Ecosystem services from forests in Victoria

Impact of the 2019-20 bushfires

Authors and analysts
Freya McCormick and Charlie Showers.

Photo
Gippsland state forest, Freya McCormick, 2019.

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Executive summary

The 2019-20 bushfires burnt over 1.2 million hectares of forest in east and north-east Victoria. This major impact on Victoria's natural capital will have implications for communities and industries in Victoria and beyond. Forest ecosystems contribute to the generation of many goods and services upon which people depend. These contributions are known as ecosystem services and they range from the provision of water and biomass, to the retention of soil and carbon, to opportunities for recreation and tourism. Although communities and industries benefit from ecosystem services, their value is either not captured in standard measures of economic activity such as gross state product or is not recognised as provided by ecosystems. This means that the full impact of bushfires may not be captured in traditional economic and social assessments of natural disasters. This study addresses this information gap by assessing the impact of the 2019-20 bushfires on the ecosystem services provided by forests in Victoria.

In 2019, the Department of Environment, Land, Water and Planning (DELWP) undertook an assessment of the types, quantity and value of ecosystem services provided by forests in Victoria. A set of ecosystem accounts consistent with the United Nations System of Environmental-Economic Accounting (SEEA) were produced. This informed the modernisation of Victoria's Regional Forest Agreements (RFAs) and was the first comprehensive assessment of forest ecosystem services across the state's five RFA regions.

The 2019 assessment was undertaken before the severe 2019-20 bushfire season in south-east Australia. The bushfires attracted global attention and had a significant impact on communities and economies in bushfire-affected areas.[1] Summer tourism was disrupted, and Melbourne and parts of regional Victoria experienced substantial air pollution from bushfire smoke.[2]

Box 1 United Nations System of Environmental-Economic Accounting

The SEEA is a framework for capturing and organising information on the environment and its contribution to economic and other human activity.

It draws on internationally agreed accounting concepts to gather and organise information in a consistent way that enables integration with other socioeconomic information.

Countries around the world are implementing the SEEA to better understand, monitor and report on linkages between the environment and the economy and society.

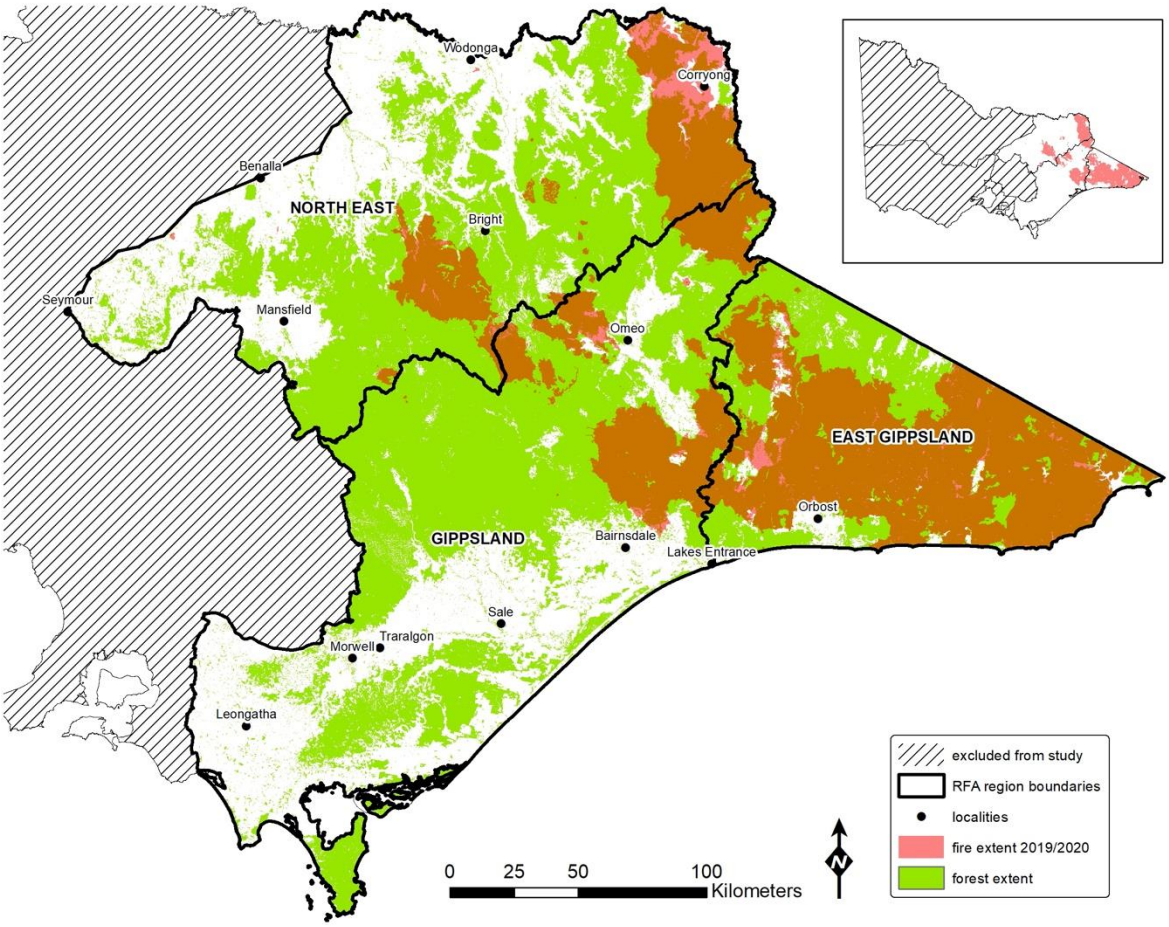
This study identifies and, where possible, quantifies and values the impact of the bushfires on forest ecosystem services. Overall, the bushfires are expected to reduce the capacity of forests to provide ecosystem services that communities and industries benefit from. While supply of ecosystem services is expected to increase over time as forests regenerate, reductions are expected in the short to medium term, and even over the long-term for certain ecosystem services such as water provision. More frequent and severe fires under climate change may place ongoing pressure on the ability of forests to provide these important ecosystem services into the future.

1. SGS Economics & Planning 2020, *COVID-19 and summer bushfires: The economic impact on your suburb and pathways to recovery*.
2. Arriagada, NB, Palmer, AJ, Bowman, DMJS, Morgan GG, Jalaludin, BB & Johnston FH 2020, 'Unprecedented smoke-related health burden associated with the 2019-20 bushfires in eastern Australia', *Medical Journal of Australia*, Research letter, March.

Forest ecosystem extent

The 2019-20 bushfires burnt 1.2 million hectares of forest across three RFA regions (see Figure 1). The vast majority was on public land in state forests and parks. East Gippsland was the most severely impacted: around 65 per cent of forest in the RFA region was burnt. The Gippsland and North East RFA regions each had around 20 per cent of forest burnt. Fire severity varied across the landscape, but more than half of forests burnt were impacted at the two highest fire severity classes: indicating significant scorching or consumption of canopy foliage.

Figure 1 Forest ecosystem extent and 2019-20 bushfire extent across eastern Victoria



Forest ecosystem services

Ecosystem services can flow directly to the community, such as when people visit a forest for recreation and relaxation, or when communities benefit from global climate regulation as forests retain stocks of carbon.

Ecosystem services also flow to industries that use them as inputs to the production of goods and services. Victorian industries that directly use forest ecosystem services include the tourism, timber, water, apiary and agricultural industries. Ecosystem services contribute to the value these industries add in the economy and the employment they provide.

Ecosystem services are typically classified as provisioning, regulating or cultural services.

Generally, supply of ecosystem services is expected to decrease due to the 2019-20 bushfires. However, the size, timing and duration of impacts varies.

Provisioning services

It is estimated that water provision from Ash forests may be reduced by around 3,900 gigalitres over 150 years if there were to be no further bushfires in this period, with half of this reduction occurring in the first 50 years post the 2019-20 bushfires. The annual reduction of water provision equates to less than 0.3 per cent of total water inflows across the East Gippsland, Gippsland and North East RFA regions. The total value of this ecosystem service loss is estimated at around $191 million over the 150 year period.

Timber provision may face longer-term impacts in terms of supply as plantations need to be replanted and regrown. Around 7,800 hectares of plantations were burnt in the bushfires, predominantly softwood plantations in the North East RFA region (around 6,500 hectares). A mix of softwood and hardwood plantations were burnt in East Gippsland.

While public access to firewood collection areas in bushfire-affected state forests has been disrupted, alternative firewood has been made available to households over the autumn 2020 firewood collection season. Firewood can be a by-product of bushfire response and recovery activities, such as road clearing or felling trees for safety purposes.

Forests provide biomass for fodder which is grazed by livestock. Around 150,000 hectares of forest licensed for agricultural use was burnt in the bushfires. Most of this is state forest licensed for grazing cattle, with the North East and Gippsland RFA regions most impacted.

The bushfires have reduced the floral resources available to apiarists for honey production and pollination services. 445 apiary sites on public land had forest burnt within bee foraging range, equating to 175,000 hectares of forest burnt within range of apiary sites. Over half of this area was burnt at the two highest fire severity classes, suggesting a significant reduction in provision of floral resources over the short to medium term. Over 75 per cent of apiary sites on public land in the East Gippsland RFA region were impacted.

Box 2 Assessing the impact of the bushfires on forest ecosystem services

Changes in supply of ecosystem services reported in this study are estimates derived through modelling and analysis and underpinned by a series of assumptions. They provide an *indication of potential change* due to the 2019-20 bushfires. Actual provision of ecosystem services is influenced by a range of factors, including environmental factors (such as rainfall) and human factors (such as the behaviour of people and businesses).

This means that ecosystem accounts produced in the future using observed data will inevitably differ from the estimates derived in this study. However, if future ecosystem accounts can isolate the impact of the bushfires, they could be compared to this study and provide a useful evaluation.

Regulating services

It is estimated that there will be an additional 724,000 tonnes of soil erosion across the three RFA regions in 2020 and 2021 due to the loss of vegetation cover. Of this, an estimated 130,000-261,000 tonnes will be discharged to waterways. The estimated value of this ecosystem services loss is $1.1-1.5 million.

The bushfires burnt forests in the upstream catchment of 108 localities across Victoria. This is expected to result in a decrease in the water flow

regulation service provided by forests to these localities. While highly dependent on the timing and severity of post-fire rainfall, as well as other factors, these localities may experience increased risk of river flooding.

Carbon stocks are estimated to decrease by 55 million tonnes in 2020 due to the bushfires, leading to a decrease in global climate regulation services provided by forests. The value of this ecosystem service loss is estimated at $575 million in 2020. East Gippsland was the most impacted, due to the large area of forest burnt in this RFA regions.

Cultural services

Around 1.2 million hectares of state forests, parks and reserves were burnt in the bushfires, affecting 49 state forests and 98 parks and reserves. This had a significant impact on provision of the recreation and tourism ecosystem service, particularly over the 2020 summer holiday season.

Box 3 Sometimes valuation is difficult, but value is unquestionable

Measuring ecosystem services in both physical and monetary terms is challenging, and some ecosystem services are not quantified or valued in this study.

Other ecosystem services have only been partially valued, and estimates may understate the full value of ecosystem services.

Where ecosystem services have been quantified or valued, the confidence around these estimates varies due to a range of factors including the availability and quality of data and the robustness of methods that can be practically applied. These limitations are discussed throughout the report.

The monetary values of ecosystem services cannot necessarily be aggregated as some services may overlap.

Introduction

The 2019-20 bushfires were exceptional in size and impact. Over 1.3 million hectares of land was burnt across Victoria between November 2019 and February 2020, predominantly in the east and north-east of the state. The fires and their aftermath have had a significant impact on communities, economies and the environment.

Bushfires have a direct impact on the economy and society through loss of life, impacts on health and wellbeing, the destruction of livestock, property and infrastructure, and business losses due to disruption and reduced tourism. Bushfires also have a major impact on natural capital – the 2019-20 bushfires burnt over 1.2 million hectares of forest – and this has flow on implications for people and businesses.

Forests have unique intrinsic value and they are also vital to our economy and society. Forest ecosystems contribute to the generation of a variety of goods and services upon which people depend. These contributions are known as ecosystem services and they range from the provision of water and biomass, to the retention of soil and carbon, to opportunities for recreation and tourism. Although communities and industries benefit from ecosystem services, their value is either not captured in standard measures of economic activity such as gross state product or is not attributable to ecosystems. This means that the full impact of bushfires may not be captured in traditional economic and social assessments of natural disasters.

In 2019, the Department of Environment, Land, Water and Planning (DELWP) completed an assessment of ecosystem services from forests in Victoria.[3] A set of ecosystem accounts consistent with the United Nations System of Environmental-Economic Accounting (SEEA) were produced. This informed the modernisation of Victoria's Regional Forest Agreements (RFAs)[4] and was the first comprehensive assessment of forest ecosystem services across the state's five RFA regions.

This study builds on the 2019 assessment and uses the SEEA framework to identify, quantify and value the potential impact of the 2019-20 bushfires on ecosystem services from forests in RFA regions. It provides new, Victoria-specific information on how bushfires can impact on natural capital.

This report provides an overview of the study, outlining the general approach and key methods and data used. This is followed by presentation and discussion of findings: the potential change (increase/decrease) in ecosystem services due to the 2019-20 bushfires and implications for communities and industries. The conclusion highlights key takeaways and future directions, while technical appendices detail the assessment of individual ecosystem services and the underpinning biophysical modelling and spatial data analysis.

3. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria.

4. RFAs are agreements between the Commonwealth Government and state governments that establish the framework for management of forests in an RFA region. Victoria has five RFAs covering over six million hectares of forest. They stretch from the southwest to the east of the state, covering all of Victoria except for the Wimmera-Mallee area in the northwest and the area east of Port Phillip Bay encompassing the Mornington Peninsula and Western Port Bay. For more information on Victoria's RFAs see https://www2.delwp.vic.gov.au/futureforests/what-were-doing/victorian-regional-forest-agreements

Overview of study

This study assesses the impact of the 2019-20 bushfires on ecosystem services from forests in Victoria using an ecosystem accounting framework consistent with the United Nations System of Environmental-Economic Accounting (SEEA).

The impact of the bushfires is assessed against a hypothetical counterfactual where the bushfires do not occur. Where possible, the change (increase or decrease) in supply of ecosystem services is quantified in physical terms and valued in monetary terms. Where this is not possible, proxy indicators are reported and/or the expected change in supply of ecosystem services is qualitatively discussed.

Bushfires can have long-term impacts on forests and may affect supply of ecosystem services for multiple years or even decades. The duration of impact is considered for each ecosystem service and, where possible, changes in supply of ecosystem services are quantified and valued over time.

Changes in supply of ecosystem services reported in this study are estimates derived through modelling and analysis and underpinned by a series of assumptions. They provide an *indication of potential change* due to the 2019-20 bushfires. Actual provision of ecosystem services is influenced by a range of factors, including environmental factors (such as rainfall) and human factors (such as the behaviour of people and businesses). This means that ecosystem accounts produced in the future using observed data will inevitably differ from the estimates derived in this study. However, if future ecosystem accounts are able to isolate the impact of the bushfires in observed data, they could be compared to this study and provide a useful evaluation.

Box 4 United Nations System of Environmental-Economic Accounting

The SEEA is a framework for capturing and organising information on the environment and its contribution to economic and other human activity. It is built on concepts and principles that align with the System of National Accounts, which is used to measure gross domestic product and other economic and social indicators.

The SEEA has two parts. The Central Framework is an international statistical standard adopted in 2012 which focus on stocks of environmental assets, flows between the environment and the economy, and economic activity related to the environment. Experimental Ecosystem Accounting (EEA) complements the Central Framework and is a spatial framework that focuses on ecosystems and the natural processes which contribute to economic and other human activity (ecosystem services). This study applies the EEA framework.

The SEEA EEA is currently an experimental framework which jurisdictions around the world – including Victoria – have been piloting. In 2017, the United Nations commenced a revision process with the intention to reach agreement on issues and formalise the framework as an international statistical standard by 2020. This study has been undertaken while the revision is underway, and consequently the application of concepts may differ from the framework that is formalised.

More information on the SEEA is available at www.seea.un.org/

Scope and methodology

Spatial boundary

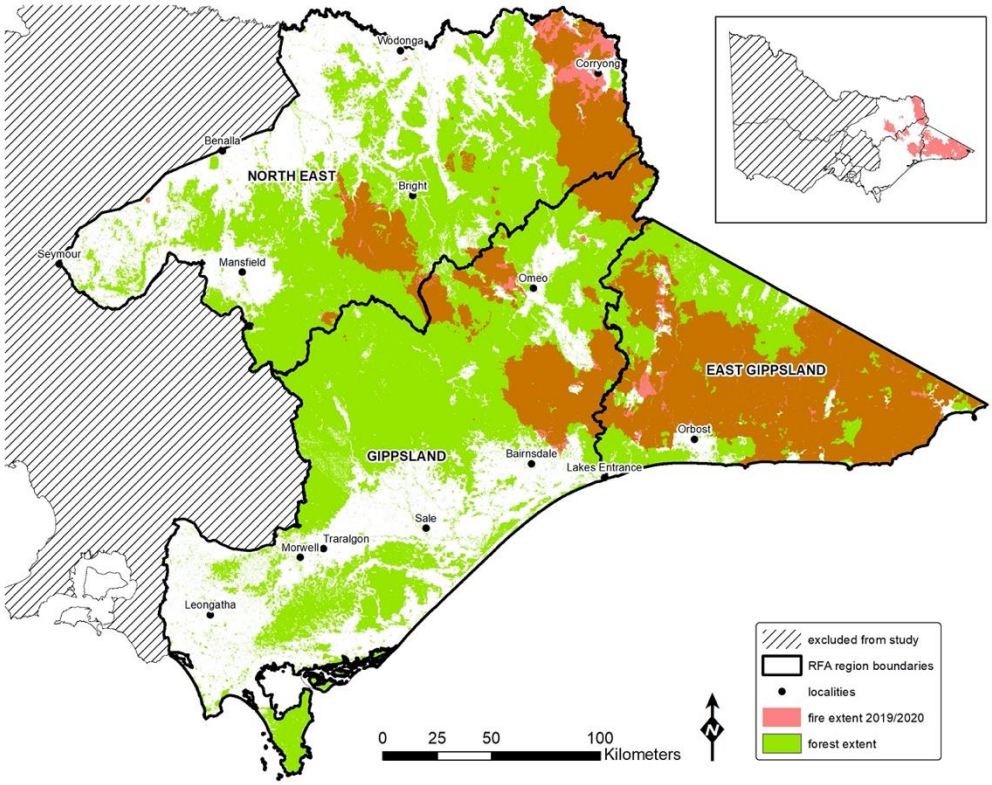
The assessment area for this study is forests in Victoria's Regional Forest Agreement (RFA) regions, including native and non-native forests on both public and private land. Forest extent is derived from the 2018 forest cover dataset developed through the Victorian Forest Monitoring Program (VFMP).[5] The 2019-20 fire extent is derived from fire severity mapping undertaken by the Department of Environment, Land, Water and Planning (DELWP).

This study primarily assesses change in supply of ecosystem services from forests burnt in the bushfires. However, where there are expected to be changes in supply of ecosystem services from unburnt forests *due to the bushfires* this is highlighted and discussed. This is particularly relevant to provisioning and cultural ecosystem services where the behaviour of 'users' of the ecosystem service may be influenced by the fires. For example, apiarists may move hives to unburnt areas of forest, meaning that these forests supply increased ecosystem services to the industry.

This study focuses on the impact of the bushfires in three RFA regions – East Gippsland, Gippsland and the North East (see Figure 2). Smaller fires occurred in other parts of the state in the 2019-20 bushfire season, such as western Victoria. However, this study focuses on the east and north-east of the state where large fires had a significant impact on natural capital. Where "the bushfires" or "the 2019-20 bushfires" are referred to in this study, this means the fires across the East Gippsland, Gippsland and North East RFA regions unless otherwise stated.

5. The VFMP, in line with the National Forest Inventory (see www.agriculture.gov.au/abares/forestsaustralia/australias-national-forest-inventory), defines forest as: "*An area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding two metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20 per cent. This includes Australia's diverse native forests and plantations, regardless of age. It is also sufficiently broad to encompass areas of trees that are sometimes described as woodlands.*" The VFMP dataset include forest cover on all land tenure types. For more information on the VFMP see www.forestsandreserves.vic.gov.au/forest-management/victorian-forest-monitoring-program

Figure 2 Forest ecosystem extent and 2019-20 bushfire extent across eastern Victoria



Timeframe

The impact of the 2019-20 bushfires is assessed over different timeframes for different ecosystem services, depending on the expected duration of impact and the data available. For example, the impact of the bushfires on water provision is assessed over 150 years, while the impact on soil retention is assessed over two years. For some ecosystem services, such as carbon retention, only the initial (one year) impact is be quantified and valued, although the expected future trajectory is qualitatively discussed.

Outputs of analysis

Change in annual supply of ecosystem services is quantified in physical terms (e.g. GL, m^3, tonnes) and valued in monetary terms ($) where possible. Where valuation is undertaken over multiple years, the net present value of future change in value is calculated using a discount rate of 4 per cent. [6,7]

Key outputs of the analysis are:

- estimated change (increase/decrease) in physical flows of ecosystem services from forests in RFA regions due to the 2019-20 bushfires
- estimated change (increase/decrease) in monetary flows ($) of ecosystem services from forests in RFA regions due to the 2019-20 bushfires
- indicators (e.g. hectares) or qualitative discussion of ecosystem services where change in flows cannot be estimated in physical and/or monetary terms.

Assessing change in future flows of ecosystem services

Change in supply of ecosystem services due to the 2019-20 bushfires is estimated for each ecosystem service using a variety of methods. While no new biophysical modelling has been undertaken for this study, it draws on EnSym modelling undertaken for the 2019 assessment of the ecosystem services of water provision and soil retention.[8] Spatial data analysis (using ArcGIS) is undertaken to inform assessment of several ecosystem services such as water provision, fodder, honey, pollination, soil retention, water flow regulation, and recreation and tourism.

Ultimately, the change (increase or decrease) in annual flow that can be attributed to the bushfires is derived. That is, the difference in annual flow of ecosystem services between a bushfire scenario and a counterfactual scenario where the 2019-20 bushfires do not occur. For some ecosystem services, total annual flow under each scenario will be derived. While useful information, total annual flows should be interpreted with caution, as they do not represent actual future projections of ecosystem services.

However, it is useful to compare the estimated change in annual flows to projected total annual flows or the annual flows reported in the forest ecosystem accounts produced for RFA regions in 2019. This comparison gives an indication of the magnitude of the impact of the bushfires on each ecosystem service.

6. In alignment with Victorian Government guidance. See Department of Treasury and Finance 2013, *Economic evaluation: Technical guidance*, State of Victoria, Melbourne.
7. Note that this approach deviates from the SEEA guidance on valuing environmental assets which suggests that private discount rates, rather than social discount rates typically used in government analysis, should be used to ensure alignment with the System of National Accounts. However, the SEEA guidance notes that this is not a straightforward choice which may, depending on the context, require consideration of various equity and other issues, including intergenerational equity. The aim of this study is not to value environmental assets for the purposes of alignment with non-environmental assets. Rather, it is to understand the value lost to society from reduced supply of ecosystem services after the 2019-20 bushfires. This has the potential inform forest and fire management policy and programs, and is best evaluated using social discount rates consistent with DTF guidance and public sector best practice. For more discussion on discount rate see United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, p. 126.
8. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria.

Box 5 Discounting future flows of ecosystem services

Generally, individuals have a 'time preference' – meaning they have a desire for benefits now rather than in the future, and a desire to defer costs until later rather than incurring them now. In relative terms the benefit and costs are larger now (worth more to us) and have a relatively lower value in the future. This means that a discount rate needs to be applied in order to consider future costs and benefits in terms of today's dollar value.

The need to apply a discount rate may not be immediately apparent when assessing the value of changes to ecosystem services caused by a bushfire that has already happened. However, if an intervention to restore ecosystems post-fire or reduce bushfire risk was being evaluated, a trade-off would need to be made between the cost of the intervention and future increases (or avoided decreases) in ecosystem services (among other benefits).

The standard approach to discounting has typically been developed for analyses where impacts are assessed over a relatively short time period (e.g. over the next 10-30 years). However, interventions or events that affect ecosystems often have impacts over a longer time period and on future generations. Choice of discount rates, and how to value future generations' costs and benefits has become a highly debated issue among economists.

Integration with ecosystem accounting

Application of ecosystem accounting in this study

An ecosystem accounting framework consistent with the United Nations System of Environmental-Economic Accounting (SEEA) conceptually underpins this study and the analysis draws on data and information from the ecosystem accounts produced for Victorian forests in 2019.[9]

This study does not produce 'future' ecosystem accounts for 2020 or beyond. The production of accounts is essentially a backwards looking exercise: a way of organising historical information and tracking trends over time. However, as this study demonstrates, information from accounts can be used to undertake forward looking analysis of ecosystem assets and services under different scenarios.

Fire in an ecosystem accounting framework

In an ecosystem accounting framework, fire is classified as a disturbance that impacts on ecosystem assets.[10] Disturbances can be natural or human-induced, and the distinction is not always clear-cut. For example, bushfires can be started by lightning, but their frequency and severity can be exacerbated by human-induced climate change. Bushfires can also be accidently or deliberately lit by people.

Fire affects the condition of an ecosystem asset. As a function of their extent and condition, ecosystem assets generate flows of ecosystem services. Consequently, changes to condition can impact on the quantity of ecosystem services provided. This is conceptually depicted in Figure 3.

