stand age and a decrease in multi-aged stands, the diversity of the forest ecosystem and therefore the acceptable habitat for biota is decreased.

The three core disturbances in these forests are fire, silviculture, and climate change. Each of these three disturbances compounds the other two disturbances, with the temporality of fire regimes being altered with silviculture's shortening of stand age and climate change's effect on temperature. Climate change as a disturbance cannot be controlled for as easily as silviculture and fire regimes. However, the easiest way to control the remaining two disturbances would be through strengthened and updated forest management, as suggested by the independent review in 2018.

Management strategies for these forests must be considered in regard to the 80-year planning horizon suggested by Climate Change in Australia Projections. Although there are concerned efforts to change the management strategies in Victoria, largely through governmental regulations, there is a need for management strategies to shift through companies. The primary logging company in these montane forests is

VicForests and with the independent review showing that they are essentially managing themselves, it is necessary to move their internal forestry practices towards best-practice silvicultural methods, or at the very least, mitigate the destruction that occurs in these forests. There is also a need for VicForests to work with researchers in a more reliable way. Whilst they have worked with researchers in the past through governmental pressure, they have still caused issues with harvesting areas that were agreed to be set aside for research[170].

Improving management methods by the inclusion of both Traditional Owners and the application of intrinsic values will allow a paradigm shift towards mindful management placing ecosystem health at the forefront. The recent report including Traditional Owners in governmental forest management is an essential measure to promote natural biodiversity and natural management methods. Returning back to previous management methods may assist in the reduction of intense fires and the integration of land ethics.

It should be noted, and care must be taken with these proposed management strategies and research findings as the majority of the research has been performed by one group and thus has not been necessarily significantly supported by independent research by other groups that have come to the same conclusion. It is also important to address the limited research outside of Victorian mountain ash forest populations. Whilst there has been some research done in other Australian states, the majority of research has been done Victoria and the findings and proposed management strategies

[170] Lindenmayer et al., 2019

may not be applicable to other states with mountain ash forests. These observations are not to cast doubt on findings, but instead to make the reader aware of such limitations on the research.