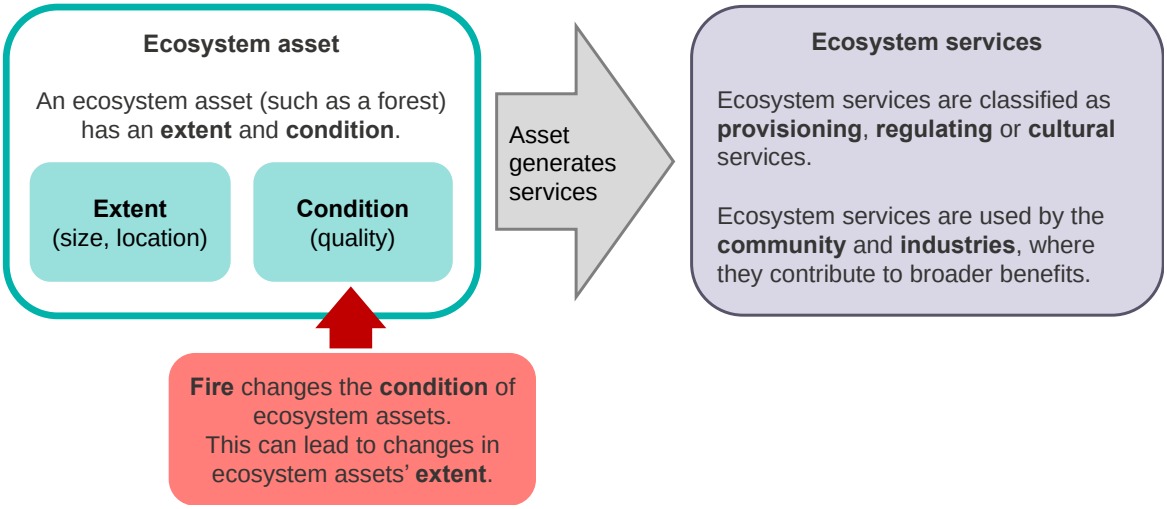
While fire does not necessarily affect the extent of ecosystem assets, if fire regimes are too frequent or severe this may affect the resilience of an ecosystem and reduce its capacity to naturally regenerate. Over time this may lead to changes in ecosystem type and consequently a reduction in the extent of a particular ecosystem asset.

It should be noted that fire is an important part of natural disturbance regimes for many ecosystems, including forests in south-east Australia. At certain intervals and severity fire can help maintain or enhance the condition of ecosystem assets, ultimately supporting the generation of ecosystem services over the long term.

Deliberately lit and controlled fires (planned burns) are a human-induced disturbance which can be used to enhance the condition of ecosystem assets. For example, Forest Fire Management Victoria conducts ecological planned burns specifically to maintain the health of plants and animals.[11]

9. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria.
10. United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, p. 15.
11. Forest Fire Management Victoria 2020, 'Planned burns – Plants and animals', accessed 31 August at https://www.ffm.vic.gov.au/bushfire-fuel-and-risk-management/plants-and-animals

Figure 3 Fire in an ecosystem accounting framework



Studies of the impact of fire on ecosystem services

The SEEA is a relatively new and developing framework, and there are limited examples of the application of ecosystem accounting principles to assess the impact of fire on ecosystem assets and services. Studies have tended to value losses of ecosystem services as a whole, rather than assessing the impact of fire on an ecosystem's capacity to provide different services.

However, there is likely to be increasing interest in application as climate change exacerbates the likelihood and severity of fires in many parts of the world. The cost of bushfires in terms of direct impacts on human health and built assets has typically been well understood. It will be increasingly important to also understand the cost of impacts on ecosystem assets and services.

- A study published by WWF-Australia in 2020 considered the impact of the 2019-20 bushfires on natural capital in eastern Australia. While the study did not quantify the impact on ecosystem services, permanent carbon stock losses were estimated at 20-70 million tonnes of carbon, and the cost of offsetting this loss was estimated at $1.0-2.8 billion.[12,13]
- A 2010 study valued losses of ecosystem services from major fires in south-east Australia, ranging from the 1983 Ash Wednesday fires to the 2009 Black Saturday fires.[14] Global estimates from a 1997 study[15] of the value of ecosystem services from different ecosystem types were applied, rather than values specific to Australian ecosystems. Estimated losses in the first year ranged from $78 million (1983 Ash Wednesday Fires) to $1.1 billion (both the 2003 Alpine Fires and 2006-07 Great Divide Fires).
- In the United States, a 2015 study estimated losses of ecosystem services from wildfire under different greenhouse gas mitigation scenarios.[16] Individual ecosystem services were not identified or quantified, rather vegetation cover was used as a proxy for all services provided by a particular ecosystem. Losses were valued based on the cost of actions to provide equivalent ecosystem services (vegetation cover), namely by undertaking fuel and land management activities. Activities were selected based on their efficiency at replacing lost ecosystem services.
- A 2013 study valued losses of ecosystem services from the Rim Fire in California.[17] Loss of vegetation cover was used as a proxy for loss of ecosystem services, which was valued using benefit transfer of values from other studies of comparable ecosystems. Estimated losses in the first year were valued at US$100-736 million.

12. Bishop, J 2020, *Burnt assets: The 2019-20 Australian bushfires*, WWF-Australia, Sydney.
13. The approach taken in the WWF-Australia study (assessing permanent carbon stock losses) differs from this study (which assesses the immediate impact of the bushfires on ecosystem services, including carbon retention). The studies have different framings and consequently yield different results. However, the underlying estimates of carbon emissions from the bushfires across south-east Australia broadly align. Emissions estimates discussed in the WWF-Australia study range from 400 to 1,000 Mt CO2, while the Department of Industry, Science, Energy and Resources estimated emissions of 850 Mt CO2. Department of Industry, Science, Energy and Resources 2020, *Estimating greenhouse gas emissions form bushfires in Australia's temperate forests: Focus on 2019-20*, Commonwealth of Australia, Canberra.
14. Stephenson, C 2010, *The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia*, Fire and adaptive management report number 88, Bushfire Cooperative Research Centre, Melbourne.
15. Costanza, R, d'Arge, R, de Groot, R, Farber, S, Grasso, M, Hannon, B, Limburg, K, Naeem, S, O'Neill, R, Paruelo, J, Raskin, R, Sutton, P & van den Belt, M 1997, 'The value of the world's ecosystem services and natural capital', *Nature*, volume 387, pp. 253–260.
16. Lee, C, Schlemme, C, Murray, J & Unsworth, R 2015, 'The cost of climate change: Ecosystem services and wildland fires', *Ecological Economics*, volume 116, pp. 261-269.
17. Earth Economics 2013, *The economic impact of the 2013 Rim Fire on natural lands: Preliminary assessment*, Tacoma.

Impact of the bushfires on forest ecosystem assets

Forest ecosystem extent and condition

Bushfires burnt over 1.3 million hectares of land in east and north-east Victoria between November 2019 and March 2020. Around 90 per cent of this land is forested: over 1.2 million hectares (see Figure 4 and Table 1). Of the forests burnt, the vast majority (around 95 per cent) are on public land. Around 800,000 hectares of state forest and 400,000 hectares of forested parks and reserves were burnt, as well as 50,000 hectares of forest of private land (see Table 2).

Three Regional Forest Agreement (RFA) regions were impacted – East Gippsland, Gippsland and the North East – which are the focus of this study. East Gippsland was the most severely affected RFA region, with 61 per cent of land and 64 per cent of forest burnt. In Gippsland 11 per cent of land and 18 per cent of forest was burnt, while in the North East 14 per cent of land and 20 per cent of forest was burnt (see Table 1).

Figure 5 Forest ecosystem extent and 2019-20 bushfire extent

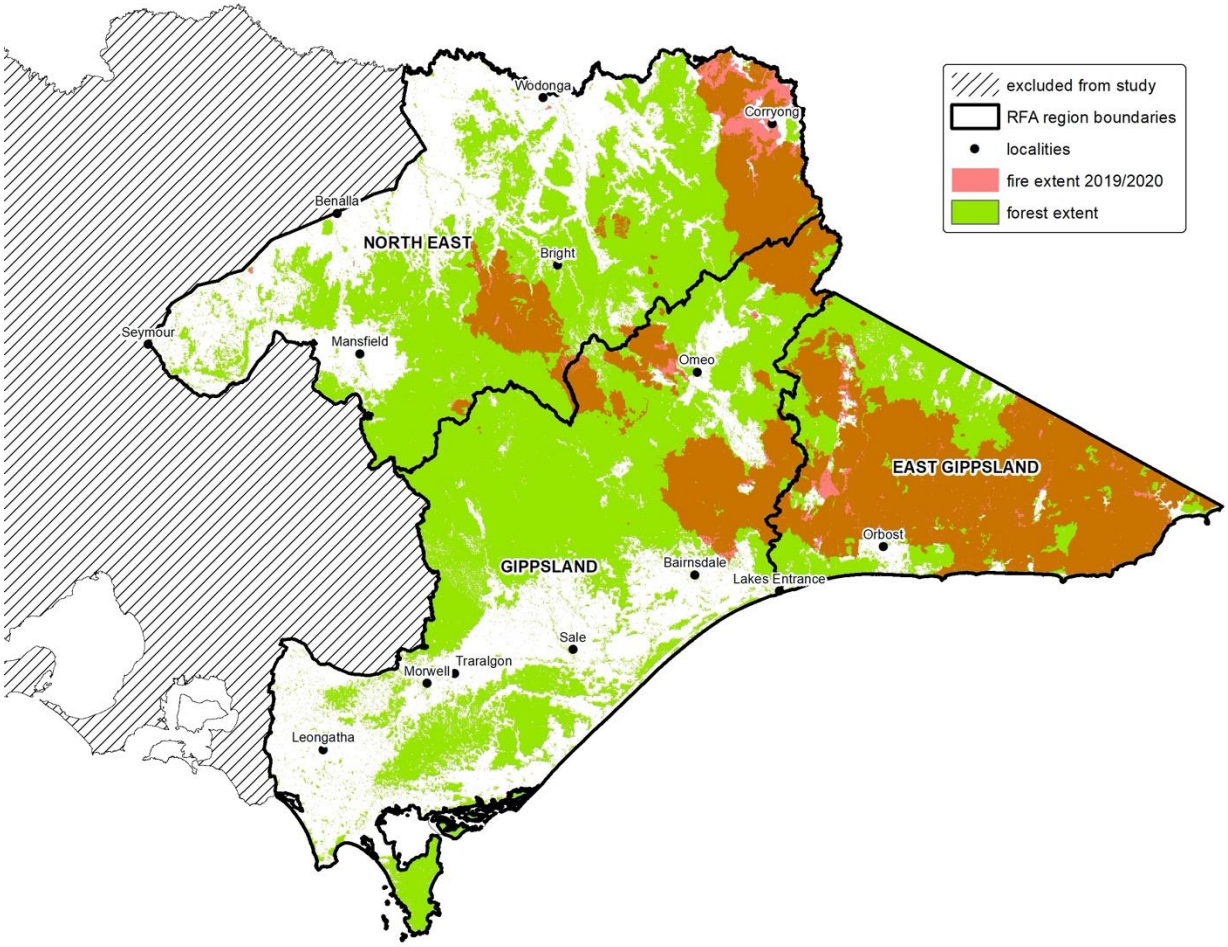


Table 1 Area of land and forest burnt in the 2019-20 bushfires in each RFA region (hectares)

RFA region	Total land area	Land area burnt	Forest area	Forest area burnt
East Gippsland	1,218,370	739,367	1,099,752	708,300
Gippsland	2,659,629	289,997	1,578,506	277,773
North East	2,318,763	328,706	1,351,316	272,442
Total	6,196,763	1,358,070	4,029,575	1,258,516

Forest area is a subset of land area.

Table 2 Area of forest burnt in the 2019-20 bushfires by tenure type in each RFA region (hectares)

RFA region	Public land				Private land	Total
	State forest	Parks and reserves	Plantation lease	Other		
East Gippsland	417,613	263,835	-	2,242	24,610	708,300
Gippsland	197,359	70,319	-	539	9,557	277,773
North East	167,101	80,605	4,804	583	19,350	272,442
Total	782,073	414,759	4,804	3,364	53,517	1,258,516

Bushfires burn at different severities across the landscape. DELWP has mapped fire severity for the 2019-20 bushfires across east and north-east Victoria using seven different classes. Fire severity classes range from ‘unburnt’, where less than 90 per cent of canopy and understory foliage is burnt, to ‘canopy burnt’, where understory foliage and more than 20 per cent of canopy foliage is consumed. (See Table 3 for fire severity class definitions.)

Across the three RFA regions, 39 per cent of forest burnt was burnt at fire severity ‘high canopy scorch’ (class 5), meaning that at least 80 per cent of canopy foliage was scorched in these areas. A further 33 per cent was burnt at ‘low canopy scorch’ (class 3), meaning that the understory was burnt but the canopy foliage largely unaffected. Smaller proportions were burnt at the highest class: class 6 (15 per cent) and class 4: medium canopy scorch (13 per cent). (Figure 6 and Table 4 show the area of forest burnt at each fire severity.)

Table 3 Fire severity classification of bushfires

Fire severity classification	
Class 6	Canopy burnt (>20% canopy foliage consumed)
Class 5	High canopy scorch (>80% of canopy foliage scorched)
Class 4	Medium canopy scorch (canopy a mosaic of both unburnt and scorched foliage, 20-80%)
Class 3	Low canopy scorch (canopy foliage is largely unaffected, <20% scorched, but understorey has been burned)
Class 2	Unburnt (canopy and understorey foliage are largely unburnt, >90%)
Class 1	Non-woody vegetation (unclassified)
Class 0	No data (e.g. due to obscuration by cloud, cloud-shadow and/or smoke and haze)

Figure 6 Fire severity of the 2019-20 bushfires

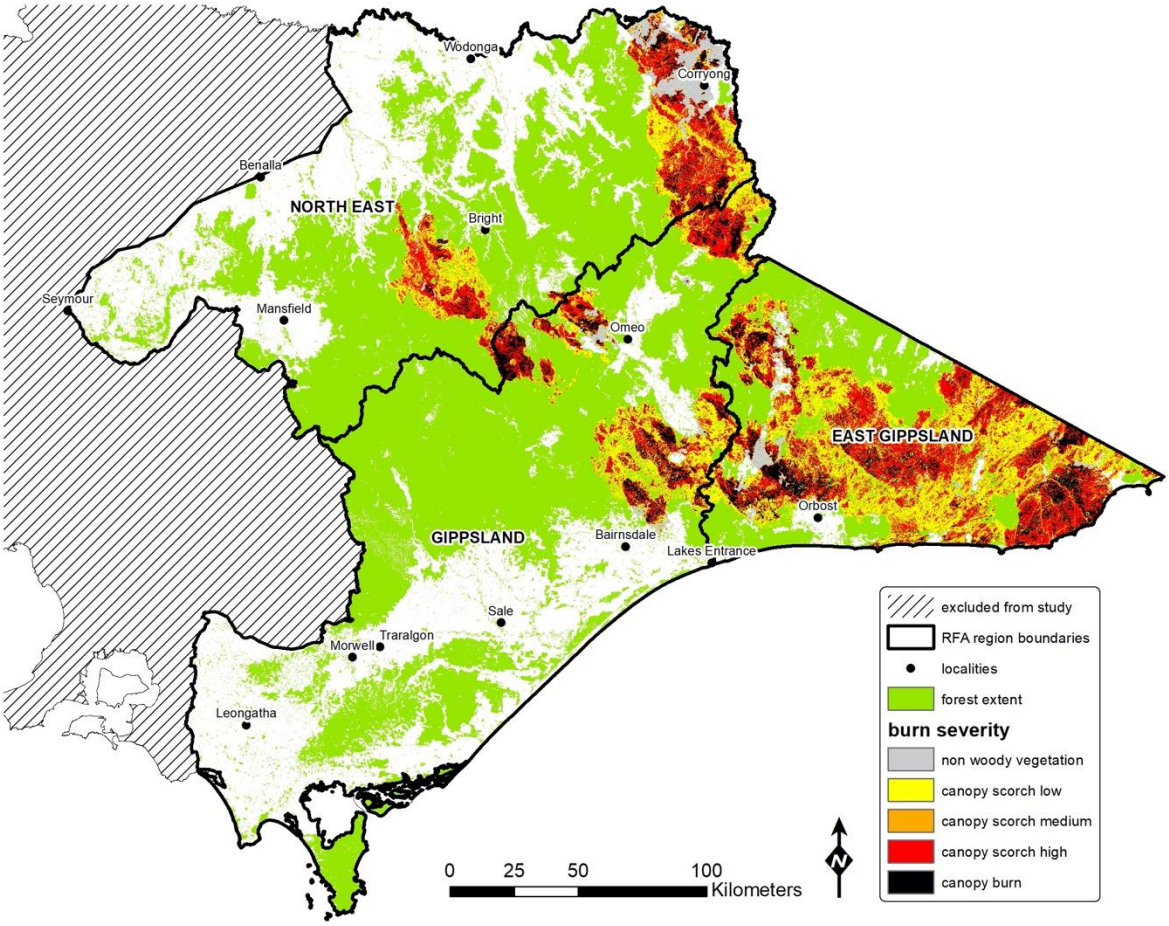


Table 4 Area of forest burnt in the 2019-20 bushfires at different fire severities (hectares)

RFA region	Non-woody vegetation (class 1)	Low canopy scorch (class 3)	Medium canopy scorch (class 4)	High canopy scorch (class 5)	Canopy burn (class 6)
East Gippsland	1,941	239,659	93,144	273,243	100,312
Gippsland	1,098	100,782	21,831	104,283	49,780
North East	1,297	71,447	49,147	114,544	36,007
Total	4,336	411,888	164,122	492,070	186,099

Areas burnt at fire severity class 1 are non-forested areas within the fire extent that overlap with the VFMP forest extent.

Fire severity is an indicator of the impact of bushfires on forest ecosystems, as it signifies reductions in vegetation and biomass. Vegetation and biomass are suggested as ecosystem condition metrics in both the 2012 SEEA EEA guidance and the draft guidance released as part of the SEEA EEA revision.[18] Vegetation and biomass are directly related to the capacity of forest ecosystem assets to supply ecosystem services such as soil and carbon retention, floral resources for honey provision and pollination services, and opportunities for recreation and tourism. As vegetation cover and biomass will increase as forests regenerate over time, fire severity provides an indication of temporary change in forest condition.

Fire can impact on species abundance directly, as flora and fauna are killed by fire, or indirectly though loss of habitat. The reduction in species abundance is related to the capacity of forests to generate ecosystem services such as pest control, opportunities for recreation and tourism, and ecosystem and species appreciation.[19] Other potential condition indicators that can be impacted by fire include landscape diversity, connectivity and fragmentation.

Because forests in south-east Australia are fire tolerant and typically regenerate after fire, fire severity is not necessarily an indicator of change in forest extent. A forest ecosystem asset can be burnt at high severity and retain the same ecosystem extent. The frequency of fire may provide a better indication of potential changes in forest extent or forest type. However, monitoring over time would be required to determine whether the 2019-20 bushfires result in any change in forest ecosystem extent.

Most of the area burnt in 2019-20 bushfires was fire-tolerant mixed-species eucalypt forest. These species typically survive most fires and regenerate by resprouting. Ash species are typically killed by high intensity fire and regenerate through seeds that are released from the canopy. However, if trees are killed before they reach seed-bearing age (around 20 years), Ash forests may not regenerate without intervention. Reseeding of Alpine Ash to initiate forest regeneration, informed by fire severity mapping and on ground assessment, has been identified as a potential biodiversity response action in the wake of the 2019-20 bushfires.[20]

Figure 7 shows areas of forest burnt multiple times since 2005. While large areas of forest have been burnt once (green) or twice (yellow), smaller areas have been burnt three (orange), four (red) or five for more (black) times. The underlying data is reported in Table 5, Table 6 and Table 7.

18. United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, p. 72-74; United Nations Statistics Division 2020, 'Chapter draft prepared for global consultation – Chapter 5: Accounting for ecosystem condition', System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting Revisions, March.
19. Ecosystem and species appreciation refers to the value people obtain from the existence of ecosystems and species, even without visiting forests that provide this ecosystem service.
20. Department of Environment, Land, Water and Planning 2020, *Victoria's bushfire emergency: Biodiversity response and recovery – Preliminary report (version one)*, State of Victoria, East Melbourne, p. 30.

Figure 7 Area of forest burnt multiple times since 2005

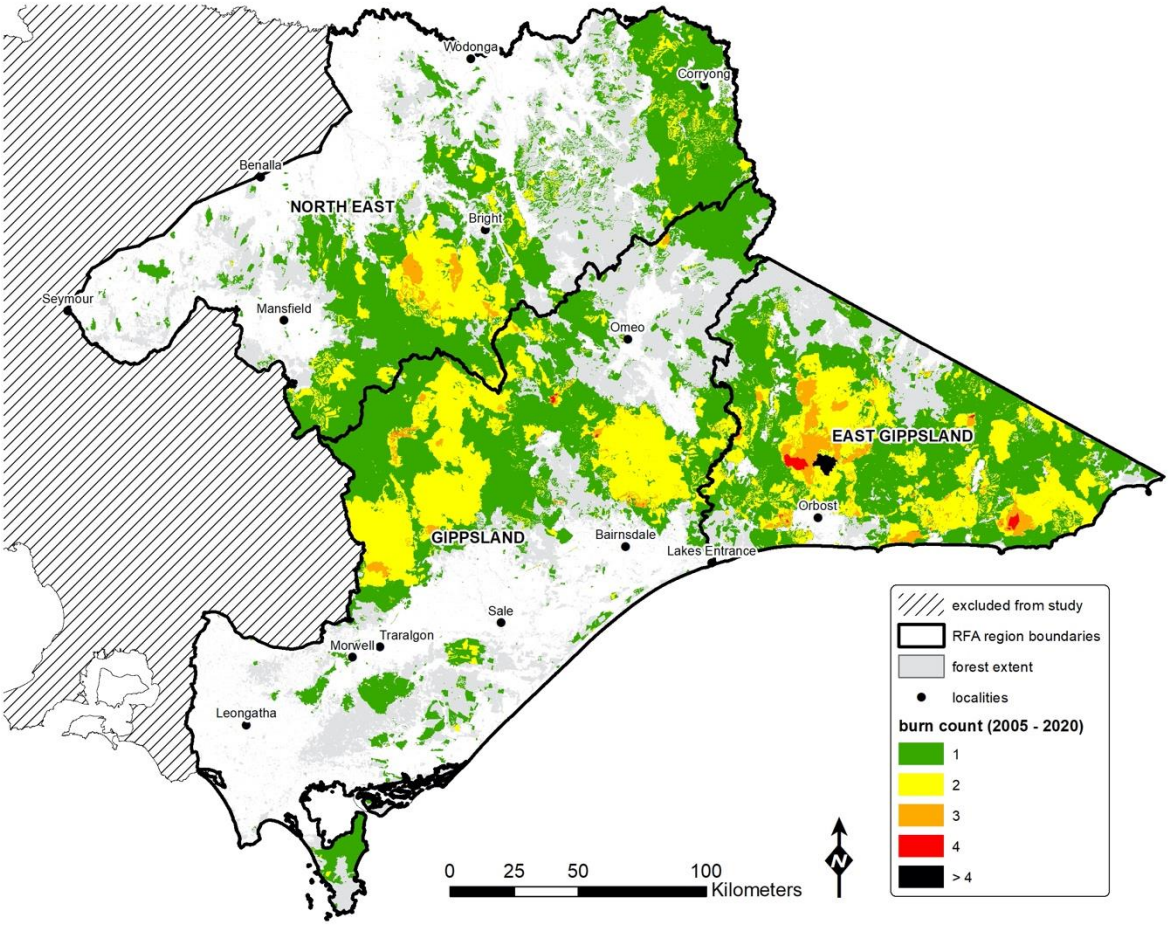


Table 5 Area (hectares) of forest burnt at different frequencies in last 5 years (2016-2020)

RFA region	1 time	2 times	3 times
East Gippsland	680,491	19,707	186
Gippsland	271,846	4,618	1
North East	255,282	14,806	-
Total	1,207,619	39,131	187

Table 6 Area (hectares) of forest burnt at different frequencies in last 10 years (2011-2020)

RFA region	1 time	2 times	3 times	4 times	5 times
East Gippsland	514,583	168,610	15,124	3,608	15
Gippsland	250,319	25,371	861	1	-
North East	240,713	29,255	180	-	-
Total	1,005,615	223,236	16,165	3,609	15

Table 7 Area (hectares) of forest burnt at different frequencies in last 15 years (2006-2020)

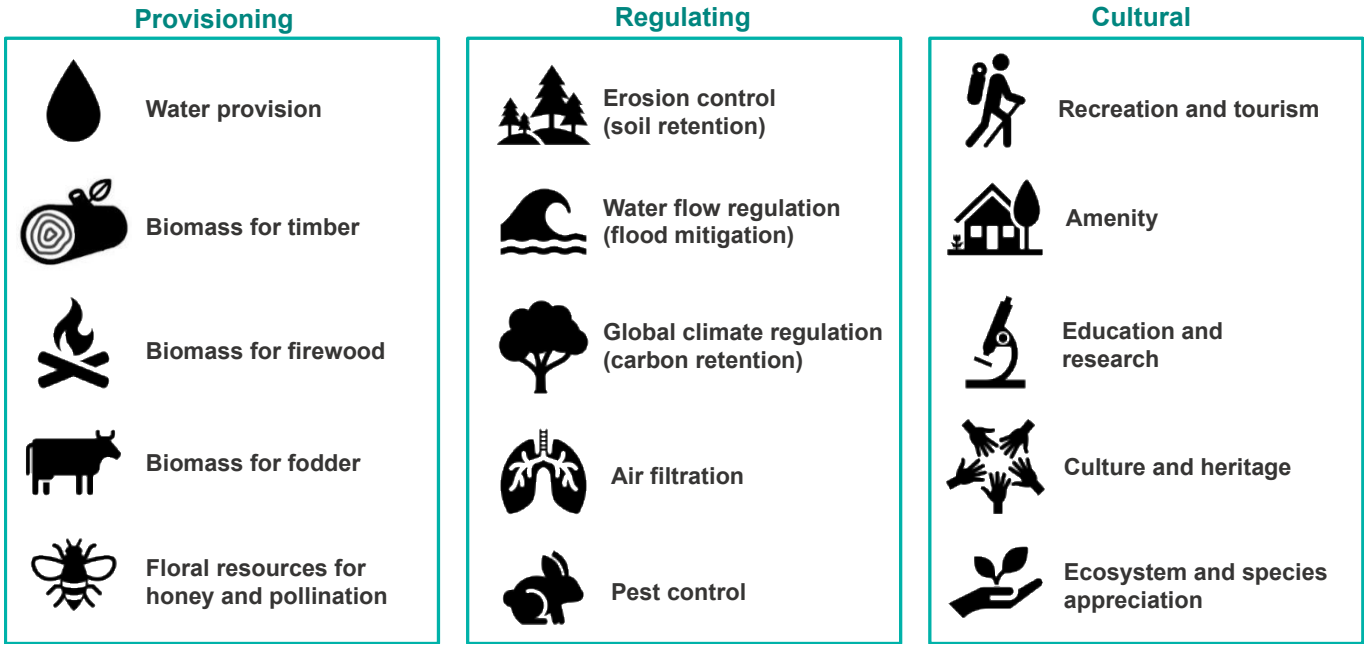
RFA region	1 time	2 times	3 times	4 times	5 times	6 times	7 times
East Gippsland	391,438	256,598	47,048	4,005	356	1,797	1,908
Gippsland	155,628	115,719	4,991	616	16	1	-
North East	150,500	103,215	17,730	39	-	-	-
Total	697,566	475,532	69,769	4,660	372	1,798	1,908

Impact of the bushfires on forest ecosystem services

What are forest ecosystem services?

Forests generate a diverse range of ecosystem services. These services flow to people and businesses (users) and contribute to benefits in the community and the economy. Ecosystem services provided by forests in Victoria are shown in Figure 8 and discussed throughout this section. These ecosystem services have been identified in line with SEEA guidance and the Common International Classification of Ecosystem Services (CICES).[21]

Figure 8 Ecosystem services from forests in Victoria



21. European Environment Agency 2020, 'CICES: Towards a common classification of ecosystem services', version 5.1, accessed 31 August at https://cices.eu/

Summary of bushfire impacts

Table 8 and Table 9 summarise the estimated impact of the 2019-20 bushfires on key ecosystem services, in physical and monetary terms.

For some ecosystem services, the impact on the actual physical quantity of service supplied could not be estimated, and proxy indicators are reported instead. An example of this is provision of fodder, where the area forest under agricultural license that was burnt is reported, instead of the actual reduction in the quantity of fodder provided.

While the change in some ecosystem services could not be valued in monetary terms, this does not imply a lack of value. For these ecosystem services, the direction of the expected change in value is reported in Table 9 and they are qualitatively discussed in the report.

Additional ecosystem services are not quantified or valued, but the impact of the bushfires is qualitatively discussed. This includes biomass for firewood, air filtration, pest control, amenity, education and research, culture and heritage, and ecosystem and species appreciation.

The remainder of this section summaries key findings on the impact of the 2019-20 bushfires on ecosystem services. Detailed discussion of the methods used to quantify, and value change is provided in Appendix A.

Table 8 Impact of the bushfires on supply of ecosystem services – physical indicators

Ecosystem service	Metric	East Gippsland	Gippsland	North East	Total
Provisioning services					
Water provision	GL reduction in water yield (2020-2169)	155	1,856	1,912	3,923
	% of total water yield (2020 – 2169)[a]	0.1%	0.3%	0.2%	0.2%
Timber provision	Ha plantation burnt	1,291	-	6,521	7,812
Fodder (grazing)	Ha licensed area burnt	24,604	59,269	64,330	148,202
Honey and pollination	No. apiary sites within range of burnt forest	261	150	34	445
	Ha of forest burnt within apiary site range	108,666	50,005	15,863	174,534
Regulating services					
Soil retention	'000 tonnes increased erosion (2020-2021)	51-102	32-65	47-94	130-261
Water flow regulation	No. localities with increased flood potential	-	-	-	108
Climate regulation	Mt reduction in carbon stock (in 2020)	36	9	10	55
Cultural services					
Recreation	No. state forests, parks and reserves burnt[b]	101	33	26	146
	Ha state forests, parks and reserves burnt	689,503	267,919	250,161	1,207,583

a. Water yield loss volumes as a proportion of total water yield, although quantifiable, are negligible and likely much smaller than future reductions in water yield due to climate change.

b. Total is less than the sum of the three RFA regions, as some state forests, parks and reserves span multiple RFA regions.

Table 9 Impact of the bushfires on supply of ecosystem services – value of ecosystem service loss

Ecosystem service	Metric	East Gippsland	Gippsland	North East	Total
Provisioning services					
Water provision (2020 – 2169)	$ million	2	70	120	191
Fodder	Not valued	↓	↓	↓	↓
Honey and pollination	Not valued	↓	↓	↓	↓
Regulating services					
Soil retention (2020 – 2021)	$ million	Up to 2.1	0.3-1.4	0.8-2.0	1.1-5.5
Water flow regulation	Not valued	↓	↓	↓	↓
Climate regulation (in 2020)	$ million	376	96	101	574
Cultural services					
Recreation	Not valued	↓	↓	↓	↓

Provisioning services

Water supply

Forests capture water and release it to natural, human modified and human created water supply systems. Provision of this ecosystem service is influenced by climate and rainfall, with greater service flows in wet years.

This ecosystem service is used by the water industry and the agricultural industry. In turn, the water industry supplies water to households and businesses.

Water provision could decrease over the long term as a result of the 2019-20 bushfires. This is driven by the regeneration of Ash forests that are killed by high-intensity fire, as Ash forests consume a substantial quantity of water while regenerating. Figure 9 shows areas of Ash forest burnt at the two highest fire severity classes (shown in red), which may be a stand-replacing event. Reductions in water provision are likely to flow from these areas of regenerating forest due to the 2019-20 bushfires if there were to be no future bushfires. It is however highly likely that bushfires will be experienced in some of the same areas over future decades which will reset forest stand age, therefore reassigning water provision losses to future fire events.

Water provision is estimated to decrease by 3,900 gigalitres over 150 years (from 2020 to 2069) due to the 2019-20 bushfires, assuming there are no fires that reset forest age over this period. Over half of this reduction occurs in the first 50 years post-fire (see Table 10). The potential reduction in annual water provision of the affected catchments as a per cent of total water inflows was in less than 0.1 per cent in the East Gippsland RFA region, less than 0.4 per cent in the Gippsland RFA region and less than 0.3 per cent in the North East RFA region. The reductions in water provision are overall less than 0.3 per cent of total water inflows. The estimated value of this ecosystem service loss is $191 million over 150 years (see Table 11).

Figure 9 Ash forests burnt at high fire severity (class 5 and class 6) in the 2019-20 bushfires

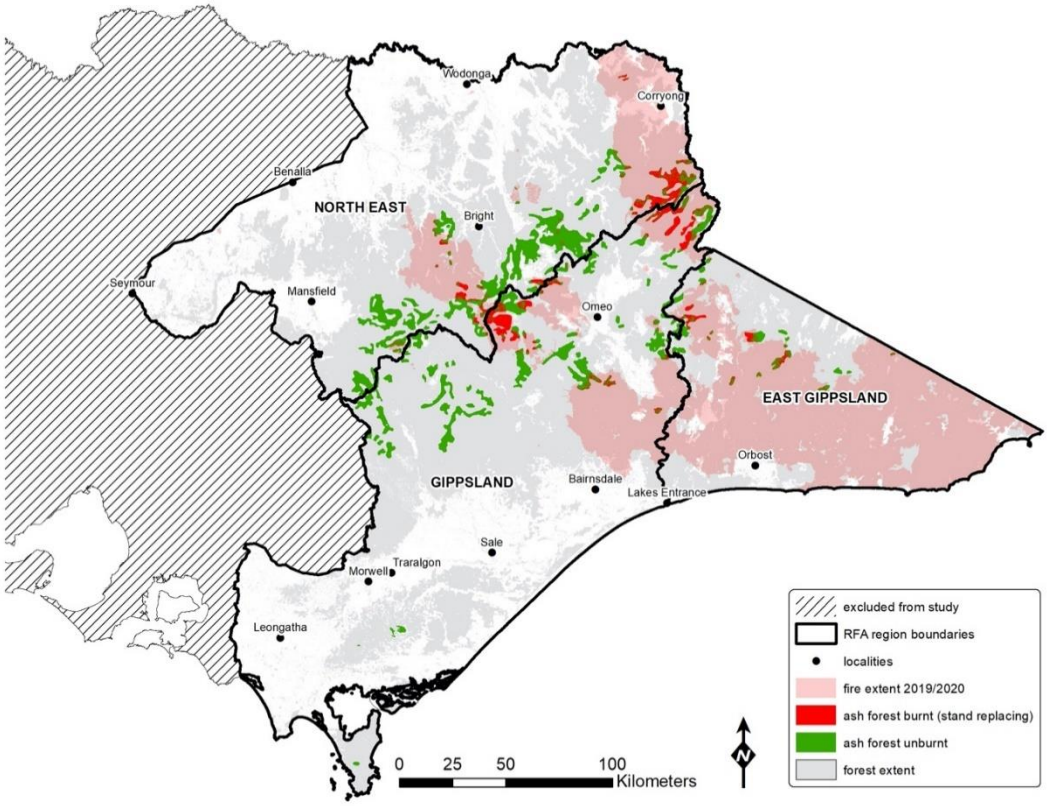


Table 10 Impact of the 2019-20 bushfires on the ecosystem service of water provision (ML)

RFA region	Total (2020-2169)	2020-2044	2045-2069	2070-2094	2095-2119	2120-2144	2145-2169
East Gippsland	-154,560	-28,740	-53,040	-34,260	-20,140	-11,660	-6,730
Gippsland	-1,856,270	-309,460	-649,740	-422,110	-248,270	-143,720	-82,970
North East	-1,911,910	-370,300	-650,940	-419,400	-246,370	-142,580	-82,310
Total	-3,922,740	-708,500	-1,353,730	-875,770	-514,780	-297,960	-172,000

Note that these reductions in water provision are overall less than 0.3 per cent of total water inflows.

Table 11 Impact of the 2019-20 bushfires on the ecosystem service of water provision ($, present value)

RFA region	Total (2020-2169)	2020-2044	2045-2069	2070-2094	2095-2119	2120-2144	2145-2169
East Gippsland	-1,550,960	-661,250	-676,560	-166,560	-36,840	-8,010	-1,740
Gippsland	-69,564,280	-25,881,090	-33,170,270	-8,215,660	-1,817,060	-394,720	-85,480
North East	-119,796,530	-53,443,400	-50,499,180	-12,393,430	-2,737,300	-594,490	-128,740
Total	-190,911,770	-79,985,740	-84,346,000	-20,775,650	-4,591,190	-997,220	-215,960

Biomass for timber

Forests provide biomass (trees) which is harvested as timber. Biomass is harvested from native forests and from plantation forests grown specifically for timber. Native timber harvesting will be phased out in Victoria by 2030.

This ecosystem service is used by the timber industry. In turn, the timber industry provides a benefit to businesses producing wood and paper products by suppling timber.

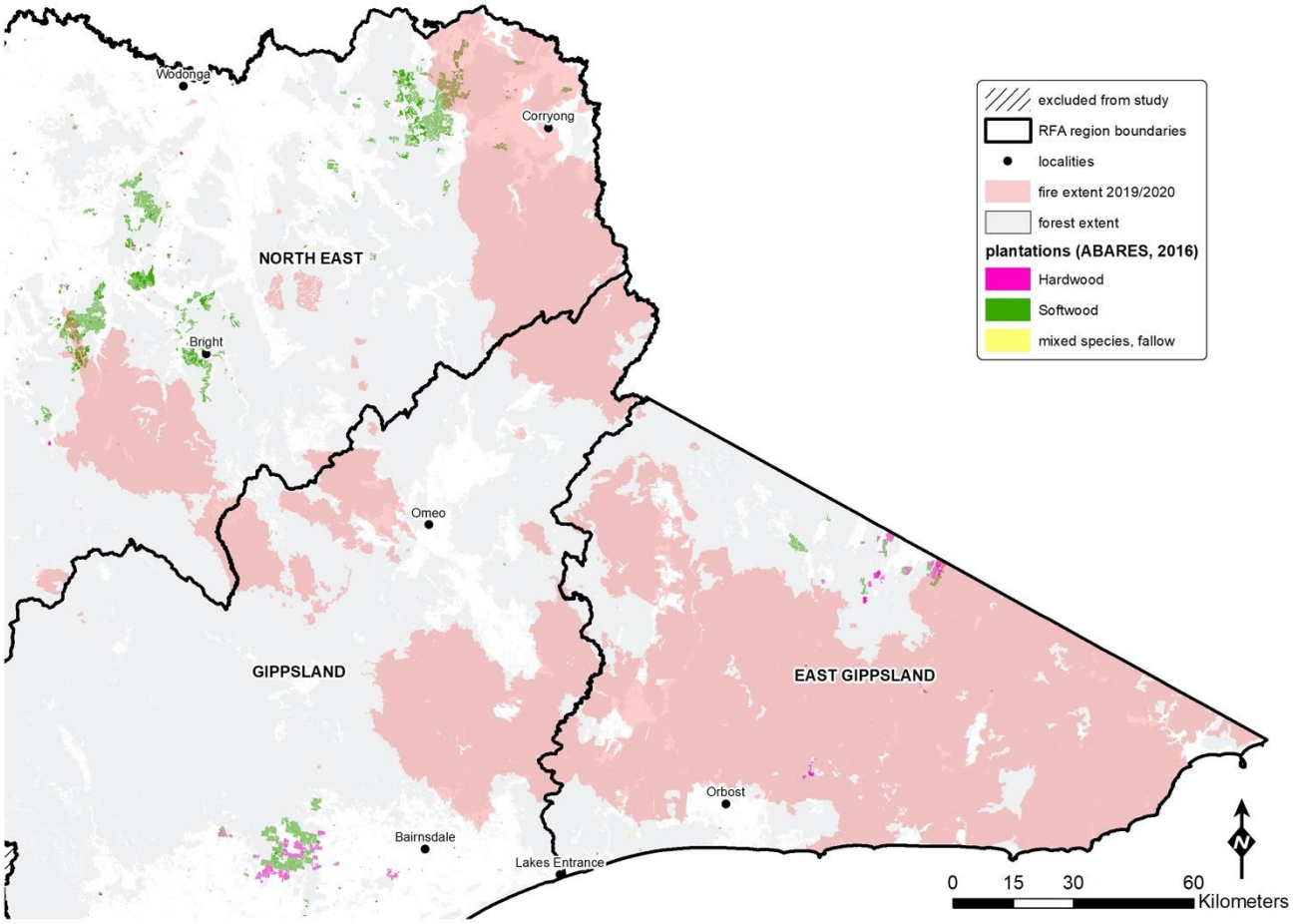
Provision of timber may face longer-term impacts in terms of supply, as plantations need to be replanted and regrown. Around 7,800 hectares of plantations were burnt in the bushfires, predominantly softwood plantations in the North East RFA region (around 6,500 hectares). A mix of softwood and hardwood plantations were burnt in East Gippsland (see Table 12 and Figure 10).

Table 12 Total plantation area and area burnt in the 2019-20 bushfires (hectares)

	Plantation area				Plantation area burnt			
	Hardwood	Softwood	Mixed/ unknown	Total	Hardwood	Softwood	Mixed/ unknown	Total
East Gippsland	3,318	2,358	124	5,801	933	328	30	1,291
Gippsland	29,065	59,775	551	89,390	-	-	-	-
North East	2,993	53,079	26	56,098	31	6,490	-	6,521
Total	35,376	115,212	701	151,289	963	6,819	30	7,812

Source: ABARES National Plantation Inventory 2016

Figure 10 Plantation forest burnt in the 2019-20 bushfires



Biomass for firewood

Forests provide biomass which is collected or harvested for firewood. In state forests, household firewood collection is permitted in spring and autumn within designated collection areas. Firewood is also a primary or by-product of commercial harvesting in native and plantation forests.

This ecosystem service is used directly by households who collect firewood for heating, cooking or aesthetic enjoyment. It is also used by commercial harvesters who supply firewood to businesses and households.

While public access to firewood collection areas in bushfire-affected state forests has been disrupted, alternative firewood was made available to households over the autumn 2020 firewood collection season.

Firewood can be a by-product of bushfire response and recovery activities such as clearing roads or felling trees for safety purposes. Cleared biomass have been made available to the public as firewood following the 2019-20 bushfires.[22]

Biomass for fodder

Forests provide plant biomass (fodder) which is grazed by livestock. In Victoria, cattle grazing is permitted in some areas of forest on public land. Livestock grazing also takes place in areas of forest on private land. This ecosystem service is used by the agricultural industry as an input to livestock production.

Fodder provision from forests burnt in the 2019-20 bushfires is likely to decrease in the short to medium term, as vegetation cover is reduced. Provision of this ecosystem service is expected to increase over time as forests regenerate.

Ideally, this ecosystem service would be quantified as the volume or weight of fodder provided by forests. That is, the quantity of plant biomass consumed by grazing livestock (cattle). However, in the absence of this information, the area of public forest licensed for agricultural use is reported as an indicator.

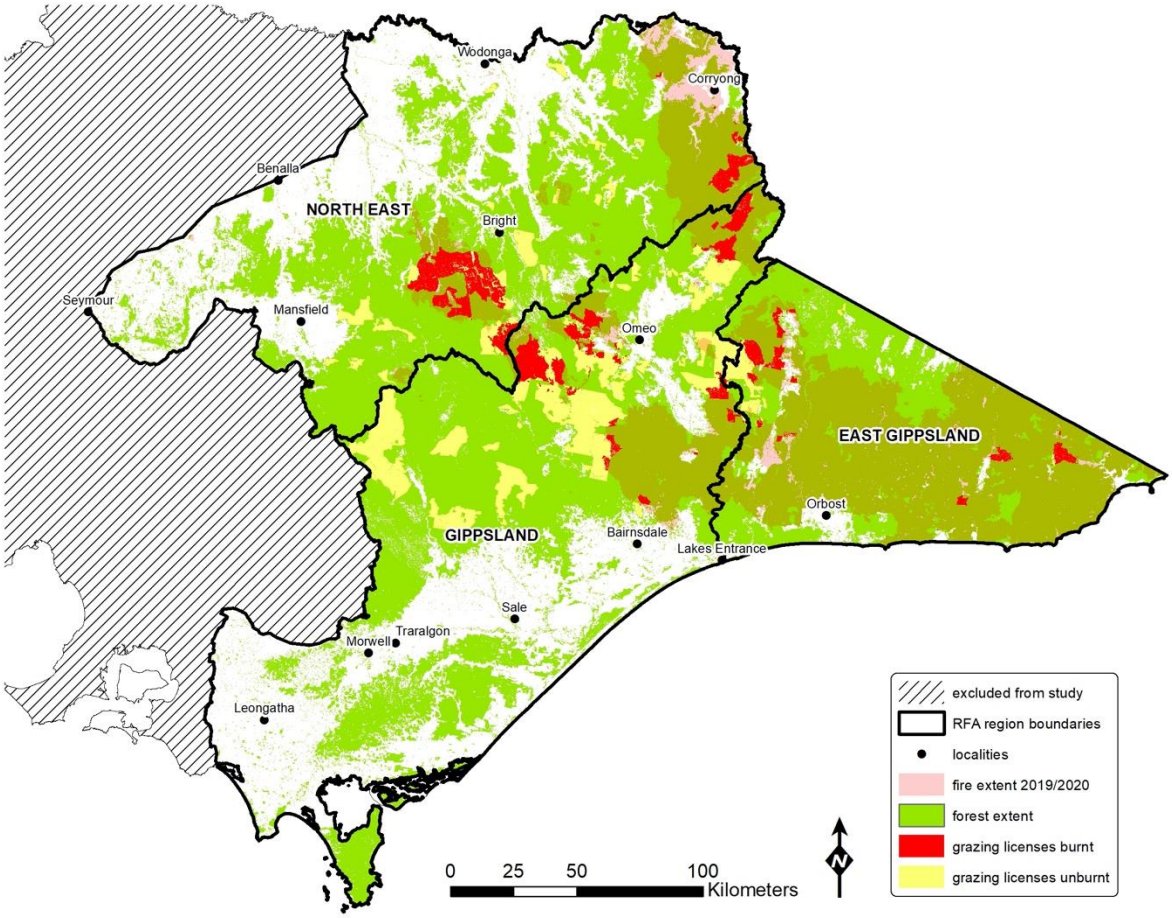
Almost 150,000 hectares of public forest licensed for agricultural use was burnt in the 2019-20 bushfires across East Gippsland, Gippsland and the North East. This represents around a third of the total area of public forest licensed for agricultural use in these RFA regions. Over half of the licensed area burnt was burnt at the two highest fire severity classes (class five and six – see Table 3 for more information on fire severity classes).

22. For example see Department of Environment, Land, Water and Planning 2020, 'Additional firewood collection area opens in the Upper Murray', accessed 31 August at https://www2.delwp.vic.gov.au/media-centre/media-releases/additional-firewood-collection-area-opens-in-the-upper-murray

Table 13 Area of forest licensed for agricultural use burnt in the 2019-20 bushfires (hectares)

RFA region	Total licensed area	Licensed area burnt	Burnt at class 1	Burnt at class 3	Burnt at class 4	Burnt at class 5	Burnt at class 6
East Gippsland	44,354	24,604	79	9,480	3,350	8,889	2,805
Gippsland	301,147	59,269	118	15,195	4,765	25,209	13,981
North East	132,126	64,330	112	21,147	14,894	24,813	3,363
Total	477,628	148,202	310	45,823	23,009	58,911	20,150

Figure 11 Area of forest licensed for agricultural use (grazing) burnt in the 2019-20 bushfires



Floral resources (for honey and pollination)

Forests provide floral resources (nectar and pollen) which support managed bee populations. Apiarists (beekeepers) place hives on public and private land within or near forests and use the floral resources (particularly eucalypts) for honey production and to strengthen hives before they are transported to pollinate agricultural crops.

This ecosystem service is used by the apiary industry, which in turn supplies commercial pollination services to the agricultural industry, and honey and other bee products to households and businesses. Households may also use this ecosystem service directly for non-commercial honey production, and farmers and households with gardens also benefit from wild pollination services.

Floral resources from forests burnt in the 2019-20 bushfires are expected to decrease in the short to medium term, reducing the capacity of these forests to support the provision of honey and pollination services. Provision of this ecosystem service is expected to increase over time as forests regenerate, and the speed at which this occurs is related to how severely forests were burnt. However, the overall impact of the bushfires on honey and pollination will depend on whether apiarists can move hives to unburnt forests and access floral resources in other areas.

The impact of the 2019-20 bushfires on apiary sites on public land gives an indication of the impact on provision of floral resources to apiarists, although the impact on apiary sites on private land is not captured.[23] Across East Gippsland, Gippsland and the North East, 305 public land apiary sites were *within* the area of forest burnt, and a further 140 sites had forest burnt within their range (see Table 14).[24] This represents 34 per cent of the total number of public land apiary sites across the three RFA regions. In total, around 175,000 hectares of forest within range of public land apiary sites was burnt, representing a quarter of total forest within range (see Table 15 and Figure 12).

Table 14 Number of apiary sites on public land impacted by the 2019-20 bushfires

RFA region	Total apiary sites	Apiary sites within burnt area	Apiary sites within range of burnt area
East Gippsland	349	196	261
Gippsland	586	85	150
North East	363	24	34
Total	1,298	305	445

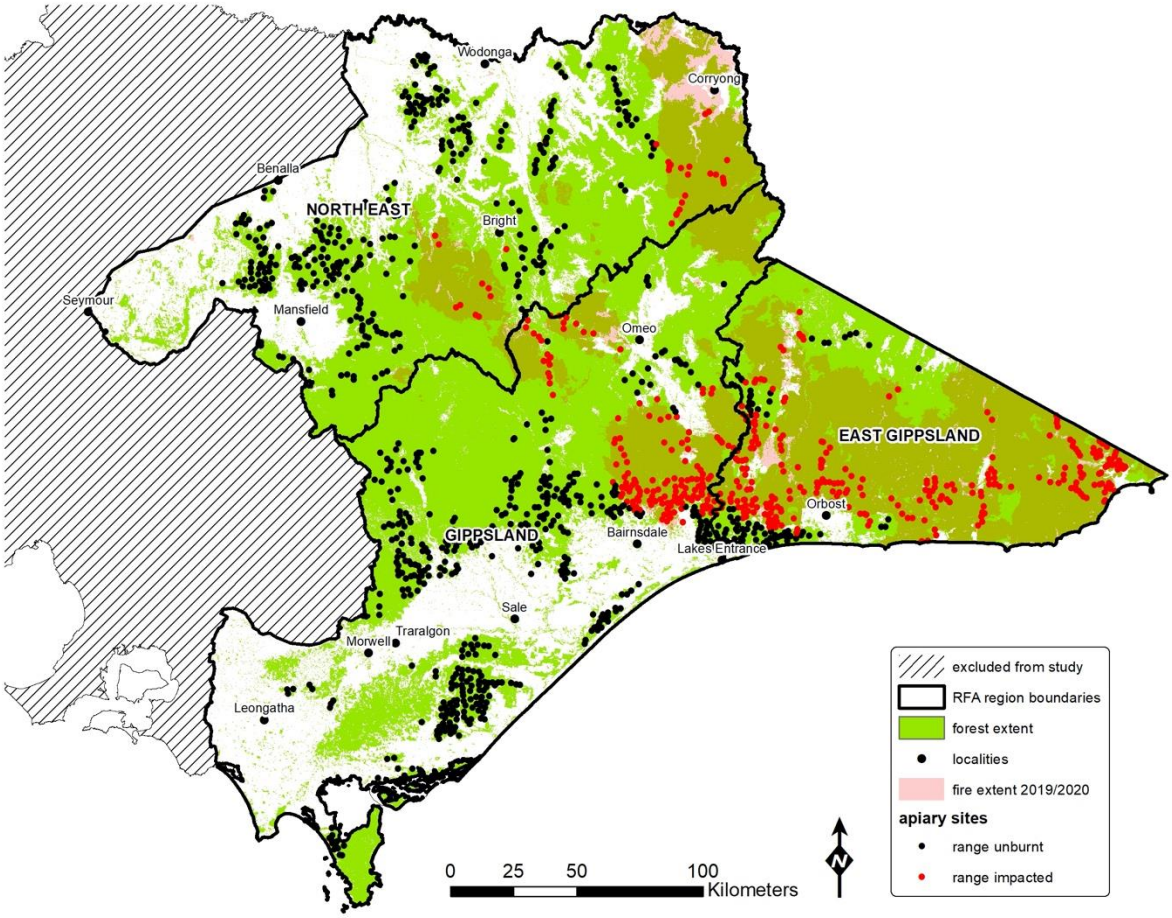
Apiary sites within burnt area is a subset of apiary sites within range of burnt area.