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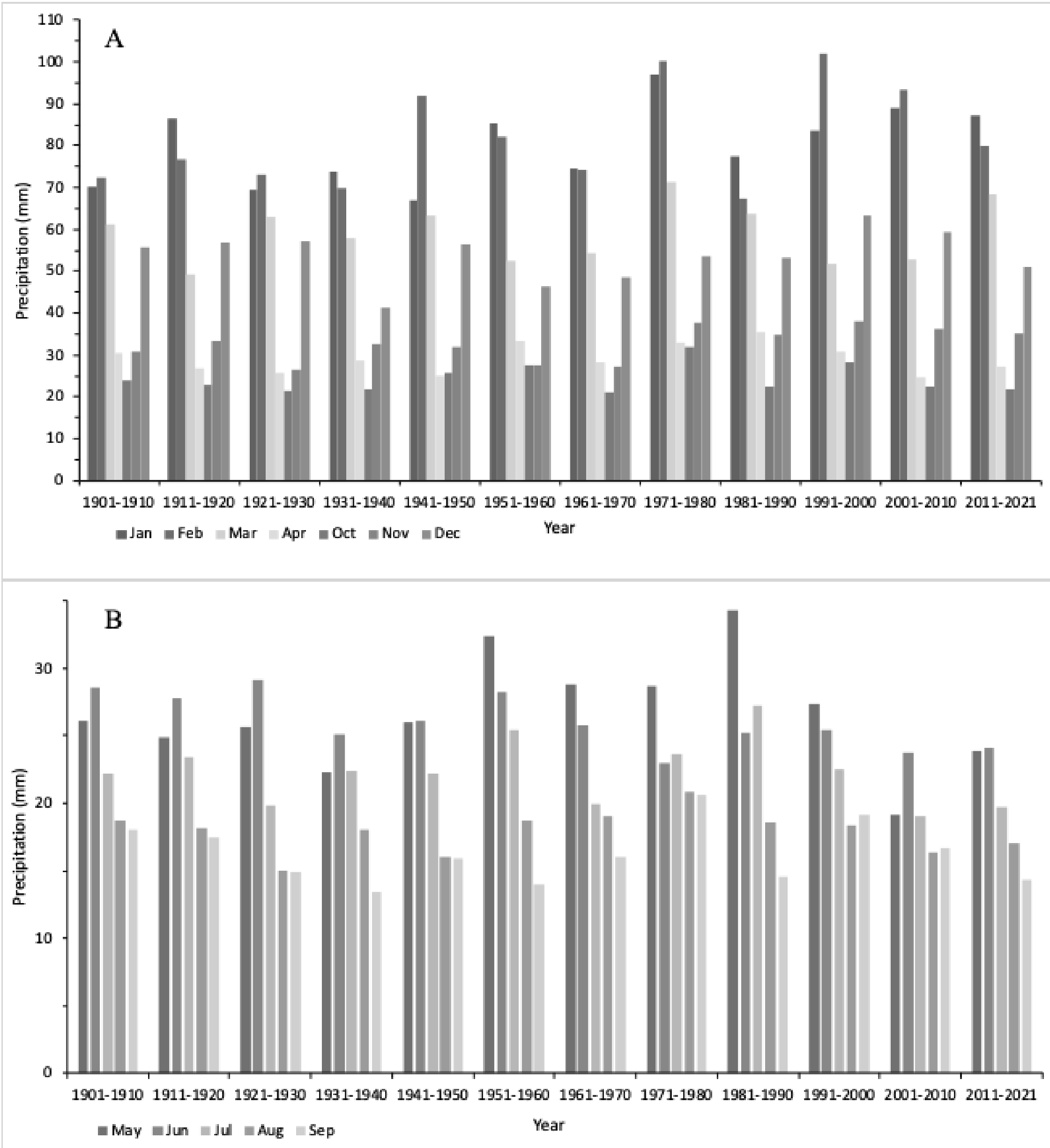
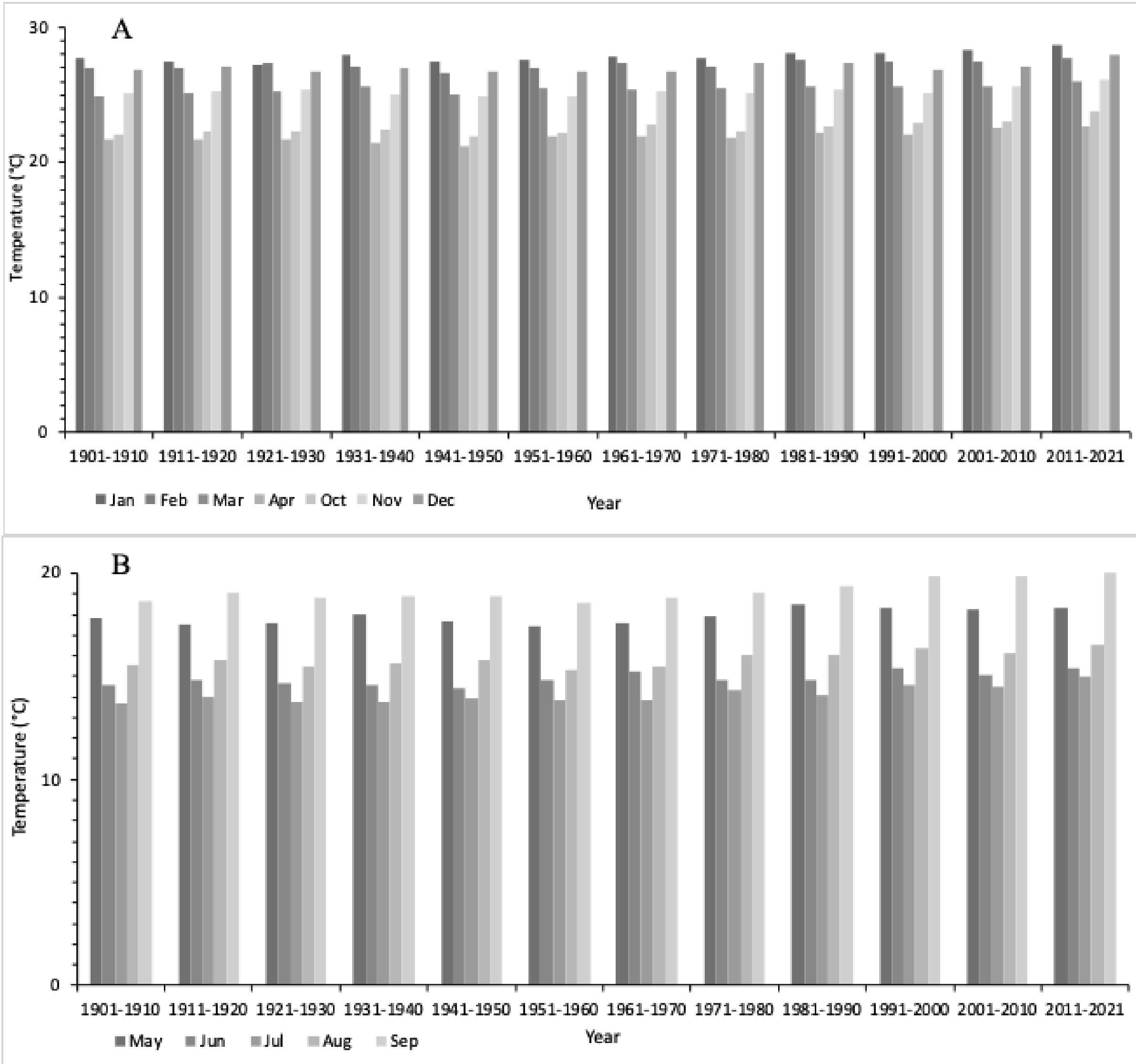
Supplementary Data




A
Temperature (°C)
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Temperature (°C)
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