23. Department of Environment, Land, Water and Planning dataset: Apiary rights and bee farm and range licenses. This spatial dataset includes apiary sites on public land only. In addition, apiary sites on public land are not always licensed, and licensed sites may not always be occupied by hives.
24. An apiary site range of 1.6 kilometres is used in this analysis in line with the Victorian Government's *Apiculture (beekeeping) on public land standard operating procedure*.

Table 15 Area of forest burnt in 2019-20 bushfires within range of apiary sites on public land (hectares)

RFA region	Area of forest within range of apiary sites	Burnt area of forest within range of apiary sites
East Gippsland	179,838	108,666
Gippsland	285,645	50,005
North East	201,052	15,863
Total	666,535	174,534

Figure 12 Apiary sites on public land impacted by the 2019-20 bushfires



Regulating services

Soil erosion control (soil retention)

Forests provide a soil retention service, as vegetation cover helps prevent erosion. Forests in areas with steep terrain and high rainfall are typically significant providers of this service, relative to drier and less mountainous areas.

This ecosystem service is used by households, industry and government. The water and agricultural industries benefit from reduced sediment in water systems. Communities may benefit from reduced risk of landslides.

Soil retention is expected to decrease as a result of the 2019-20 bushfires. The size of the decrease will depend on the timing and severity of post-fire rainfall, which exacerbates soil erosion.

Soil erosion to major waterways is estimated to increase by 130,000-261,000 tonnes over 2020 and 2021 due to the bushfires, if rainfall and other conditions are similar to the historical average (see Table 16). The estimated value of this ecosystem service loss is $1.1-1.5 million over the two years, based on the cost of artificially removing sediment from waterways (see Table 17). However, decreased soil retention can have other implications – such as increased risk of debris flows impacting infrastructure and poor water quality events – meaning that the overall impact of the bushfires on this ecosystem service is only partially assessed and valued.

Figure 13 Increase in soil erosion in 2020 due to the 2019-20 bushfires

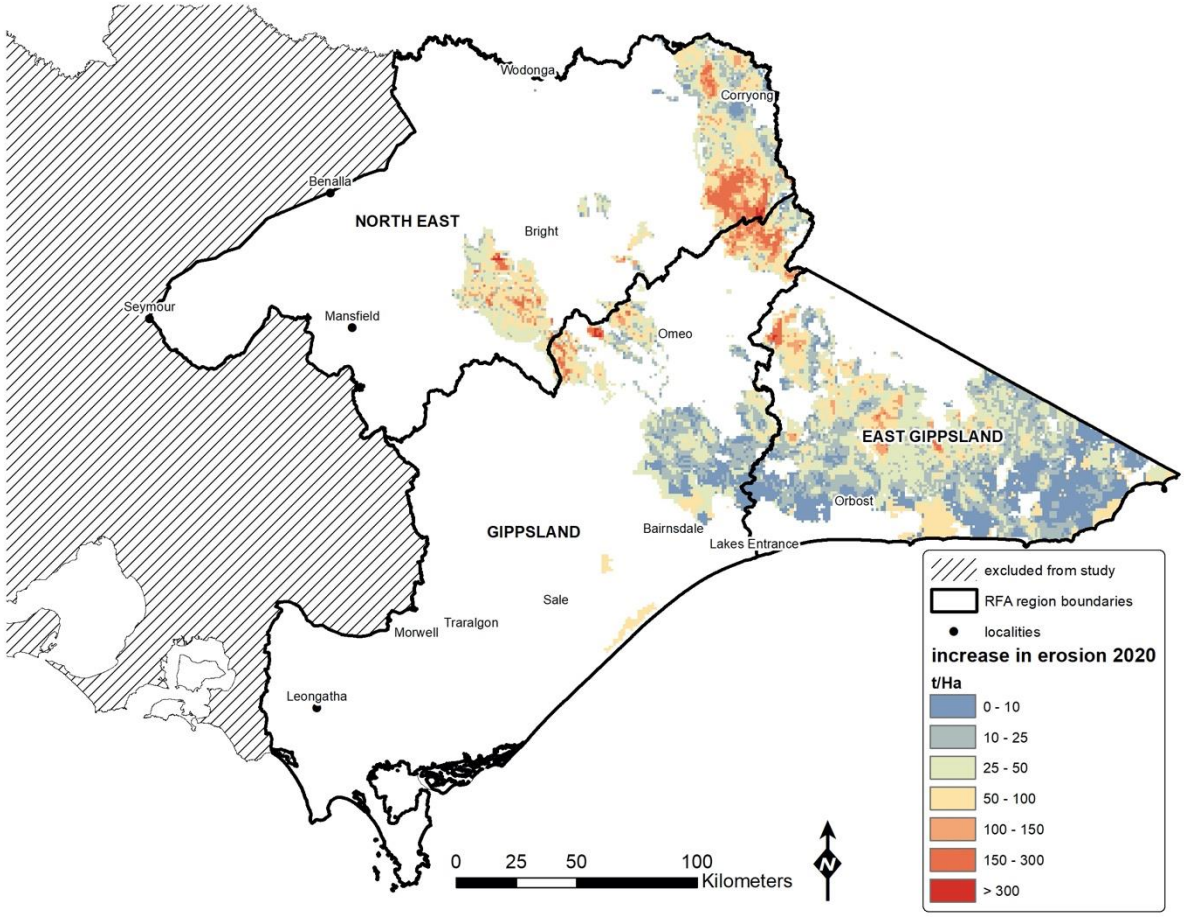


Table 16 Increase in soil erosion to major waterways due to the 2019-20 bushfires ('000 tonnes)

RFA region	2020	2021	Total
East Gippsland	46-92	5-11	51-102
Gippsland	28-56	4-8	32-65
North East	41-83	6-11	47-94
Total	115-231	15-30	130-261

Table 17 Increase in soil erosion to major waterways due to the 2019-20 bushfires ($ '000)

RFA region	2020	2021	Total
East Gippsland	Up to 1,925	Up to 215	Up to 2,140
Gippsland	282-1,185	34-166	316-1,351
North East	733-1,734	87-224	820-1,959
Total	1,015-4,844	121-606	1,136-5,450

Water flow regulation

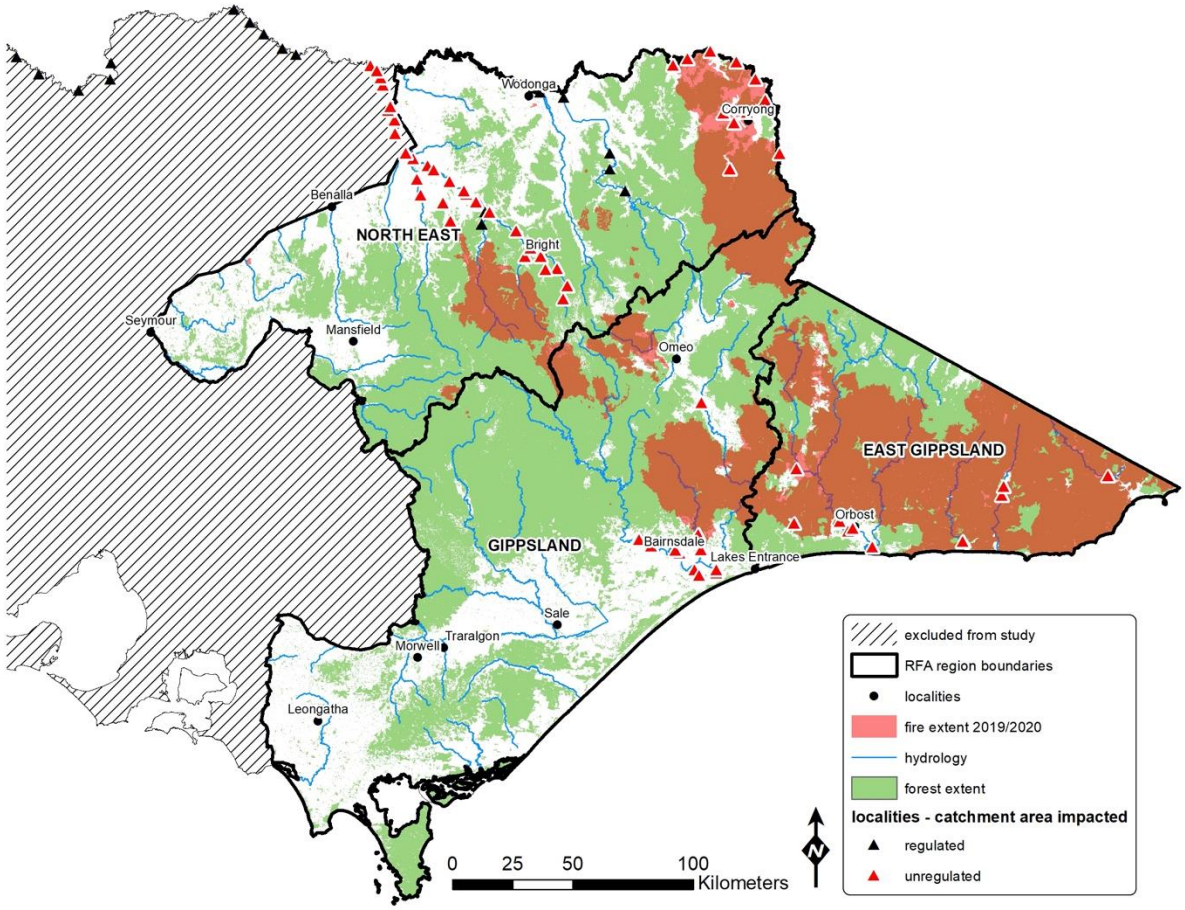
Forests provide a water flow regulation service, as they store, transpire and redirect water from rainfall. This reduces and slows runoff to waterways and can help mitigate flooding. The level of service provided depends on factors such as catchment topography and rainfall.

This ecosystem service is used by households, industry and government who benefit from reduced frequency or severity of river flooding.

Water flow regulation is expected to decrease as a result of the 2019-20 bushfires, as vegetation cover is reduced. The size of the decrease will depend on the timing and severity of post-fire rainfall.

The 2019-20 bushfires burnt forests in the catchment of 108 localities[25] across Victoria (see Figure 14). This is expected to result in a decrease in the water flow regulation service provided to these localities. While highly dependent on the timing and severity of post-fire rainfall, as well as other factors, these localities may experience increased risk of river flooding.

Figure 14 Localities with forest in their upstream catchment burnt in the 2019-20 bushfires



25. A locality is a statewide standardised boundary registered by the Registrar of Geographic Names. In urban areas it is analogous to a suburb.

Global climate regulation (carbon retention)

Forests provide a global climate regulation service by removing carbon dioxide from the atmosphere and storing carbon in plant biomass and soil. Mature forests typically provide a high level of this service by retaining large stocks of carbon.

This ecosystem service is used by the Victorian, Australian and global communities who benefit from reduced impacts of climate change.

Supply of this ecosystem service is expected to decrease as a result of the 2019-20 bushfires, as fire burns plant biomass and releases carbon dioxide to the atmosphere, reducing the stocks of carbon retained by forest ecosystems. Supply is then expected to increase over time as vegetation regenerates and carbon stocks increase.

It is estimated that there will be a net decrease in forest carbon stocks of 55 million tonnes in 2020 (see Table 18). This includes emission of 57 million tonnes due to fire and sequestration of 2 million tonnes due to post-fire regrowth. The estimated value of this ecosystem service loss is $574 million in 2020.[26]

Comparing this to historical forest carbon stocks across Victoria,[27] this represents around a 3 per cent decrease in carbon retention across the whole of the state. Comparing this to historical above-ground carbon stocks on public land in each RFA region, this represents around a 15 per cent decrease in carbon retention in East Gippsland, and a 3 to 4 per cent decrease in Gippsland and the North East.[28] (Note that this overstates the magnitude of change in overall carbon retention in each region as below-ground carbon stocks and carbon stocks on private land are not included.)

Table 18 Impact of the 2019-20 bushfires on the ecosystem service of global climate regulation in 2020

RFA region	Net change in carbon stocks / Change in supply of climate regulation service (Mt C)	Change in supply of climate regulation service ($ million)
East Gippsland	-36	-376
Gippsland	-9	-96
North East	-10	-101
Total	-55	-574

Source: DELWP analysis of emissions data from Department of Industry, Science, Energy and Resources

Note carbon stocks do not include methane emissions.

26. As discussed previously (see footnote 13), this differs from the approach taken in a study published by WWF-Australia in early 2020, which quantified and valued permanent carbon stock losses from the bushfires across south-east Australia. This study quantifies and values the impact of the bushfires on the ecosystem service of global climate regulation (carbon retention) in Victoria in 2020. This approach is consistent with an ecosystem accounting framework and aligns with the assessment of other ecosystem services. As the studies address different questions, they consequently yield different results. However, the underlying estimates of carbon emissions from the bushfires across south-east Australia broadly align. Emissions estimates discussed in the WWF-Australia study range from 400 to 1,000 Mt CO2, while the Department of Industry, Science, Energy and Resources estimated emissions of 850 Mt CO2. See Bishop, J 2020, *Burnt assets: The 2019-20 Australian bushfires*, WWF-Australia, Sydney; Department of Industry, Science, Energy and Resources 2020, *Estimating greenhouse gas emissions form bushfires in Australia's temperate forests: Focus on 2019-20*, Commonwealth of Australia, Canberra.
27. Average historical forest carbon stocks for the whole of Victoria are 2 billion tonnes (including living biomass, deadwood and litter and soil carbon. Source: Experimental carbon stock accounts 2016 – Victoria, Department of Industry, Science, Energy and Resources.
28. Average historical above-ground forest carbon stocks on public land are 233 million tonnes for East Gippsland, 270 million tonnes for Gippsland and 235 million tonnes for the North East. Source: Victorian Forest Monitoring Program, Above-ground biomass on public land.

Air filtration

Forests provide an air filtration service as vegetation captures airborne pollutants (such as particulate matter) and removes them from airsheds. This ecosystem service is used by households near forests who benefit from improved health and amenity due to better air quality.

Air filtration is expected to decrease as a result of the 2019-20 bushfires, as vegetation cover is reduced. The size of the decrease depends on the proximity of communities to severely burnt areas of forest. Provision of this ecosystem service will increase over time as forests regenerate.

Pest control

Forests provide a pest control service by supporting species (such as bats or birds) that are predators of pest species. This ecosystem service is used by the agricultural industry as well as households with gardens.

Pest control is expected to decrease as a result of the 2019-20 bushfires, as animals are killed by fire and habitat is reduced. However, the size of the decrease is unknown.

Cultural services

Recreation and tourism

Forests provide opportunities for recreation and tourism. People visit forests for a wide range of experiences that are supported or enhanced by nature. That is, forest ecosystems contribute to the benefit visitors receive along with built assets such as walking tracks or picnic facilities.

This ecosystem service is used by the Victorian community (households) as well as interstate and international visitors. The tourism industry also uses this service as an input to tour operations in parks and state forests.

Recreation and tourism is expected to decrease as a result the 2019-20 bushfires. Areas of parks and state forests have been closed to protect visitor safety and support forest regeneration. However, the overall impact on forest visitation in Victoria will depend on whether people visit other parts of the state. The bushfires may place increased pressure on other parks and state forests.

1.2 million hectares of state forests, parks and reserves were burnt in the 2019-20 bushfires, affecting 49 state forests and 98 parks and reserves (see Figure 15, Table 19 and Table 20).

Figure 15 State forests, parks and reserves impacted by the 2019-20 bushfires

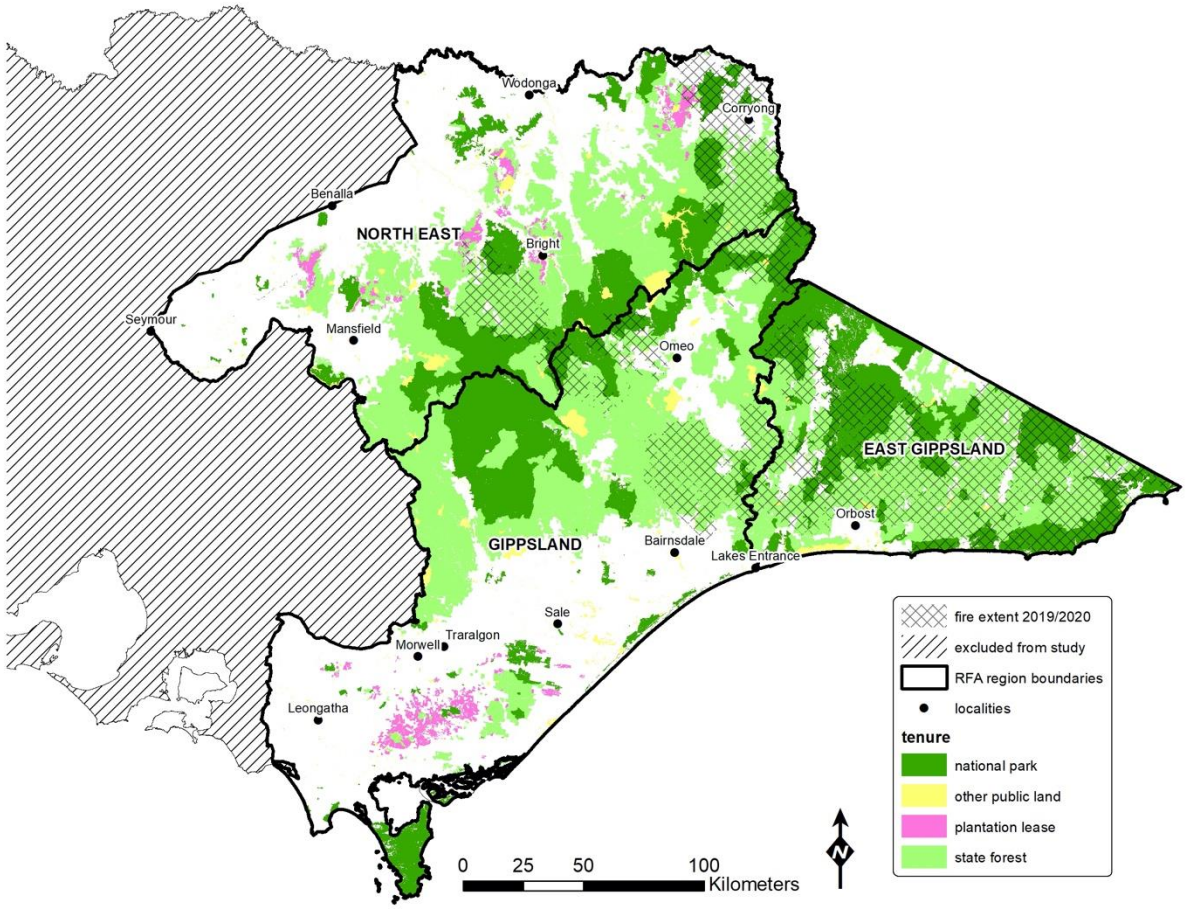


Table 19 Number of state forests, parks and reserves burnt in the 2019-20 bushfires

	East Gippsland	Gippsland	North East	Total
State forests	30	24	4	49
Parks (national, state and regional)	10	1	5	14
Reserves	61	8	17	83
Total	101	33	26	146

Total is less than the sum of the three RFA regions, as some parks and state forests span multiple RFA regions.

Table 20 Area of state forests, parks and reserves burnt in the 2019-20 bushfires

	East Gippsland	Gippsland	North East	Total
State forests	423,823	198,120	168,704	790,647
Parks (national, state and regional)	248,762	64,065	79,843	392,670
Reserves	16,918	5,734	1,614	24,265
Total	689,503	267,919	250,161	1,207,583

Amenity

Forests provide amenity to nearby residents, enabling a range of individual and community benefits. This includes the benefit of having close access to forests or gaining health and enjoyment benefits from forest views and experiences.

Amenity is expected to decrease as a result of the 2019-20 bushfires, as nearby residents are unable to safely access burnt forests and visual appeal is reduced. Provision of this ecosystem service will increase over time as forests regenerate.

Education and research

Forest ecosystems are an input to research and education activities. This directly benefits people or institutions who study forests or visit for educational purposes. Victorian, Australian and global communities benefit from the outcomes of education and research.

The overall impact of the 2019-20 bushfires on this ecosystem service is unknown. Outdoor education visits will be reduced in fire-affected areas. However, there may be an increase in scientific research and knowledge in response to the bushfires.

Culture and heritage

Forests encompass landscapes and sites of cultural and historical significance. Forests provide immense value to Traditional Owners and Aboriginal communities, as well as providing heritage value to non-Aboriginal Victorians.

Opportunities for cultural heritage connection are not always provided solely by ecosystems: forest ecosystems combine with other attributes (such as historic structures or artefacts) to deliver benefits. However, forest ecosystems support and enhance connections, allowing place-based experiences rather than preservation in museums or other contexts.

This ecosystem service may decrease as a result of the 2019-20 bushfires. Several cultural and heritage sites have been burnt by the bushfires.

Ecosystem and species appreciation

Forests provide habitat for plants and animals that are appreciated by people. The users of these ecosystem services are the Victorian, Australian and global communities who value the existence of habitat and species, even if they never physically visit the ecosystem.

This ecosystem service is expected to decrease as a result of the 2019-20 bushfires, as large numbers of plants and animals were killed by fire and the habitat of many species impacted.

Conclusion

Over 1.2 million hectares of forest was burnt in the 2019-20 bushfires and the impact on this important natural capital will have implications for the economy and society. This study shows that the bushfires have reduced the capacity of forests to supply valuable ecosystem services that communities and industries rely on.

The East Gippsland Regional Forest Agreement (RFA) region was most significantly affected by the fires, with around 700,000 hectares of forest burnt (over half of the total area of forest burnt in the bushfires). However, significant areas of forest were burnt in the Gippsland and North East RFA regions (around 300,000 hectares each). Specific ecosystem services were more substantially affected in different RFA regions. For example, due to the large area of forest burnt, the greatest loss of carbon retention services is expected to be in East Gippsland. However, the loss of water provision services is expected to mainly occur in the North East and Gippsland due to the areas of Ash forest burnt in these RFA regions.

Supply of most ecosystem services is expected to decrease as a result of the 2019-20 bushfires. Key impacts of across the three RFA regions are:

- Water provision – water provision from forests is estimated to decrease by around 3,900 gigalitres over 150 years due to the 2019-20 bushfires on the assumption that there are no further fires to reset the ash forest stand age. Over half of this reduction occurs in the first 50 years post the 2019-20 bushfires. This impact is driven by Ash forests burnt at high fire severity, which consumes a substantial quantity of water while regenerating. The annual reduction in water provision equates to less than 0.3 per cent of total inflows to the affected RFA regions. The estimated value of this ecosystem service loss is $191 million over the 150 period.
- Provision of floral resources for honey and pollination: 445 apiary sites on public land had forest burnt within bee foraging range. This includes 75 per cent of public land apiary sites in East Gippsland and 25 per cent in Gippsland. In total, 175,000 hectares of forest was burnt within bee foraging range of apiary sites on public land. The overall impact on honey and pollination will depend on the extent to which apiarists can access this ecosystem service in other parts of the state.
- Erosion control – soil erosion to major waterways is estimated to increase by 130,000-261,000 tonnes over 2020 and 2021 due to the bushfires, if rainfall and other conditions are similar to the historical average. The estimated value of this ecosystem service loss is $1.1-5.5 million.
- Water flow regulation – 108 localities across Victoria has forest burnt in their upstream catchment. This is expected to result in a decrease in the water flow regulation service provided to these localities. While highly dependent on the timing and severity of post-fire rainfall, as well as other factors, these localities may experience increased risk of river flooding.
- Global climate regulation – the bushfires caused a reduction in forest carbon stocks of 55 megatonnes in 2020, which is equivalent to around 3 per cent of Victoria's historical forest carbon stock. The value of this ecosystem service loss is estimated at $574 million in 2020 alone.
- Recreation and tourism: The bushfires are expected to cause a reduction in supply of recreation and tourism services, with Victorian, interstate and international visitors unable

or unwilling to visit fire-affected parks and state forests. Around 1.2 million hectares of forest was burnt across 146 state forests, parks and reserves.

Supply of most ecosystem service is expected to increase over time as forests regenerate, and generally impacts are likely to be greater or more prolonged in areas burnt at high fire severity. For all ecosystem services, supply and use is partly determined by how people and businesses engage with the ecosystem in order to use the ecosystem service. The impact of the bushfires on overall supply of ecosystem services from forests across Victoria is heavily dependent on the behaviour of people and businesses. This is particularly the case for provisioning and cultural services. For example, while supply of recreation and tourism services from forests in eastern Victoria may decrease, this could be partly offset by increased visitation to forests in other parts of the state. Consequently, the bushfires may lead to an *increase* in provision of ecosystem services by unburnt forests.

The findings presented in this report provide an indication of potential change in supply of ecosystem services as a result of the bushfires. Actual supply of ecosystem services is influenced by a range of factors, including environmental factors (such as rainfall) or human factors (such as the behaviour of people and businesses). This means that ecosystem accounts produced in the future using observed data will inevitably differ from the estimates derived in this study. However, if future ecosystem accounts can isolate the impact of the bushfires in observed data, they could be compared to this study and provide a useful evaluation.

Glossary

ArcGIS	Geographical information system used to view, process and analyse spatial data
CICES	The Common International Classification of Ecosystem Services – a typology for classifying ecosystem services that was developed to support environmental-economic accounting.
Cultural services	Non-material ecosystem outputs that provide cultural, social, intellectual or health benefits to people through cultural and community connection, recreation and relaxation, and knowledge development.
DELWP	Victorian Department of Environment, Land, Water and Planning
Ecosystem accounting	Statistical framework for organising spatial biophysical data about ecosystem assets and ecosystem services, tracking changes in ecosystems over time, and linking to economic and other human activity. Ecosystem accounting can be in both physical and monetary terms.
Ecosystem assets	Spatial areas containing a combination of biotic and abiotic components that function together as a specific combination of ecosystem characteristics forming a system.
Ecosystem services	Ecosystem services are the contributions of ecosystems to benefits used in economic and other human activity. Ecosystem services are often classified into provisioning, regulating and cultural services.
Ecosystem service flows	Quantity of services provided from ecosystem assets to beneficiaries in a period (typically a year).
Gross state product	The total value of (market) goods and services produced within a state's borders in a specific period (typically a year). It is also measured at the national level (gross domestic product) and the regional level (gross regional product).
Provisioning services	Material ecosystem outputs that provide benefits to people from the consumption of tangible goods and services. Examples include food, water and other raw materials.
Regulating services	Ecosystem functions that provide benefits to people from regulating climate, hydrologic, biogeochemical and other cycles. An example is the capacity of ecosystems to regulate climate and contribute to climate change mitigation.
RFA	Regional Forest Agreement
SDL	Sustainable diversion limit
SEEA	United Nations System of Environmental-Economic Accounting – common statistical framework for environmental-economic accounting. The central framework (environmental accounting) is an agreed statistical standard, while experimental ecosystem accounting is currently in development and being piloted around the world (including Victoria).
VFMP	Victorian Forest Monitoring Program
VLUIS	Victorian Land Use Information System

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Appendix A: Detailed assessment of the impact of the bushfires on forest ecosystem services

Provisioning services

Water provision

Description of ecosystem service and users

Forests capture water and release it to natural, human modified and human created water supply systems. In Victoria this includes Melbourne's water supply system and regulated and unregulated systems across the state.[29] Provision of this ecosystem service is influenced by climate and rainfall, with greater flows in wet years.

This ecosystem service is used by the water industry, the agricultural industry and government (including for environmental purposes). In turn, the water industry supplies water to households and businesses.

Forest ecosystems also influence the quality of water supplied by naturally filtering and purifying it, reducing the amount of sediment and pollutants that would otherwise reach waterways. Water filtration can be conceptualised as a separate regulating ecosystem service, which is not assessed in the study. Depending on the method used, the value of water provision is likely to capture some of the value of water filtration, as the quality of water is implicit in market prices. If water filtration was separately assessed, care would need to be taken to avoid double counting.

Forest ecosystems also regulate the flow of water, which is assessed separately in this study as a regulating service.

Impact of fire on ecosystem service

The impact of fire on this ecosystem service is complex and varies depending on forest type. While water yield may initially increase, if rainfall occurs soon after a fire, this is typically accompanied by an increase in soil erosion, a decrease in water quality, and increased likelihood of flooding. These adverse impacts are considered in the assessment of regulating ecosystem services.

For mixed-species forests, fire is not expected to have a long-term impact on provision of this ecosystem service. Research into mixed-species forests shows relatively little impact on water yield (compared to other forest types like single Ash stand forests). Results vary from no impact on water yield 3 years post fire,[30] to a 10 per cent reduction in stream flow 1 to 4 years post fire.[31]

For Alpine and Mountain Ash forests, fire is expected to have a long-term impact on provision of this ecosystem service. These species are killed outright by high-severity fire and regenerate from seeds that are stored in the canopy, if trees are of seed-bearing age (around 20 years or older). This disturbance and subsequent regeneration results in major reductions in water yield for up to 150 years, peaking at approximately 33 years post-

29. Regulated systems are water systems where the flow of the river is regulated through the operation of major storages or weirs to secure water supplies. Unregulated systems are river systems where no major dams or weir structures have been built to regulate the supply, or extraction, of water for consumptive use.

30. Turnbull, T 2015, *Quantifying the impact of fire on tree water use*, Fire Note issue 115, Bushfire CRC & University of Sydney.

31. Nolan, R, Lane, PNJ, Benyon, RG, Bradstock, RA, Mitchell, P 2015, 'Trends in evapotranspiration and streamflow following wildfire in re-sprouting eucalypt forests' *Journal of Hydrology*, volume 525, pp. 614-624.

disturbance with approximately 50 per cent reductions in water yield.[32] Consequently, this analysis focuses on the impact of fire on water provision from Ash forests.

Quantification of impact

This impact of the bushfires on this ecosystem service is quantified as the change in water yield to water systems from Ash forests across the three RFA regions. To do this, two scenarios are constructed: a scenario reflecting the 2019-20 bushfires and a 'no fire' counterfactual scenario.

Fire severity mapping is used to identify areas of Ash forest that were burnt at the two highest fire severity classes (class five and six), which signifies significant crown foliage scorch or burn. Fire at this severity is assumed to be a stand replacing event for Ash forests[33]. That is, it is assumed that these areas of Ash forest are killed by fire and regenerate, beginning a new growth cycle in 2020.[34] Around 84,000 hectares of Ash forest was burnt in the 2019-20 bushfires. Of this, 52,000 hectares was burnt at fire severity classes five and six, which represents 16 per cent of Ash forest and around 1 per cent of total forest across the three RFA regions. The largest area of Ash forest was burnt in Gippsland, closely followed by the North East (see Table 21). East Gippsland has a smaller area of Ash forest burnt, although it represented a large proportion of the region's Ash forests.

Water yield over the next 150 years is estimated by applying relative impacts from the Kuczera Curve to modelled maximum potential catchment water yield from the Ensym model. This approach takes spatially and temporally varying forest stand age into account, to all Ash forest across the three RFA regions. This approach is applied to both the bushfire scenario and the no fire counterfactual, ensuring that the impacts of previous fires and other Ash forest stand replacing events are taken into account. The difference between the two scenarios equates to the reduction in water yield from Ash forests due to the 2019/2020 bushfires.

Figure 16 shows water yield from Ash forests under the two scenarios. From 2020 to 2024 water yield is actually greater under the fire scenario. This is because some of the areas of Ash forest burnt in the 2019-20 bushfires were previously burnt in the 2003 or 2006-07 bushfires. These areas were approaching their high water use phase (i.e. the bottom of the Kuczera curve) when impacted by the 2019-20 bushfires: water use by Ash forests is at a maximum around 15-25 years of age. When these areas were burnt by the 2019-20 bushfires, their age is effectively re-set to zero, and consequently their water use is initially less under the fire scenario. From 2025 onwards water yield is greater under the no fire scenario.

Over the 150 years modelled (2020-2169), water yield from Ash forests is expected to decrease by 3,900 gigalitres due to the bushfires. This represents around 2 per cent of total water yield from Ash forests across the three RFA regions over the same time period, and less than 1 per cent of total water yield from all land. Table 22 shows the decrease for each 25-year period: over half of the decrease occurs in the first 50 years post-fire. Despite the extensive fires in East Gippsland, the Gippsland and North East RFA regions have been

32. Kuczera, G 1987, 'Prediction of water yield reductions following bushfire in Ash-mixed species eucalypt forest', *Journal of Hydrology*, volume 94, pp. 215-236.

33. Vivian, L.M., Cary, G.J., Bradstock, R.A. & Gill, A. (2008). Influence of fire severity on the regeneration recruitment and distribution of eucalypts in the Cotter River Catchment, Australian Capital Territory. Austral Ecol. 33, 55-67.

34. For the purposes of this analysis all Ash forests burnt at fire severity class five and six are assumed to regenerate. In reality, if Ash forests are killed by fire before they reach seed-bearing age (around 20 years), they will require human intervention (reseeding) to regenerate.

more affected in terms of water yield, as larger areas of Ash forest were burnt in these RFA regions.

The bushfires have also impacted on water yield to certain water supply systems (see Table 23). Water yield to the northern Victoria system is expected to be most impacted, representing 65 per cent of the total reduction in water yield (from 2020 to 2169), as fire-affected Ash forests in the North East and Gippsland RFA regions supply this system. The remaining 35 per cent of the total reduction is water yield to unregulated systems.[35]

Figure 16 Water yield from Ash forests 2020-2069 (assuming no further disturbance)

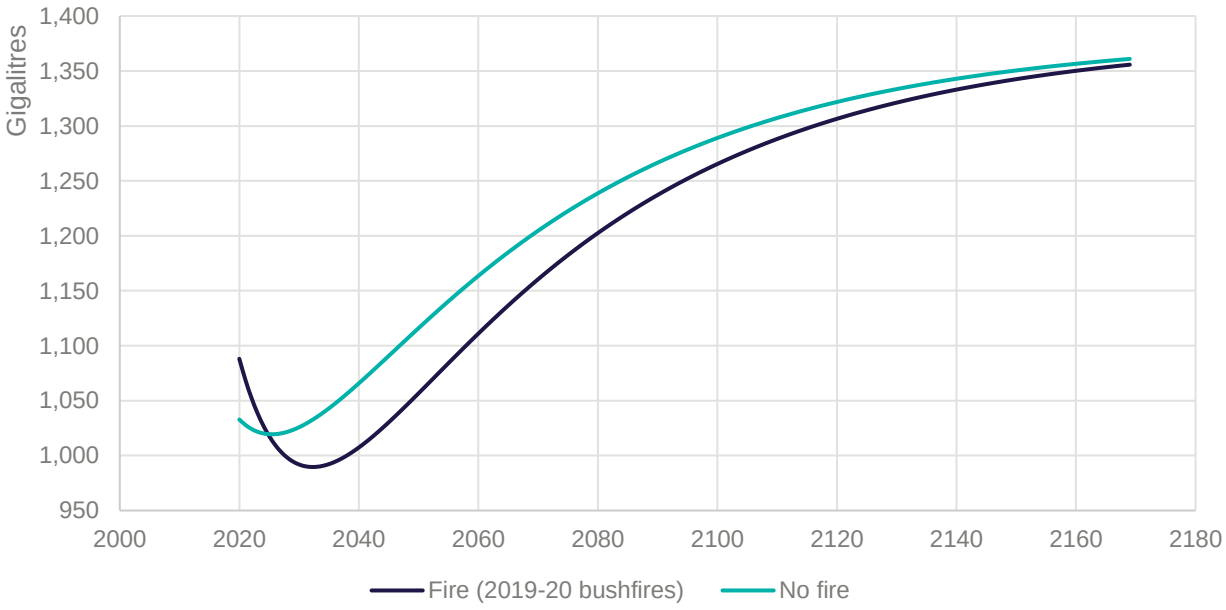


Table 21 Area of Ash forest burnt in the 2019-20 bushfires (hectares)

RFA region	Total forest	Ash forest	Total forest burnt	Ash forest burnt	Ash forest burnt at class 5 & 6
East Gippsland	1,099,752	24,380	708,300	11,089	5,697
Gippsland	1,578,506	139,504	277,773	38,962	25,850
North East	1,351,316	152,527	272,442	34,171	20,008
Total	4,029,575	316,411	1,258,516	84,222	51,555

Table 22 Change in water provision from Ash forests due to the 2019-20 bushfires (ML)

RFA region	Total (2020-2169)	2020-2044	2045-2069	2070-2094	2095-2119	2120-2144	2145-2169
East Gippsland	-154,560	-28,740	-53,040	-34,260	-20,140	-11,660	-6,730
Gippsland	-1,856,270	-309,460	-649,740	-422,110	-248,270	-143,720	-82,970
North East	-1,911,910	-370,300	-650,940	-419,400	-246,370	-142,580	-82,310

35. All have sustainable diversion limits.

Total	-3,922,740	-708,500	-1,353,730	-875,770	-514,780	-297,960	-172,000

Table 23 Impact of the 2019-20 bushfires on water yield to water supply systems (GL)

RFA region	Destination	Total change (2020-2169)
East Gippsland	Unregulated systems	-155
Gippsland	Northern Victoria system	-935
	Unregulated systems	-920
North East	Northern Victoria system	-1,625
	Unregulated systems	-290
Total		-3,920

Figure 17 Catchment valuation zones

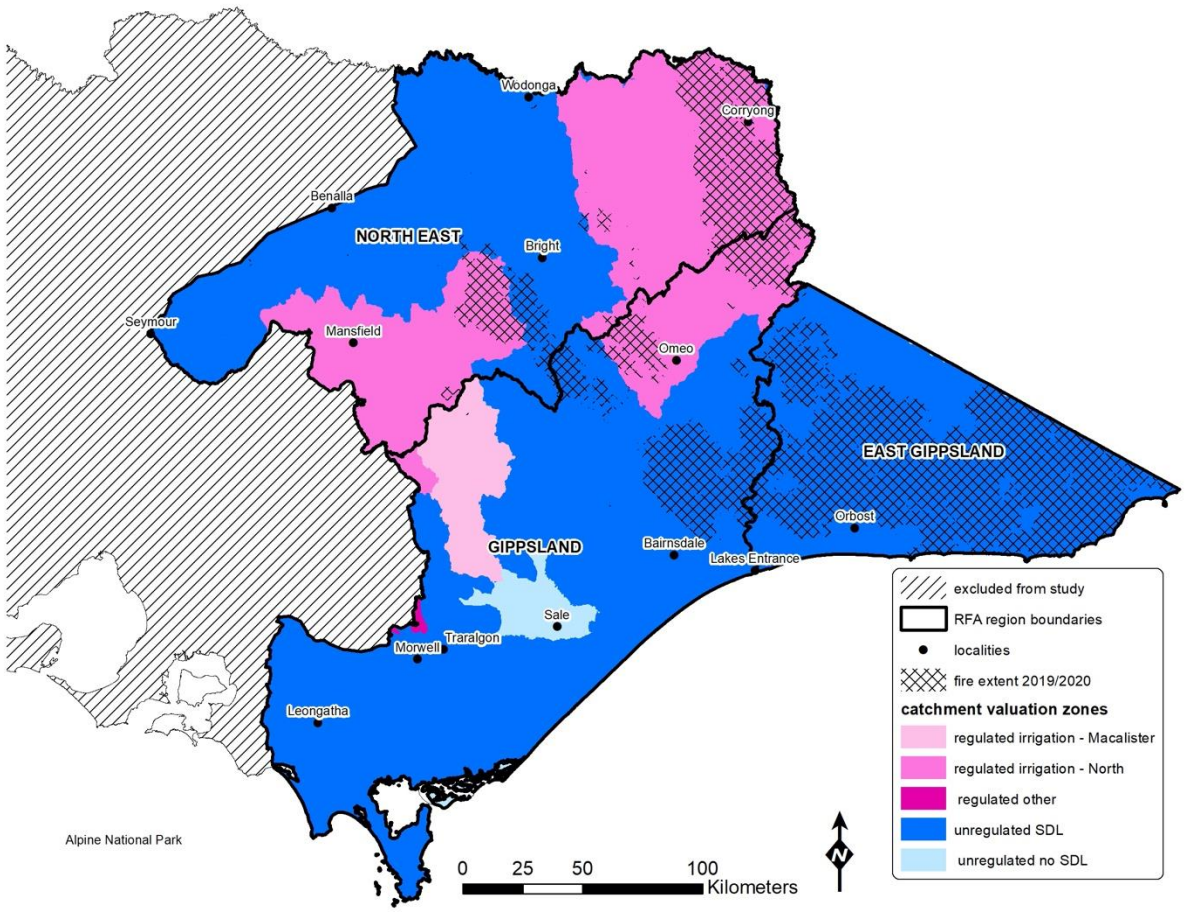


Figure 18 Ash forests burnt at high fire severity (class 5 and class 6) in the 2019-20 bushfires

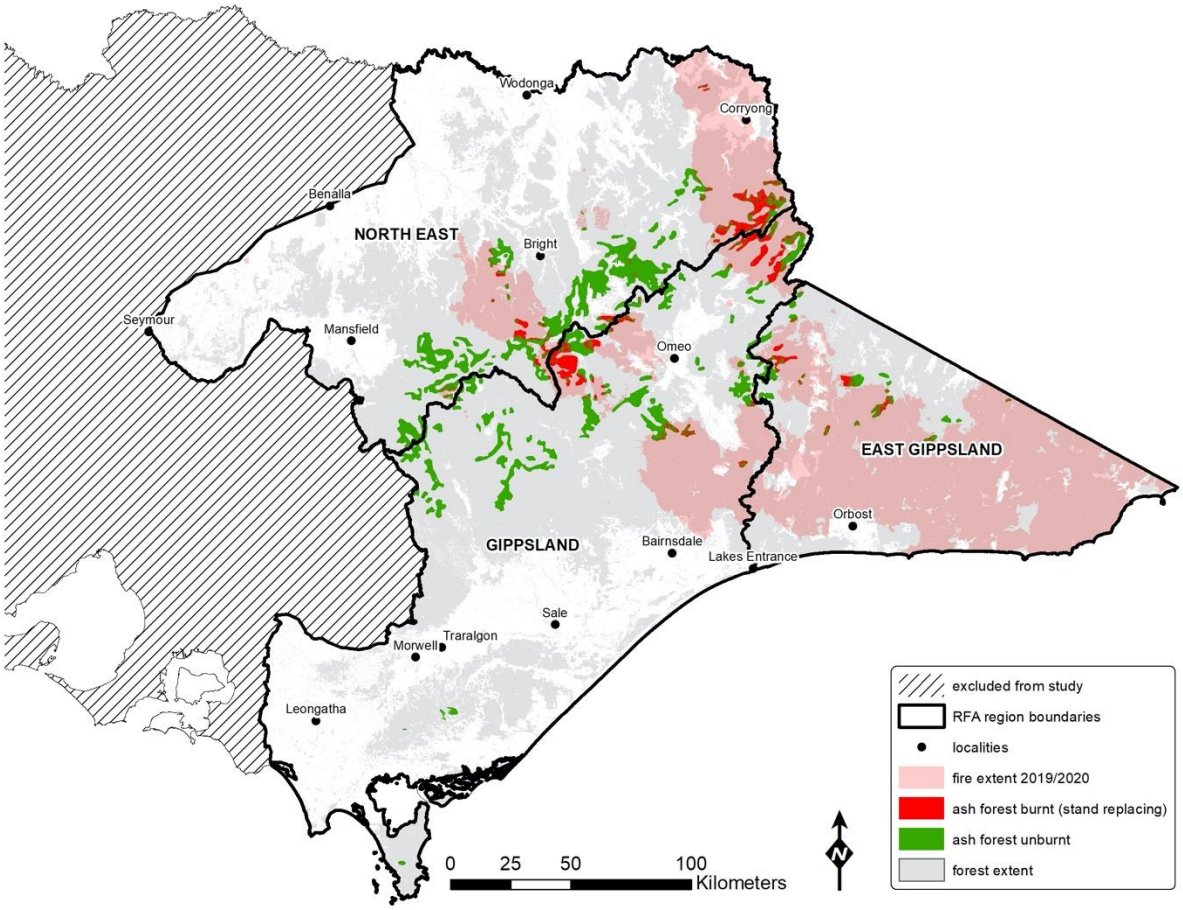


Figure 19 Potential maximum annual water yield (ML/Ha)

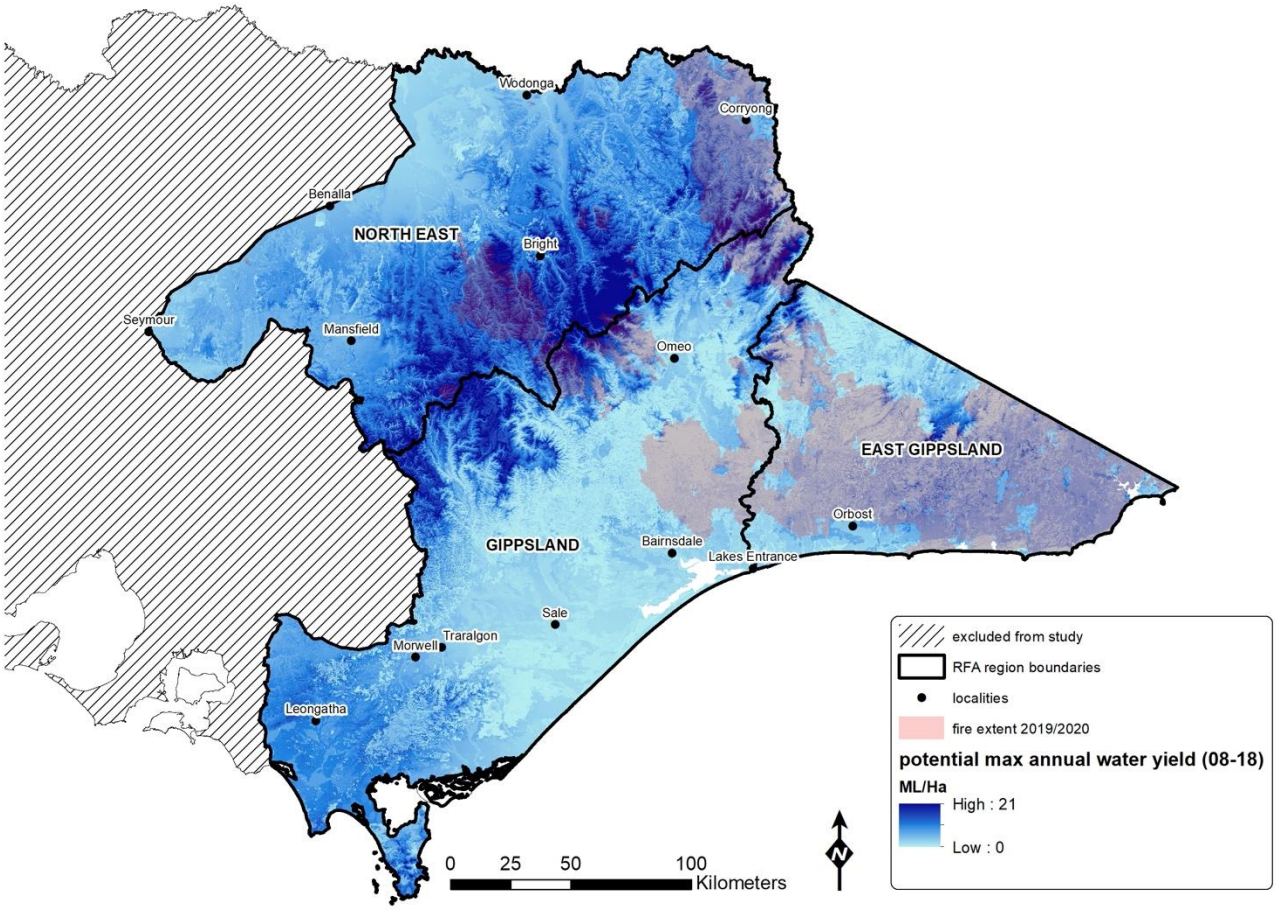
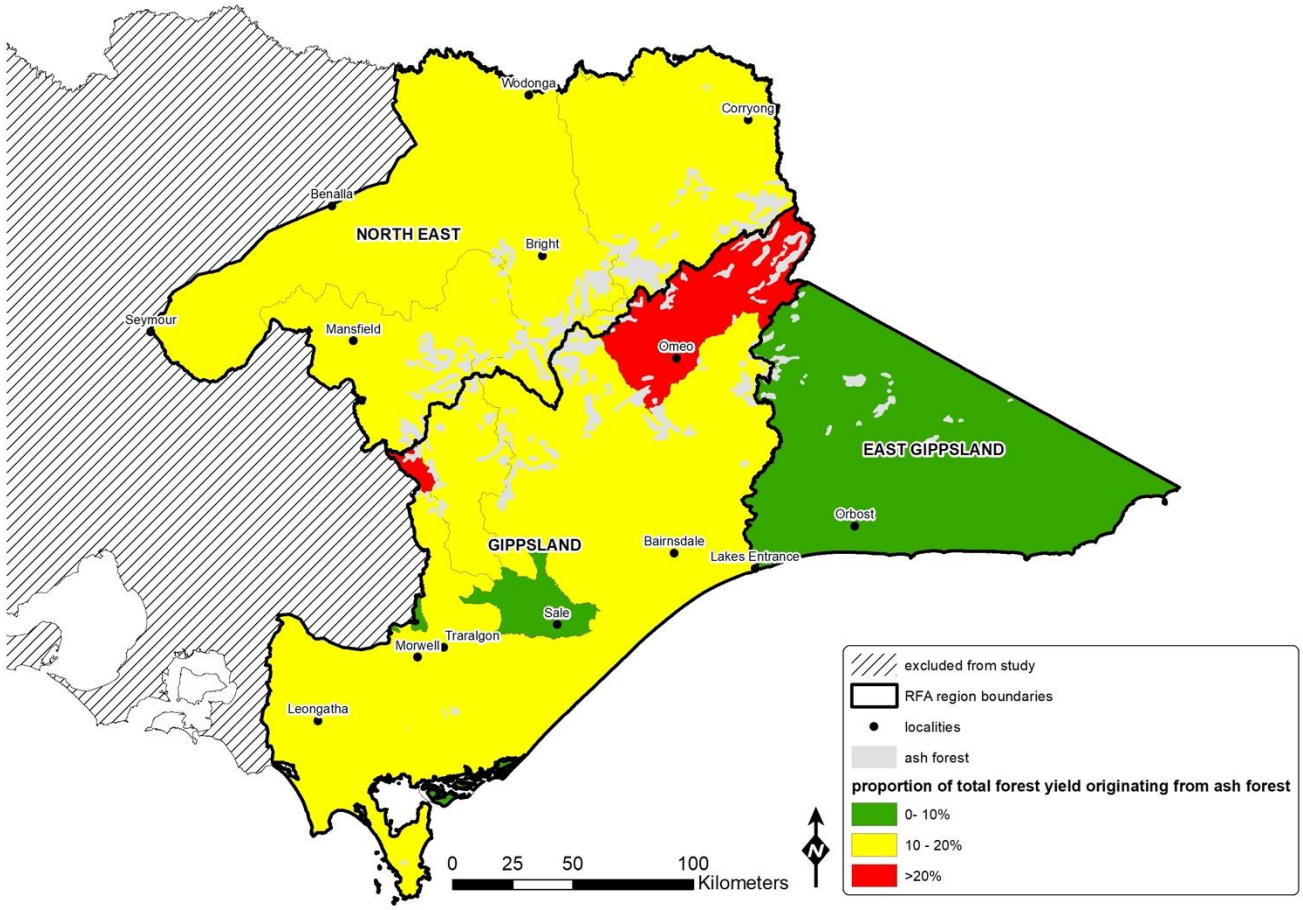


Figure 20 Proportion of total water yield from forests originating from ash forests, by catchment valuation zone in each RFA region



Valuation of impact

Water provision can be valued using a market price approach. Valuation is linked to the destination of water provision from forests (e.g. see Table 23). When water is supplied to households and businesses by the water industry, the price of water is a combination of capital, labour and other inputs including the ecosystem service of water provision. For this reason, the market price of urban water supply to households and businesses is not used to value the ecosystem service. However, market prices (allocation prices) for rural water are used, as these prices more accurately reflect the value of the ecosystem service, isolated from other inputs such as capital and labour. This is because there are separate fees for (known as delivery shares) that cover the costs of operating and maintaining channels, pipes and gates which deliver water.[36] This approach was used to value water provision in the 2019 assessment of ecosystem services from RFA regions, although values have been updated to better reflect potential future water prices.

A different market price is used for each water supply system (see Table 24). They are drawn from difference sources but draw on historical water price data. For the northern Victoria system an ABARES estimate of the average water allocation price over ten years

36. Victorian Water Register 2020, 'About water entitlements: Delivery shares', accessed 31 August at https://waterregister.vic.gov.au/water-entitlements/about-entitlements/delivery-shares

under current market conditions is used.[37] For water yield to unregulated systems with sustainable diversion limits[38], median price per megalitre of trade in temporary take and use licenses is used. Unregulated systems with sustainable diversions limits are systems where there is no major infrastructure regulating the supply of water, but where take and use licenses can still be traded.

The average water prices outlined in Table 24 are applied to the change in water yield in each year and results are discounted[39] and summed to derive the present value of the reduction/increase in water provision due to the bushfires. This may be a conservative estimate as water prices are likely to increase over time under climate change and water scarcity.

Over the 150 years modelled (2020-2169), the estimated value of ecosystem service loss is around $191 million (see Table 25). The majority (over 85 per cent) of this loss occurs in the first 50 years. Over half of the total loss is in the North East RFA region, due to the area of Ash forest and the impact on water yield to the northern Victoria system, which is high value water.

Table 24 Water prices

Water supply system	Price per megalitre ($)	Source
Northern Victoria system	356	ABARES – future average (current market conditions)
Unregulated systems with a sustainable diversion limit	51	Victorian Water Register – historical median

Table 25 Impact of the 2019-20 bushfires on water provision ($, present value)

RFA region	Total (2020-2169)	2020-2044	2045-2069	2070-2094	2095-2119	2120-2144	2145-2169
East Gippsland	-1,550,960	-661,250	-676,560	-166,560	-36,840	-8,010	-1,740
Gippsland	-69,564,280	-25,881,090	-33,170,270	-8,215,660	-1,817,060	-394,720	-85,480
North East	-119,796,530	-53,443,400	-50,499,180	-12,393,430	-2,737,300	-594,490	-128,740
Total	-190,911,770	-79,985,740	-84,346,000	-20,775,650	-4,591,190	-997,220	-215,960

Note the values have been converted to present values using a 4 per cent discount rate

37. ABARES also estimates an average water allocation price for future market conditions ($455) and future market condition and a dry climate ($533). Future market conditions reflect full maturity of recently established almond plantings, and future water recovery to meet Basin Plan requirements (3,200 GL target) via on-farm infrastructure upgrades. This suggests that using a price of $356 represents a conservative valuation approach, however the price is still substantially higher than historical average allocation prices in northern Victoria. See: Gupta, M, Hughes, N, Whittle, L, & Westwood, T 2020, *Future scenarios for the southern Murray-Darling Basin*, *Report to the Independent Assessment of Social and Economic Conditions in the Basin*, ABARES research report, Canberra, February.
38. Sustainable diversion limits (SDLs) provide an indication of the sustainable volume of water that can be diverted from a system without causing detrimental environmental impact. SDLs are used to determine upper limits on diversion from unregulated systems across Victoria.
39. A 4 per cent discount rate is used consistent with Victorian Department of Treasury and Finance guidance on discount rates. Department of Treasury and Finance 2013, *Economic evaluation: Technical guidance*, State of Victoria, Melbourne, pp. 24-27.

Biomass for timber

Description of ecosystem service and users

Forests provide biomass (trees) which is harvested as timber. In Victoria, biomass is harvested from native forests (state forests) and from plantation forests grown specifically for timber. In 2019, the Victorian Government announced that native timber harvesting will cease by 2030, with a phased reduction from 2024-25.

This ecosystem service is used by the timber industry. In turn, the timber industry provides a benefit to businesses producing wood and paper products by supplying timber.

Impact of fire on ecosystem service

The impact of fire on this ecosystem service is complex. A bushfire will typically reduce the quality and quantity of biomass *available* for harvesting from burnt forests. However, how this translates into actual supply of the ecosystem service (harvested timber) depends on a number of factors, including human factors.

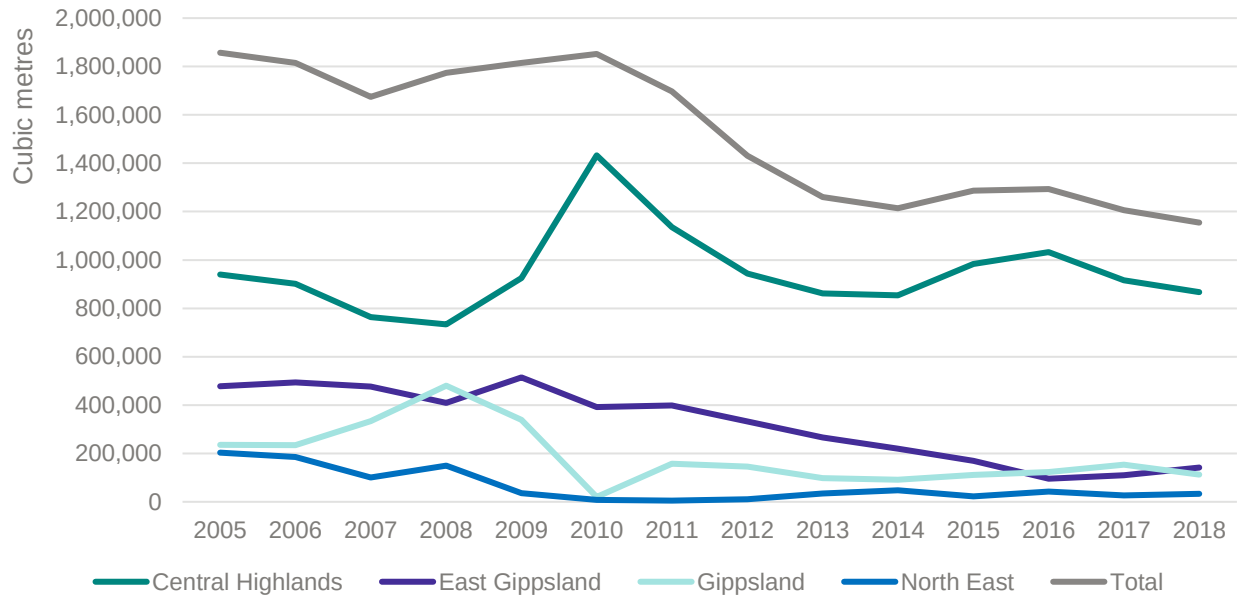
Supply of this ecosystem service may be sustained after a bushfire, if harvesting activity is brought forward to harvest fire-affected timber before it declines in quality and value. This is known as 'salvage harvesting' and it occurs in both native and plantation forests. Salvage harvesting has occurred after previous bushfires in Victoria, which can be seen in historical native timber harvesting data (see Figure 20). For example, from 2007 to 2009 there was a spike in the volume of timber harvested in the Gippsland RFA region following the 2006-07 Alpine fires. In 2010 there was a large spike in the Central Highlands RFA region following the 2009 Black Saturday fires.

However, there may be longer-term impacts on this ecosystem service, as plantation forests need to be cleared and a new rotation planted. A 2017 assessment by the Victorian Environmental Assessment Council found that major bushfires have had a profound effect on timber supply from Victoria's state forests, particularly bushfires that have burnt large areas of Ash forests, such as the 2009 Black Saturday fires.[40]

The overall change in supply of this ecosystem service at a regional or state-wide scale will depend on the extent to which harvesting activity shifts to other areas of forest. As with other ecosystem services, such as provision of floral resources (for honey and pollination) and recreation and tourism, unburnt areas of forest may increase supply of ecosystem services as businesses and households shift their behaviour (use) in response to the bushfires.

40. Victorian Environmental Assessment Council 2017, *Fibre and wood supply: Assessment report*, State of Victoria, East Melbourne, p. 42.

Figure 21 Quantity of biomass for timber from native forests in RFA regions (2005-2018)



Data source: VicForests

Quantification of impact

Native timber

There will continue to be some supply of this ecosystem services from native forests that were burnt in the 2019-20 bushfires, as salvage harvesting occurs. VicForests has announced plans to salvage harvest 3,500 hectares of severely fire affected timber over several years, while unburnt areas of native forest within the fire footprint will not be harvested.[41]

Plantation timber

Supply of this ecosystem service is likely to be sustained, as salvage harvesting occurs in plantation forests that were burnt in the 2019-20 bushfires. The Australian Forest and Wood Products Association reported that 6,000 hectares of HVP's softwood plantations in north east Victoria were burnt, and that salvage harvesting has commenced.[42] After salvage harvesting occurs, plantation forests are cleared and a new rotation planted, meaning that impacted plantations will not provide timber again until the end of their rotation length. Softwood plantations are predominantly long rotation (25-35 years) radiata and southern pines, while hardwood plantations are predominantly short rotation (10-12 years) southern blue gum and shining gum.[43]

There are over 150,000 hectares of plantations in East Gippsland, Gippsland and the North East RFA regions, predominantly in Gippsland and the North East (see Table 16). Around three quarters is softwood plantation (mainly in Gippsland and the North East) and a quarter is hardwood plantation (mainly in Gippsland). There are around 270,000 hectares of plantations in the rest of Victoria, largely in the west of the state.

41. VicForests 2020, 'VicForests starts post-fire timber recovery', accessed 31 August at https://www.vicforests.com.au/fire-management-1/vicforests-starts-post-fire-timber-recovery
42. Australian Forest Products Association 2020, 'Submission to the Royal Commission into Natural Disaster Arrangements', April, p. 7.
43. BAEconomics 2016, *The economic potential for plantation expansion in Australia*, report to the Australian Forest Products Association, p. 3.

Around 7,800 hectares of plantation forest was burnt in the 2019-20 bushfires, in the North East and the East Gippsland RFA regions. Around 1,300 hectares was burnt in East Gippsland – a mix of hardwood and softwood. While this is a very small proportion of total plantations across Victoria, this represents around 20 per cent of East Gippsland plantations. In the North East mainly softwood plantations were burnt – around 6,500 hectares. Again, while this is a small proportion of total plantations across Victoria, it represents 10 per cent of plantations in the North East.

Figure 22 Plantation forest burnt in the 2019-20 bushfires

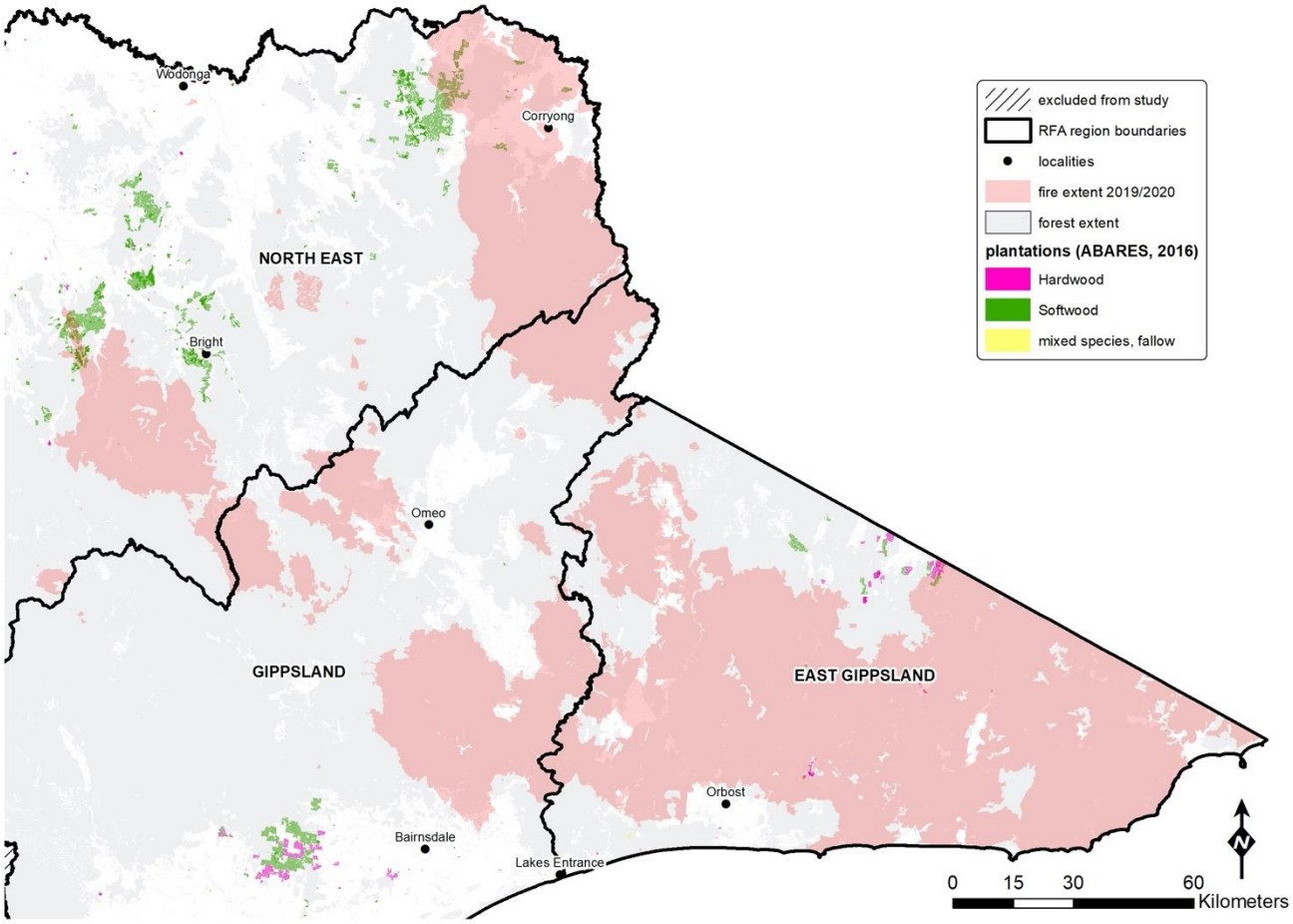


Table 26 Total plantation area and area burnt in the 2019-20 bushfires

	Plantation area (hectares)				Plantation area burnt (hectares)			
	Hardwood	Softwood	Mixed/ unknown	Total	Hardwood	Softwood	Mixed/ unknown	Total
East Gippsland	3,318	2,358	124	5,801	933	328	30	1,291
Gippsland	29,065	59,775	551	89,390	-	-	-	-
North East	2,993	53,079	26	56,098	31	6,490	-	6,521
Total	35,376	115,212	701	151,289	963	6,819	30	7,812

Source: ABARES National Plantation Inventory 2016; Note: Due to rounding, some totals may not correspond with the sum of the separate figures.

Fire severity provides another indicator of the impact of the bushfires on this ecosystem service. Table 27 shows the area of plantations burnt at different fire severity in each RFA region, ranging from low canopy scorch (class 3) to canopy burn (class 6). In the North East, plantations were burnt at a very high severity, with nearly 80 per cent burnt at class 5 or 6. These were largely softwood plantation. In East Gippsland, plantations were burnt at a lower severity, with around 50 per cent burnt at class 3. Fire severity classes are defined in Table 28.

Table 27 Area of plantation burnt at different fire severities (hectares)

RFA region	Non-woody vegetation (class 1)[a]	Low canopy scorch (class 3)	Medium canopy scorch (class 4)	High canopy scorch (class 5)	Canopy burn (class 6)
East Gippsland	33	550	111	100	100
Gippsland	0	1	0	0	0
North East	33	689	476	1,585	1,585
Total	66	1,240	587	3,216	1,685

a Areas burnt at fire severity class 1 are non-forested areas within the fire extent that overlap with the National Plantation Inventory extent. This may include non-forested areas within plantations (such as grass) or recently cleared plantation forests.
Source: ABARES National Plantation Inventory 2016 and DELWP fire severity mapping

Table 28 Fire severity classification of bushfires

Fire severity classification	
Class 6	Canopy burnt (>20% canopy foliage consumed)
Class 5	High canopy scorch (>80% of canopy foliage scorched)
Class 4	Medium canopy scorch (canopy a mosaic of both unburnt and scorched foliage, 20-80%)
Class 3	Low canopy scorch (canopy foliage is largely unaffected, <20% scorched, but understorey has been burned)
Class 2	Unburnt (canopy and understorey foliage are largely unburnt, >90%)
Class 1	Non-woody vegetation (unclassified)
Class 0	No data (e.g. due to obscuration by cloud, cloud-shadow and/or smoke and haze)

Source: Department of Environment, Land, Water and Planning

Biomass for firewood

Description of ecosystem service and users

Forests provide biomass which is collected or harvested for firewood. In Victorian state forests, public (household) firewood collection is permitted in spring and autumn within designated collection areas. Households also collect firewood from forests on private land. In addition, firewood is a primary or by-product of commercial harvesting in native and plantation forests.

This ecosystem service is used directly by households who collect firewood from forests on public or private land. Households benefit from using firewood for heating, cooking or aesthetic enjoyment. The ecosystem service is also used by industry (commercial harvesters) who supply firewood to businesses and households. Industry use is largely captured in the assessment of provision of biomass for timber: this section focuses on direct household use.

Impact of fire on ecosystem service

The impact of fire on this ecosystem service is complex. Bushfires consume trees and woody debris on the forest floor, reducing the quantity of biomass within an ecosystem. It is estimated that the 2019-20 bushfires consumed approximately 120 million tonnes of biomass across the East Gippsland, Gippsland and North East RFA regions.[44]

However, the actual quantity of firewood provided by an ecosystem is influenced by several factors, including human factors. For example, firewood provision in Victoria is constrained by the availability of collection areas in state forests and restrictions on how much firewood a household can collect.[45]

While there may be reduced public access to firewood collection areas within bushfire-affected state forests, alternative firewood collection areas can be made available. At the opening of the autumn season (1 March 2020), there were limited firewood collection areas available in the fire affected areas of DELWP's Gippsland and Hume regions.[46] However, the regions recovered through the season and the peak of the season saw an additional 60 firewood collection areas open across Victoria, with an additional 21 in the DELWP Gippsland region and an additional 36 in the DELWP Hume region. The average firewood season has between 240 and 280 firewood collection areas open at any time. The autumn 2020 season had a peak of 285 collection areas. While the autumn 2020 season opened with only 194 collection areas, the peak of the season had 253 collection areas open, within the average for a season.[47]

Biomass is also a by-product of bushfire response and recovery activities such as road clearing or felling of trees for safety purposes. Cleared biomass can be made available to the public as firewood following these works.[48] This occurred after the 2019-20 bushfires. For example, a collection area was opened in the Nariel Valley in the North East RFA region,

44. DELWP estimate based on data from the Department of Industry, Science, Energy and Resources. This estimate includes all above-ground biomass and debris; biomass that is suitable and available for firewood is a small subset of this. A conversion factor of 0.47 is used to convert biomass to carbon, see: Gifford, R 2000, *Carbon contents of above-ground tissues of forest and woodland trees*, National Carbon Accounting System Technical Report No. 22, Australian Greenhouse Office, Canberra, p. 24.
45. Designated collection areas are opened in autumn (1 April to 30 June) and spring (1 September to 30 November). A household is not allowed to collect more than 16 cubic metres a year, and a person is not allowed to collect more than 2 cubic metres in a day.
46. The DELWP Gippsland region roughly encompasses the Gippsland and East Gippsland RFA regions, while the DELWP Hume region roughly encompasses the North East RFA region.
47. Department of Environment, Land, Water and Planning, unpublished
48. Department of Environment, Land, Water and Planning 2020, 'Sustainable firewood management', accessed 31 August at https://www.ffm.vic.gov.au/firewood/sustainable-firewood-management

where households could collect firewood from trees salvaged from works undertaken to reopen the Benambra-Corryong road.[49]

Quantification of impact

This ecosystem service can be quantified as the volume of firewood collected or harvested from forests. In 2019, it was estimated that a minimum of 45,000 cubic metres of firewood is provided to the public from state forests across RFA regions each year, which has an estimated ecosystem service value of $3-7 million.[50] As discussed above, it is difficult to determine the overall impact of the bushfires on this ecosystem service, which has not been quantified or valued in this study.

49. Department of Environment, Land, Water and Planning 2020, 'Additional firewood collection area opens in the Upper Murray', accessed 31 August at https://www2.delwp.vic.gov.au/media-centre/media-releases/additional-firewood-collection-area-opens-in-the-upper-murray

50. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria, p. 76-9.

Biomass for fodder

Description of ecosystem service and users

Forests provide plant biomass (fodder) which is grazed by livestock. The user of this ecosystem service is the agricultural industry which uses fodder as an input to livestock production.

In Victoria, forests on private land and some areas of public forests can be used for grazing livestock. Forests provide space for livestock to move around and graze wild plants for nutrition and energy. Agricultural use of public forests in Victoria is restricted by policy governing the use of public land.

Impact of fire on ecosystem service

Fire is expected to have a negative impact on this ecosystem service. Provision of fodder from forests burnt in the 2019-20 bushfires is likely to decrease in the short to medium term, as grass and understory vegetation is reduced. License holders for agricultural use of public land are required to keep the licensed land in good order and condition. This means taking all reasonable steps to conserve soil and protect water resources,[51] which can be fragile after bushfires. Provision of this ecosystem service is expected to increase over time as forests regenerate. The speed at which this occurs is likely to depend on how severely forests were burnt.

However, the quantity of fodder provided by an ecosystem is influenced by a number of factors, including human factors. For example, provision of fodder from public forests in Victoria is constrained by the availability and location of grazing licenses. Consequently, the overall impact of the bushfires on provision of fodder within or across RFA regions will depend on whether livestock grazing patterns can be shifted to unburnt areas of forest.

Quantification of impact

Ideally, this ecosystem service would be quantified as the volume or weight of fodder provided by forests. That is, the quantity of plant biomass consumed by grazing livestock (cattle). However, in the absence of this information, the area of public forest licensed for agricultural use is reported as an indicator. This ecosystem service has not been valued in this study.

Key types of agricultural use licenses that intersect with forest extent are:

- Grazing licenses – allowing grazing of livestock on public land.
- Water frontage and riparian management licenses – allowing access to waterways for agricultural use (such as stock access to water) or recreational use. Riparian management licenses ensure waterway access is managed to both protect and improve the riparian environment, and typically attract a reduced license fee.
- Unused roads licenses – allowing owner/occupiers of adjoining private land to access unused roads of public land for agricultural purposes.

There are almost 480,000 hectares of public forest licensed for agricultural use across the East Gippsland, Gippsland and North East RFA regions. Most of this is grazing licenses (90 per cent of total forest area licensed), with smaller areas licensed for water frontage access and riparian management, unused road access, and other uses.

51. Department of Environment, Land, Water and Planning 2017, ‘Crown water frontages: An explanatory guide to your license condition’, State of Victoria.

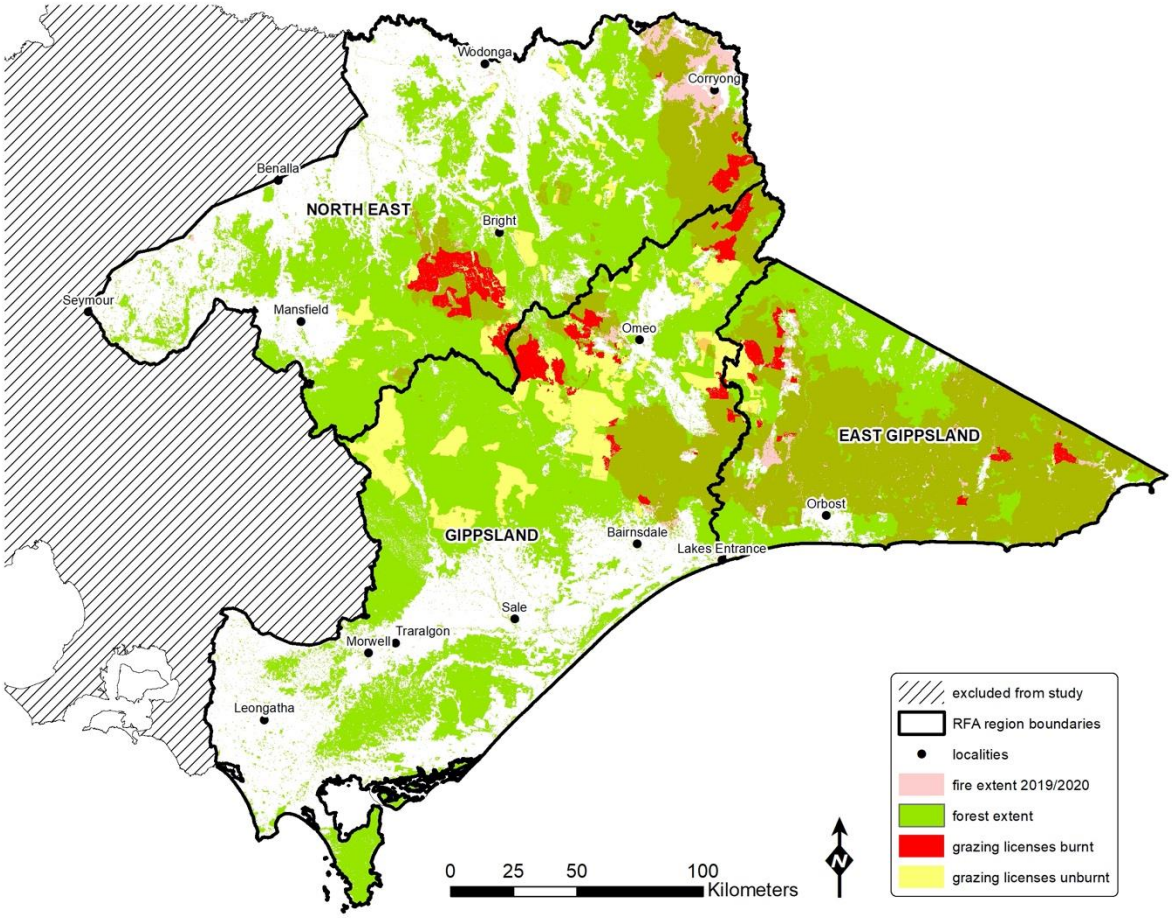
Of the area of forest licensed for agricultural use, around a third (almost 150,000 hectares) was burnt in the 2019-20 bushfires. Over half of the licensed area burnt was burnt at the two highest fire severity classes (class five and six – see Table 28 for more information on fire severity classes).

The licensed area burnt was greatest in the North East RFA region (around 65,000 hectares) followed by the Gippsland RFA region (around 60,000 hectares), although the East Gippsland had the greatest proportion of licensed area burnt within an RFA region (55 per cent).

Table 29 Area of forest licensed for agricultural use burnt in the 2019-20 bushfires (hectares)

RFA region	Total licensed area	Licensed area burnt	Burnt at class 1	Burnt at class 3	Burnt at class 4	Burnt at class 5	Burnt at class 6
East Gippsland	44,354	24,604	79	9,480	3,350	8,889	2,805
Gippsland	301,147	59,269	118	15,195	4,765	25,209	13,981
North East	132,126	64,330	112	21,147	14,894	24,813	3,363
Total	477,628	148,202	310	45,823	23,009	58,911	20,150

Figure 23 Area of forest licensed for agricultural use (grazing) burnt in the 2019-20 bushfires



Floral resources for honey and pollination

Description of ecosystem service and users

Forests provide floral resources (nectar and pollen) which support managed bee populations. Apiarists (beekeepers) place hives on public and private land within or near forests and use the floral resources (particularly eucalypts) for honey production and to strengthen hives before they are transported to pollinate agricultural crops.

This ecosystem service is used by the apiary industry, which in turn supplies commercial pollination services to the agricultural industry, and honey and other bee products to households and businesses. Households may also use this ecosystem service directly for non-commercial honey production, and farmers and households with gardens also benefit from wild pollination services.

Most Victorian honey is produced by European honeybees, although there is a small amount of production by native bees. Honey production is heavily dependent on access to native floral resources. Nationally, native flora has been estimated to support 70-80 per cent of honey production.[52]

Many agricultural crops rely on commercial pollination, which in turn is dependent on access to native floral resources. Apiarists typically store and strengthen bee colonies by placing hives in or near forests. Hives are then transported to farms to pollinate specific crops (such as Victoria's almond orchards).

Impact of fire on ecosystem service

Bushfires have a direct impact on the apiary industry through the destruction of hives and/or bees. In March 2020, B-QUAL estimated that 800 hives were lost to fire in Victoria and at least 50,000 hives across Australia are operating at reduced strength due to losing bees.[53] AgriFutures Australia estimate 650 hives were lost in Victoria.[54] However, this study focus is on the impact of the bushfires on the ecosystem service used by the apiary industry.

Floral resources from forests burnt in the 2019-20 bushfires are expected to decrease in the short to medium term, reducing the capacity of these forests to support the provision of honey and pollination services. In a survey conducted in 2016 by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), 62 per cent of Victorian beekeeping businesses said that fire was a factor affecting their floral resource base.[55]

Provision of this ecosystem service is expected to increase over time as forests regenerate and as access to apiary sites is restored. The speed at which this occurs is likely to depend on how severely forests were burnt. Some estimates suggest that the recovery time for floral resources ranges from 3 to 25 years. Eucalypts that have had their crowns burnt can take over 10 years to recover.[56]

However, the quantity of floral resources provided by an ecosystem is influenced by several factors, including human factors. For example, provision of floral resources is constrained by

52. Gibbs, D, & Muirhead, I 1998, *The economic value and environmental impact of the Australian beekeeping industry*, report prepared for the Australian beekeeping industry, p. 37.
53. B-QUAL Australia 2020 'March 2020 newsletter', volume 19, issue 3, B-QUAL Australia, Brisbane, p. 2.
54. AgriFutures Australia 2020, *Bushfire recovery plan: Understanding what needs to be done to ensure the honey bee and pollination industry recovered from the 2019-20 bushfire crisis*, publication number 20-057, Wagga Wagga, p. 2.
55. Australian Bureau of Agricultural and Resource Economics and Sciences 2016, *Australian honey bee industry: 2014-15 survey results*, Commonwealth of Australia, Canberra, p. 22.
56. AgriFutures Australia 2020, *Bushfire recovery plan: Understanding what needs to be done to ensure the honey bee and pollination industry recovered from the 2019-20 bushfire crisis*, publication number 20-057, Wagga Wagga, p. vi.

the availability and location of apiary sites on public land. Consequently, the overall impact of the bushfires on provision of floral resources within or across RFA regions will depend on whether apiarists can move hives to unburnt forests and access floral resources in other areas.

Quantification of impact

The impact of the 2019-20 bushfires on apiary sites on public land gives an indication of the impact on provision of floral resources to apiarists.[57] Apiary sites are a good indicator as they spatially show where there is demand for this ecosystem service, although the dataset used does not include apiary sites on private land.[58] Consequently, apiary sites on public land represents a lower bound indicator. A key caveat is that sites are not always occupied and the number of hives on each site varies. There are over 68,000 hives in Victoria on both public and private land, registered to over 3,000 beekeepers.[59]

Apiary sites are typically located in or near forests to ensure access to native floral resources (see Figure 24). Across the three RFA regions, 305 public land apiary sites were *within* the area of forest burnt, and a further 140 sites had forest burnt within their range (see Table 32).[60] This represents 34 per cent of the total number of public land apiary sites across the three RFA regions. East Gippsland the most impacted RFA region, with 75 per cent of sites affected. Twenty-six per cent of sites in the Gippsland RFA region were affected, and 10 per cent of sites in the North East RFA region.

In total, around 175,000 hectares of forest was burnt within range of apiary sites on public land. This represents a quarter of all forest within range of apiary sites across the three RFA regions (see Table 31). Fire severity is another indicator of the impact of the bushfires on provision of floral resources. Forests impacted by lower intensity fire are expected to regenerate and become productive faster than sites impacted by higher intensity fire. Table 32 shows the area of forest burnt at different fire severities within range of apiary sites. Over half of this area was burnt at the two highest fire severity classes, indicating significant scorching or consumption of canopy foliage.

This reduction in floral resources is expected to reduce the quantity of honey and commercial pollination attributable to fire-affected forests. However, as discussed above, the overall impact on honey production and commercial pollination will depend on whether apiarists can move hives to unburnt forests and access floral resources in other areas.

Industry experts have suggested that honey production across Australia is down 50 per cent since the 2019-20 bushfires.[61] The Australian Honey Bee Industry Council expects to see an reduction in honey production[62] and the Honey Packers & Marketing Association points to a 2019-20 crop that is 51 per cent of the long-term average.[63] Honey production levels are

57. Department of Environment, Land, Water and Planning dataset: Apiary rights and bee farm and range licenses. This spatial dataset includes apiary sites on public land only. In addition, apiary sites on public land are not always licensed, and licensed sites may not always be occupied by hives.
58. In 2001 it was estimated that 30 per cent of hives were located on private land. Centre for International Economics 2005 *Future directions for the Australian honeybee industry*, report prepared for the Department of Agriculture, Fisheries and Forestry, p. 141.
59. Australian Bureau of Agricultural and Resource Economics and Sciences 2016, *Australian honey bee industry: 2014-15 survey results*, Commonwealth of Australia, Canberra, p. 3.
60. An apiary site range of 1.6 kilometres is used in this analysis in line with the Victorian Government's *Apiculture (beekeeping) on public land standard operating procedure*.
61. AgriFutures Australia 2020, *Bushfire recovery plan: Understanding what needs to be done to ensure the honey bee and pollination industry recovered from the 2019-20 bushfire crisis*, publication no. 20-057, Wagga Wagga, p. iii.
62. Australian Honey Bee Industry Council 2020, 'April 2020 newsletter', Australian Honey Bee Industry Council, Canberra, p. 16.
63. AgriFutures Australia 2020, *Bushfire recovery plan: Understanding what needs to be done to ensure the honey bee and pollination industry recovered from the 2019-20 bushfire crisis*, publication no. 20-057, Wagga Wagga, p. vii.

forecast to be 30 to 50 per cent lower for 5 years.[64] The Australian Honey Bee Industry Council has raised concerns about the loss of pollination services for almond and avocado growers and potential reductions in production of pollination dependent crops and price increases for consumers.[65]

Figure 24 Apiary sites on public land impacted by the 2019-20 bushfires

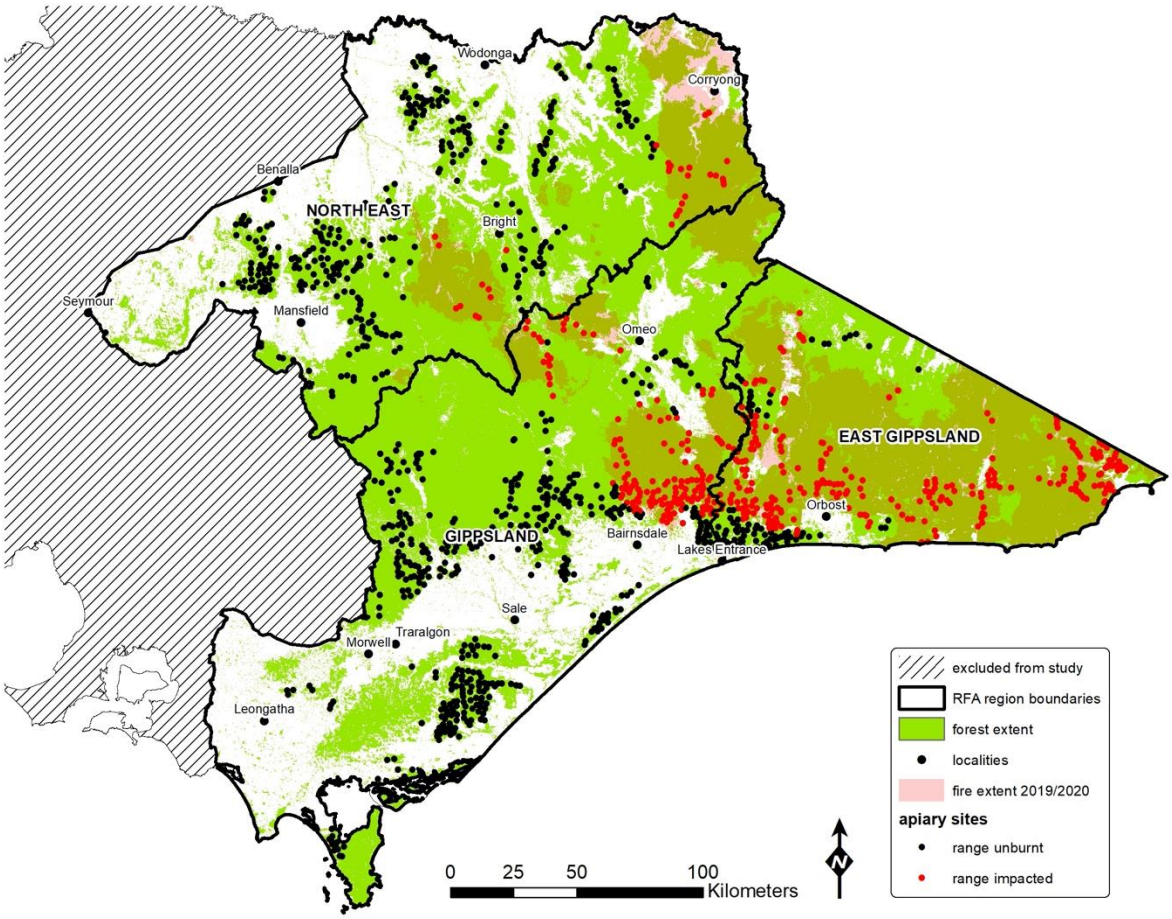


Table 30 Number of apiary sites on public land impacted by the 2019-20 bushfires

RFA region	Total apiary sites	Apiary sites within burnt area	Apiary sites within range of burnt area
East Gippsland	349	196	261
Gippsland	586	85	150
North East	363	24	34
Total	1,298	305	445

Apiary sites within burnt area is a subset of apiary sites within range of burnt area.

64. AgriFutures Australia 2020, *Bushfire recovery plan: Understanding what needs to be done to ensure the honey bee and pollination industry recovered from the 2019-20 bushfire crisis*, publication no. 20-057, Wagga Wagga, p. 5.

65. Australian Honey Bee Industry Council 2020, 'April 2020 newsletter', Australian Honey Bee Industry Council, Canberra, p. 16.

Table 31 Area of forest burnt in 2019-20 bushfires within range of apiary sites on public land (hectares)

RFA region	Area of forest within range of apiary sites	Burnt area of forest within range of apiary sites
East Gippsland	179,838	108,666
Gippsland	285,645	50,005
North East	201,052	15,863
Total	666,535	174,534

Source: DELWP

Table 32 Area of forest burnt at different fire severities within range of apiary sites on public land (hectares)

RFA region	Non-woody vegetation (class 1)	Low canopy scorch (class 3)	Medium canopy scorch (class 4)	High canopy scorch (class 5)	Canopy burn (class 6)
East Gippsland	325	40,284	14,978	33,745	19,337
Gippsland	157	20,957	2,318	17,609	8,962
North East	35	4,264	3,003	7,170	1,390
Total	517	65,504	20,300	58,523	29,688

Source: DELWP Note: Due to rounding, some totals may not correspond with the sum of the separate figures.

Regulating services

Erosion control (soil retention)

Description of ecosystem service and users

Forests provide a soil retention service, as vegetation cover helps prevent erosion. Forests in areas with steeper terrain and higher rainfall (such as northeast Victoria) are typically significant providers of this service, relative to drier and less mountainous areas (such as west Victoria).

This ecosystem service is used by households, industry and government. The water and agricultural industries benefit from reduced sediment in water systems. In addition, communities may benefit from reduced risk of post fire debris flows/mudflows.

Impact of fire on ecosystem service

Provision of this ecosystem service is expected to decrease as a result of the 2019-20 bushfires, as vegetation cover is reduced. The size of the decrease depends on a number of factors including fire severity (i.e. how much vegetation cover is burnt), topography, aridity and the timing and severity of post-fire rainfall.

Soil retention is expected to increase over time as forests regenerate and vegetation cover increases. The impact of the bushfires is expected to be realised predominantly in the first two years post-fire, with a significant impact in year one and a smaller impact in year two.

This study assesses the impact of the 2019-20 bushfires on soil retention in terms of increased soil erosion to major waterways. However, as noted above, decreased soil retention may have other implications such as increased risk of debris flow/mudflows and poor water quality events meaning that the overall impact of the bushfires on this ecosystem service is only partially assessed and valued.

Quantification of impact

In the 2019 assessment of forest ecosystem services, annual soil erosion from forests in RFA regions was modelled from 2008 to 2018. Total soil erosion was quantified, as well as soil discharged to major waterways (which is a subset of total erosion).[66,67] Avoided soil erosion to major waterways is reported as the measure of the ecosystem service, as this has a more clearly identified user (e.g. the water and agricultural industries). However, in an ecosystem accounting framework, soil erosion that is deposited in catchments still has an impact as it would affect the condition of ecosystem assets, and the ecosystem services these assets can generate.

To quantify the impacts of the bushfires on this ecosystem service, annual soil erosion modelling produced by Alluvium Consulting specifically for the 2019/2020 fires was used[68]. Background average annual hillslope erosion was used as the counterfactual 'no-fire' scenario and post fire annual hillslope erosion rates for the first- and second-year following fire were used for the 2020 and 2021 erosion estimates respectively. More detail on this process is contained in Appendix B: Technical summary.

66. 82 per cent of soil assumed to be deposited in the catchment before reaching a major waterway.
67. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria, pp. 98-103.
68. Alluvium Consulting 2020, 'Regional scale mapping of fire severity and erosion risk', https://www.alluvium.com.au/news/river-impacts-and-recovery-after-fire

Table 33 reports the results of this analysis in terms of total soil erosion from forests in the East Gippsland, Gippsland and North East RFA regions, while Table 34 reports soil erosion to major waterways. The difference between the 'no fire' counterfactual (i.e. average annual soil erosion from 2008-2018) and the bushfire scenario is shown in Figure 25. That is, the estimated increase in soil erosion due to the bushfires, if rainfall and other conditions were similar to the background annual average value.

The bushfires are estimated to result in an additional 724,000 tonnes of soil erosion in 2020 and 2021, with 88 per cent occurring in the first year (see Table 33). Of this, 130,000-261,000 is estimated to discharge to major waterways (see Table 34). This is a 290 per cent increase in soil erosion from forests across the three RFA regions in 2020 (compared to the 2008-2018 average). However, this represents a small decrease in provision of the ecosystem service of soil *retention*. Over 2008-2018, forests across the three RFA regions prevented, on average, around 600 million tonnes of soil erosion to major waterways per year. The decrease in soil retention due to the bushfires represents a less than 1 per cent decrease in total provision of the ecosystem service. However, this does not imply that the ecosystem service loss is without consequences or value, rather that forests provide a very significant soil retention service to begin with.

Valuation of impact

The impact of the 2019-20 bushfires on the ecosystem service of soil retention can be valued using a damage cost approach. That is, the avoided cost of repairing damages incurred due to the loss of soil retention, such as the cost of removing sediment from waterways. This is among a number of approaches for directly valuing soil retention services identified in a discussion paper authored as part of the SEEA revision process,[69] and was applied in the 2019 assessment of ecosystem services from forests in RFA regions. This approach requires clearly identifying users or beneficiaries of the ecosystem service, and appropriate actions that could be taken to repair the damage caused by loss of soil retention.[70]

There is limited information available on the cost of sediment removal from inland waterways. A cost estimate from 2007 and 2008 in Western Australia was $17 per tonne.[71] Inflated to AUD2019, the cost can be applied to the quantity of increased soil erosion to major waterways resulting from the bushfires. A key limitation of this approach is that it assumes there is demand for the removal of all of the increased sediment by artificial means. This is partly addressed by applying the cost estimate to soil erosion to regulated water systems (systems that have water storages or weirs) to derive a lower bound value. This does not mean that soil erosion to unregulated systems does not have a cost – it undoubtably has a direct or indirect impact on households or industries – but that the level of demand for the ecosystem service is less established. Consequently, an upper bound value is derived that includes the cost of removing sediment from unregulated waterways.

The estimated value of ecosystem service loss due to the bushfires is $1.0-4.8 million in 2020 and $0.1-0.6 million in 2021 (see Table 35). Given the difficultly in estimating the level of demand for this ecosystem service, and the lack of location specific replacement or

69. Burkahrd, B, Guerra, CA & Davidsdottir, B 2019, *Discussion paper 3: Soil retention (regulating) ecosystem services*, paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York, 22-24 January 2019 and subsequently revised, version of 15 April 2019.

70. Burkahrd, B, Guerra, CA & Davidsdottir, B 2019, *Discussion paper 3: Soil retention (regulating) ecosystem services*, paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York, 22-24 January 2019 and subsequently revised, version of 15 April 2019.

71. Department of Water 2009, *Water notes for river management: Advisory notes for land managers on river and wetland restoration*, WN38 February 2009, Government of Western Australia, Perth.

damage cost information, the value loss should be interpreted as an indicative estimate only. In addition, as previously noted, decreased soil retention can have other implications – such as increased risk of debris flows impacting infrastructure and poor water quality events – meaning that the overall impact of the bushfires on this ecosystem service is only partially assessed and valued.

Figure 25 Indicative increase in soil erosion in 2020 due to the 2019-20 bushfires

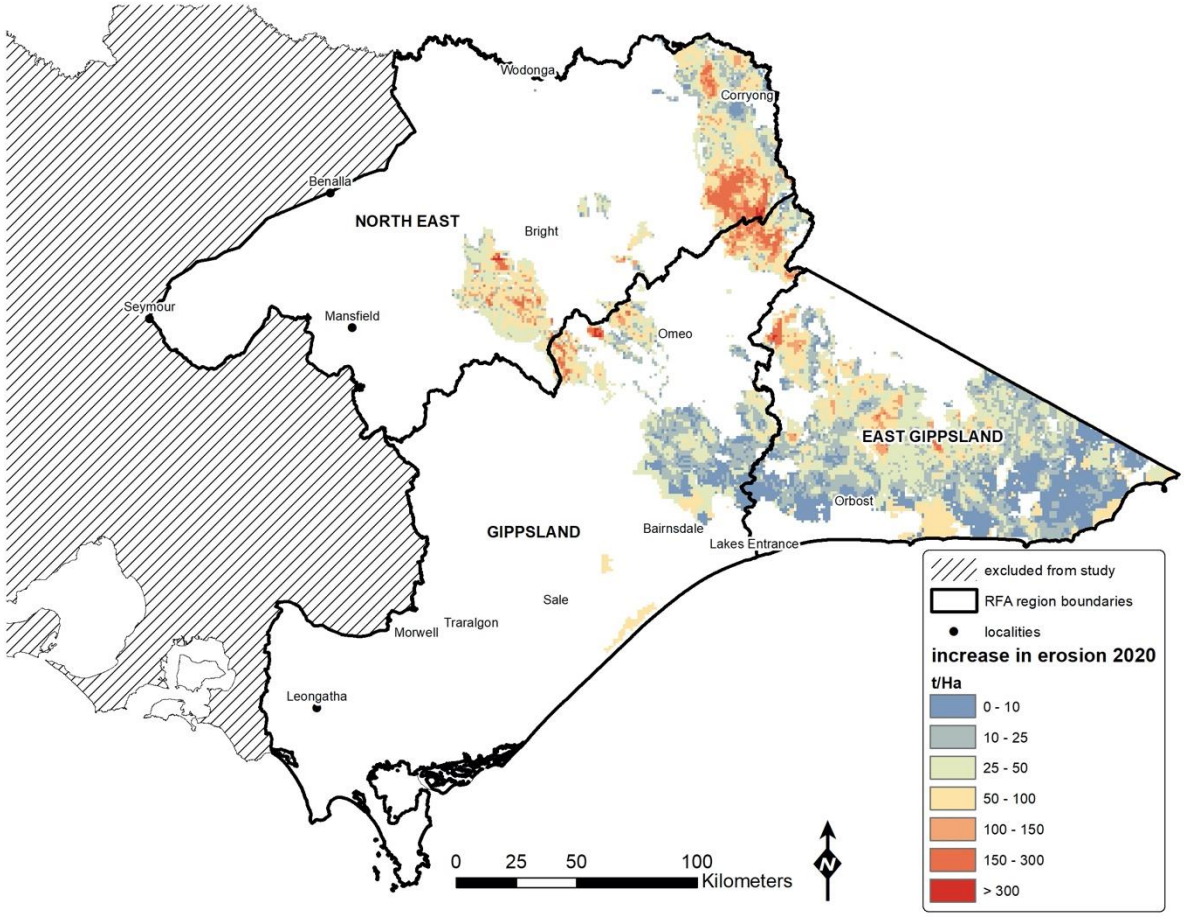


Table 33 Total indicative increase in soil erosion due to the 2019-20 bushfires ('000 tonnes)

RFA region	2020	2021	Total
East Gippsland	255	30	284
Gippsland	157	23	180
North East	229	31	260
Total	641	83	724

Note: Due to rounding, some totals may not correspond with the sum of the separate figures.

Table 34 Indicative increase in soil erosion to major waterways due to the 2019-20 bushfires ('000 tonnes)

RFA region	2020	2021	Total
East Gippsland	46-92	5-11	51-102
Gippsland	28-56	4-8	32-65
North East	41-83	6-11	47-94
Total	115-231	15-30	130-261

Note: Due to rounding, some totals may not correspond with the sum of the separate figures.

Table 35 Indicative increase in soil erosion to major waterways due to the 2019-20 bushfires ($ '000)

RFA region	2020	2021	Total
East Gippsland	Up to 1,925	Up to 215	Up to 2,140
Gippsland	282-1,185	34-166	316-1,351
North East	733-1,734	87-224	820-1,959
Total	1,015-4,844	121-606	1,136-5,450

Water flow regulation (flood mitigation)

Description of ecosystem service and users

Forests provide a water flow regulation service, as they store, transpire and redirect water from rainfall. This reduces and retards peak runoff events to river systems and can help mitigate riverine flooding.[72] The level of service provided depends on factors such as catchment topography and rainfall.

This ecosystem service is used by households, industry and government who benefit from reduced frequency and/or severity of river flooding.

Impact of fire on ecosystem service

Supply of this ecosystem service is expected to decrease as a result of the 2019-20 bushfires, as vegetation cover is reduced. However, the size of the impact will depend on the timing and severity of post-fire rainfall: there will be a bigger decrease in water flow regulation (i.e. decreased flood mitigation) if a bushfire is followed by a wet year rather than a dry year. The size of the impact is also related to fire severity and vegetation type, with higher fire severity likely to result in a greater decrease in water flow regulation.

Supply of this ecosystem service is expected to increase over time as forests regenerate and vegetation cover increases. The impact is greatest in the first-year post-fire, with water flow regulation (flood mitigation) expected to increase substantially in years two and three as supply returns to pre-fire levels.

Quantification of impact

In the 2019 assessment of forest ecosystem services, spatial analysis was undertaken to identify the users, or beneficiaries, of the water flow regulation service provided by forests.[73] Victoria is divided into a total of 2,973 localities[74] and 770 have residential, commercial or industrial areas[75] within the 1 in 100-year flood zone.[76] Of these, 646 localities have RFA forest in their upstream catchment (even if the locality itself is not in an RFA region). The combination of a locality being in the 1 in 100-year flood zone and having RFA forest in its catchment is used as an indicator of receipt of water flow regulation services, suggesting that forests in RFA regions are providing some level of water flow regulation service to 646 localities across Victoria. Combined these localities have 13,596 hectares of urban, commercial and industrial land within the 1 in 100-year flood zone.

In this study, localities that are in the 1 in 100-year flood zone and have forest in their upstream catchment that was burnt in the 2019-20 bushfires are reported as an *indicator of the potential impact* of the bushfires on this ecosystem service. This gives an indication of localities that *may* experience a decrease in water flow regulation and increased risk of riverine flooding as a result of the bushfires. It should be noted that the relationship between bushfires, vegetation loss, aridity, water yield, stream flow and flood events is complex.

72. Crossman, N, Nedkov, S, Brander, L 2019, *Discussion paper 7: Water flow regulation for mitigating river and coastal flooding*, paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York 22-24 January 2019 and subsequently revised, version of 1 April 2019, p. 4.
73. Department of Environment, Land, Water and Planning 2019, *Ecosystem services from forests in Victoria: Assessment of Regional Forest Agreement regions*, State of Victoria, pp. 87-97.
74. A locality is a statewide standardised boundary registered by the Registrar of Geographic Names. In urban areas locality is analogous to suburb.
75. A defined by VLUIS land use mapping.
76. The 1 in 100-year flood zone delineates modelled statistical flood extents with an average recurrence interval (ARI) of 100 years, for further information see https://discover.data.vic.gov.au/dataset/1-in-100-year-flood-extent

Consequently, this approach provides a high-level *indicator of potential impact* only, rather than actual forecasts of increased flood risk.

The 2019-20 bushfires burnt forest in the upstream catchment of 108 localities across Victoria (see Figure 26 and Table 36), indicating that these localities may experience a decreased water flow regulation and increased risk of riverine flooding. This means that the bushfires impacted 17 per cent of the 646 localities that have forest in RFA regions in their upstream catchment. Combined these localities have nearly 2,500 hectares of urban, commercial and industrial land within the 1 in 100-year flood zone. However, it should be noted that this assessment only considers localities with urban, commercial or industrial land, whereas agricultural land can also be affected by decreases in water flow regulation post-fire.

Of the 108 localities impacted by the bushfires, 69 localities have 'unregulated' catchments, meaning that there is no upstream infrastructure such as reservoirs to retard peak flood flows. The other 39 have 'regulated' catchments, meaning that the localities are downstream of major reservoirs (see Table 36). Forests are expected to provide a greater water flow regulation service to localities with unregulated catchments, although they can still provide a service in regulated catchments, as the major reservoirs, Lake Hume and Dartmouth Dam, are primarily managed to optimise irrigation and water supply with flood mitigation being a secondary management objective[77].

Localities have varying proportions of forest burnt in the 2019-20 bushfires in their upstream catchment. For example, 34 localities have burnt forest in 10-19 per cent of their catchment, while 27 localities have burnt forest in 0-9 per cent of their catchment (see

[77] Murray Darling Basin Authority, 1992, Murray Darling Basin Agreement

Table 36). A number of localities had significant proportions of their catchment burnt. Table 37 lists localities where over 50 per cent of their catchment is burnt forest. These 19 localities all have unregulated catchments.

Catchments were also burnt at varying fire severity. Table 38 shows the proportion of catchments burnt at different severities. For example, 7 localities had 10-19 per cent of their catchment burnt at the highest fire severity (class 6). Eight localities had more than 30 per cent of their catchment burnt at class 5 – the second highest fire severity rating where there is significant canopy foliage scorch. Localities that had large proportions of their catchments burnt at higher fire severity may experience a greater decrease in water flow regulation services and increased risk of flooding. However, a more definitive analysis would need to account for other factors, such as topography, aridity and vegetation type.

This ecosystem service has not been valued in this study.

Table 36 Proportion of burnt forest in the upstream catchment of localities

% of catchment that is burnt forest	Number of localities		Area of urban, commercial and industrial land within 1 in 100-year flood zone (ha)	
	Unregulated	Regulated	Unregulated	Regulated
0-9	9	18	248	481
10-19	23	11	692	414
20-29	8	7	270	117
30-39	4	-	36	-
40-49	6	3	12	13
50-59	4	-	59	-
60-69	5	-	10	-
70-79	4	-	43	-
80-89	3	-	32	-
90-99	3	-	32	-
Total	69	39	1,433	1,025

Regulated refers to localities with built infrastructure (such as reservoirs) in their upstream catchment. Unregulated refers to localities without upstream infrastructure

Table 37 Localities where burnt forest is more than 50 per cent of the catchment

% of forest in catchment burnt	Localities	
90-99	Genoa Nariel Valley	Wairewa
80-89	Noorinbee Cann River	Colac
70-79	Bemm River Corryong	Sarsfield Towong
60-69	Biggara Buckland Marlo	Nicholson Tintaldra
50-59	Cudgewa Mount Alfred	Pine Mountain Walwa

Table 38 Proportion of catchment burnt at different fire severities, number of localities

% of catchment	Low canopy scorch (class 3)	Medium canopy scorch (class 4)	High canopy scorch (class 5)	Canopy burn (class 6)
0-9	78	93	71	99
10-19	21	15	18	7
20-29	4	0	11	2
30-39	5	0	4	0
40-49	0	0	3	0
50-59	0	0	1	0
60-69	0	0	0	0
70-79	0	0	0	0
80-89	0	0	0	0
90-99	0	0	0	0
Total	108	108	108	108

Figure 26 Localities with forest in their upstream catchment burnt in the 2019-20 bushfires

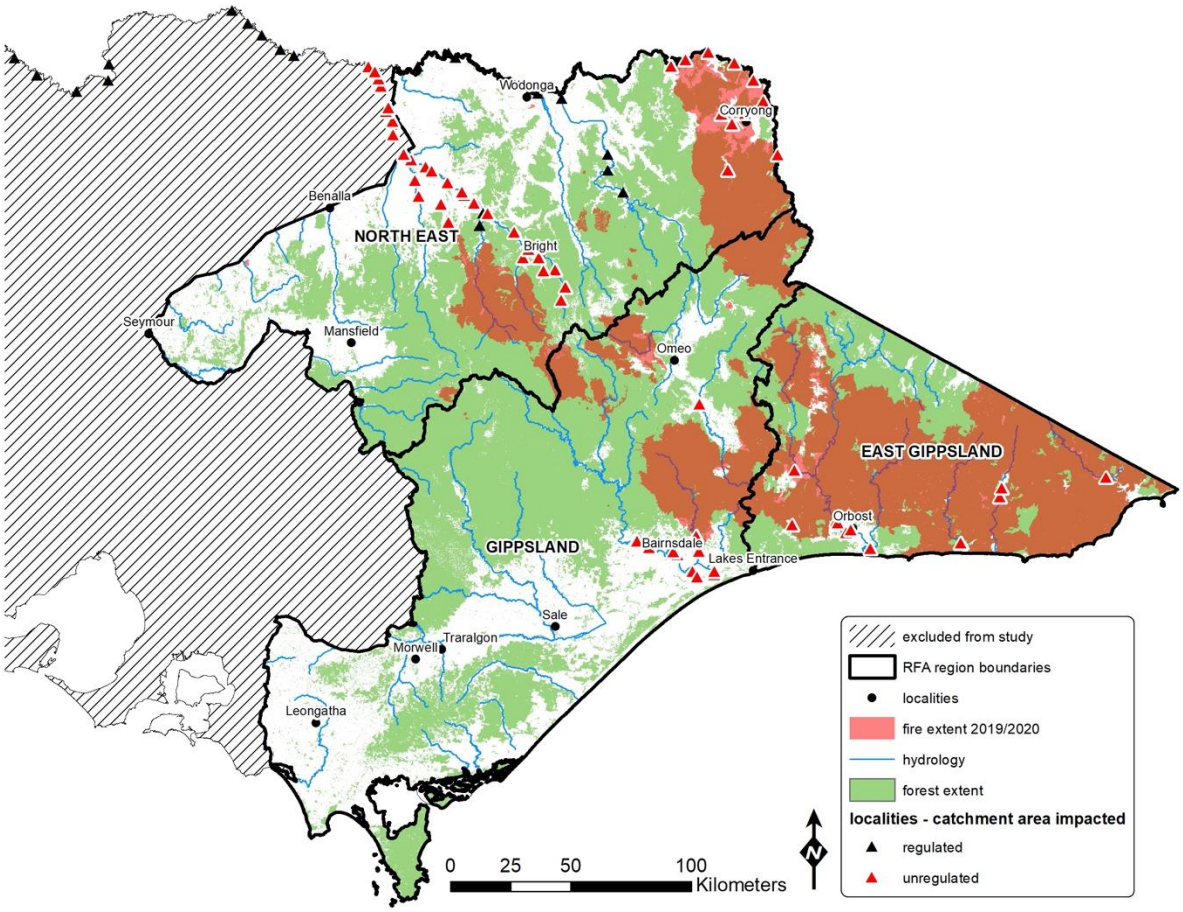
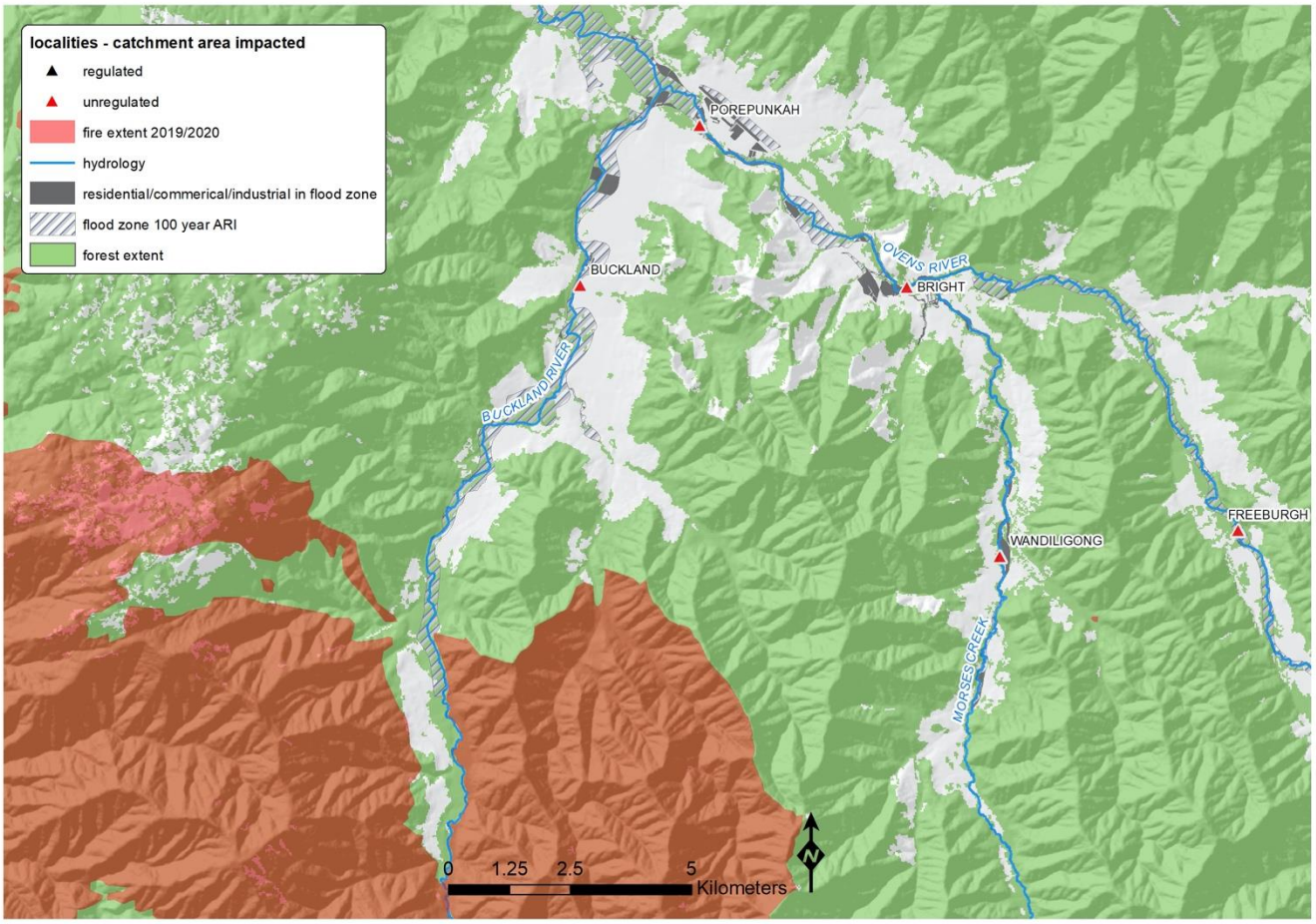


Figure 27 Zoomed example of localities with forest in their upstream catchment burnt in the 2019-20 bushfires



Global climate regulation (carbon retention)

Description of ecosystem service and users

Forests remove carbon dioxide from the atmosphere and store carbon in plant biomass and soil, while carbon is released from forests ecosystems due to disturbances such as fire or the degradation of vegetation and soils. Carbon is also removed from forest ecosystems when biomass is harvested or collected and is stored in wood products until burned or degraded. The sequestration and storage of carbon by ecosystems reduces atmospheric concentrations of carbon dioxide and helps regulate the global climate. The 'user' of this ecosystem service is the Victorian, Australian and global communities who benefit from reduced impacts of climate change.

There are several ways climate regulation services can be conceptualised in an ecosystem accounting context. Carbon is a rapidly developing area of ecosystem accounting, and expert thinking and international discussions have progressed since DELWP's 2019 assessment of ecosystem services from forests in Victoria. Carbon is a key focus of the United Nations System of Environmental-Accounting (SEEA) Experimental Ecosystem Accounting (EEA) revision, however the definitive treatment of climate regulation services is yet to be determined.[78]

With the SEEA EEA revision still underway, this appendix outlines two distinct approaches to framing and measuring the climate regulation service – a carbon sequestration approach and a carbon retention approach – and discusses the merits and limitations of each. Carbon retention has emerged as the preferred approach in the SEEA EEA revision,[79] superseding the previous focus on carbon sequestration. In addition, a carbon retention approach clearly captures the impact of bushfires on ecosystem service flows. For these reasons, a carbon retention approach is used to quantify and value the climate regulation service in this study. However, a carbon sequestration approach is also outlined and applied here for completeness and comparability with other studies. Both approaches are based on the recording of stocks and changes in stocks of carbon in an ecosystem: a physical carbon stock account.

Carbon sequestration approach

Under this approach, the ecosystem service is defined as carbon sequestration: the accumulation of carbon in an ecosystem. This approach was set out in the 2012 SEEA EEA guidance[80] and variations of it have been widely applied in ecosystem accounting studies, including DELWP's 2019 assessment of ecosystem services from forests in Victoria and the Central Highlands ecosystem accounts published in 2017 by the Australian National University Fenner School of Environment and Society[81].

Carbon sequestration can be quantified as the gross or net accumulation of carbon in an ecosystem, and both have advantages and disadvantages. Gross sequestration will always be positive, which is an important attribute for ecosystem accounting and aligns with the

78. The United Nations SEEA EEA revision is expected to be finalised by 2021 and will provide guidance on how to define, quantify and value climate regulation services. Further information on the revision is available at: https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision

79. United Nations Statistics Division 2020, 'Chapter draft prepared for global consultation – Chapter 6: Ecosystem services concepts for accounting', System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting Revisions, July, pp. 16-17.

80. United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, pp. 64-66.

81. Keith, H, Vardon, M, Stein, J, Stein J & Lindenmayer, D 2017a, *Experimental ecosystem accounts for the Central Highlands of Victoria: Final report*, Australian National University Fenner School of Environment and Society, Canberra; Keith, H, Vardon, M, Stein, J, Stein J & Lindenmayer, D 2017b, *Experimental ecosystem accounts for the Central Highlands of Victoria: Appendices*, Australian National University Fenner School of Environment and Society, Canberra.

conceptualisation of other ecosystem services in that 'disservices' or negative contributions from the ecosystem to society (such as carbon emissions) are excluded.[82] However, this means that the impact of disturbances can be poorly reflected in ecosystem service flows. Bushfires will have a wholly positive impact on gross sequestration, as only the accumulation of carbon through post-fire regrowth will be measured. Net sequestration more fully captures the impact of disturbances such as bushfires, as carbon emissions will be netted off from carbon accumulated through regrowth. However, this means that ecosystem service flows can be negative in years where emissions exceed carbon accumulated through regrowth.

By focusing solely on additions and reductions to carbon stocks, both gross and net sequestration fail to capture the contribution ecosystems make by storing carbon over time. For example, mature forests will typically sequester less carbon than young or regenerating forests (net sequestration in mature forests can be close to zero) but they may hold large stocks of carbon. A distinct 'carbon storage' service that is additional to carbon sequestration has previously been conceptualised in ecosystem accounting literature,[83] but an approach has not been agreed or widely applied. The limitations of the carbon sequestration approach for understanding ecosystem services, as well as concerns of double counting if aggregated with carbon storage, have informed the emergence of a new approach: carbon retention.

Carbon retention approach

The SEEA EEA revision has sought to address the limitations of previous conceptualisations of climate regulation services and a new approach – carbon retention – has emerged. Under this approach, the ecosystem service is conceptualised as the retention of carbon in an ecosystem. That is, the *avoided* release of carbon.[84] Carbon retention is envisioned as the only climate regulation service. Carbon sequestration is not a service in and of itself, but supply of carbon retention services will increase as a result of positive net carbon sequestration.

Carbon retention can be quantified by measuring the stock of carbon in an ecosystem over an accounting period, which is as proxy indicator for ecosystem service flow.[85] If carbon stocks increase over time then the quantity of carbon retention service supplied will have increased, and vice versa. The minimum carbon retention service that can be supplied is zero, when the stock of carbon is zero. Carbon dense ecosystems (such as forests) will supply greater carbon retention services compared to less carbon dense ecosystems (such as grasslands).

The impact of major disturbances is reflected in ecosystem service flows. Bushfires will reduce supply of carbon retention services as carbon stocks decrease, but ecosystem service flows will still be positive as fire-affected forests still hold stocks of carbon. In fire-

82. United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, pp. 48-94.

83. The 2012 SEEA EEA guidance outlines a distinct carbon storage service in addition to carbon sequestration. See United Nations 2014, *System of Environmental-Economic Accounting 2012: Experimental ecosystem accounting*, United Nations, New York, pp. 64-66.

    A paper presented at the 25th meeting of the London Group on Environmental Accounting highlights the limitations of assessing carbon sequestration in isolation and proposes a distinct carbon storage service in addition to carbon sequestration. See Keith, H, Vardon, M, Lindenmayer, D, Mackey, B 2019, 'Accounting for carbon stocks and flows: storage and sequestration are both ecosystem services', Paper for the 25th meeting of the London Group on Environmental Accounting, Melbourne.

84. United Nations Statistics Division 2020, 'Chapter draft prepared for global consultation – Chapter 6: Ecosystem services concepts for accounting', System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting Revisions, July, p. 16.

85. This use of a stock measure to quantify service flow is analogous to quantifying the services supplied by a storage company in terms of the volume of goods stored. For further discussion see United Nations Statistics Division 2020, 'Chapter draft prepared for global consultation – Chapter 6: Ecosystem services concepts for accounting', System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting Revisions, July, pp. 16-17.

tolerant forests, ecosystem service flows will increase over time as vegetation regenerates and carbon stocks increase.

The carbon retention approach is still being developed and refined through the SEEA EEA revision. However, it is applied in this study given the direction of the revision, the merits of the approach, and the limitations of assessing bushfire impacts using a carbon sequestration approach.

Impact of fire on carbon stocks

Fire burns plant biomass and releases carbon dioxide to the atmosphere, reducing stocks of carbon in forests. The size of the reduction in carbon stocks depends on bushfire intensity. Lower intensity fire mainly burns debris and understory vegetation and has a lesser impact on carbon stocks. Higher intensity fire can burn forest canopy and tree trunks and has a greater impact on carbon stocks.

In fire-tolerant forests, such as those in parts of south-east Australia, vegetation regenerates over time and carbon stocks increase, typically returning to pre-fire levels within 10-15 years.[86] However, if forests are severely burnt more than once within the tolerable fire interval of a vegetation type, this may impact on the ability of the ecosystem to fully regenerate and return to pre-fire levels of carbon stock.

Carbon stock accounts and ecosystem service flow accounts can be used to track the impact of bushfires on forest carbon stocks and climate regulation services. This provides valuable information for monitoring post-fire recovery and the long-term impact of disturbances on the capacity of forests to supply climate regulation services.

Quantification of impact

It is estimated that there will be a net decrease in forest carbon stocks of 55 million tonnes in 2020 (see Table 39). This includes emission of 57 million tonnes of carbon due to fire and sequestration of 2 million tonnes of carbon due to post-fire regrowth.

Comparing this to historical forest carbon stocks across Victoria,[87] this represents around a 3 per cent decrease in carbon retention across the whole of the state. Comparing this to historical above-ground carbon stocks on public land in each RFA region, this represents around a 15 per cent decrease in carbon retention in East Gippsland and a 3 to 4 per cent decrease in Gippsland and the North East.[88] (Note that this overstates the magnitude of change in overall carbon retention in each region as below-ground carbon stocks and carbon stocks on private land are not included.)

It should be noted that the estimated decrease in forest carbon stocks is based on net emissions and removals of carbon dioxide only, in line with the current SEEA EEA. If emissions of methane were also included, the estimated net decrease in forest carbon stocks would increase from 55 to 71 million tonnes in 2020. Inclusion of other greenhouse gases is a topic of discussion in the current SEEA EEA revision process.

86. Department of Industry, Science, Energy and Resources 2020, *Estimating greenhouse gas emissions form bushfires in Australia's temperate forests: Focus on 2019-20*, Commonwealth Government, Canberra.

87. Average historical forest carbon stocks for the whole of Victoria are 2 billion tonnes (including living biomass, deadwood and litter and soil carbon. Source: Experimental carbon stock accounts 2016 – Victoria, Department of Industry, Science, Energy and Resources.

88. Average historical above-ground forest carbon stocks on public land are 233 million tonnes for East Gippsland, 270 million tonnes for Gippsland and 235 million tonnes for the North East. Source: Victorian Forest Monitoring Program, Above-ground biomass on public land.

Carbon sequestration approach

Gross carbon sequestration can be quantified using estimates of post-fire removals from the Commonwealth Department of Industry, Science, Energy and Resources (DISER) – see Table 39.[89] It is estimated that around 1.7 megatonnes of carbon will be removed from the atmosphere in 2020 due to post-fire regrowth across the three RFA regions.

Net carbon sequestration can also be quantified using DISER's estimates. It is estimated that around 56.7 megatonnes of carbon was emitted to the atmosphere due to the 2019-20 bushfires across the three RFA regions, resulting in a net reduction in carbon stock of 55.1 megatonnes across the three RFA regions (see Table 39). East Gippsland was the most significantly impacted due to the size and severity of the bushfires, with 36.2 megatonnes of carbon emitted. Around 10 megatonnes of carbon was emitted in both Gippsland and the North East.

Carbon retention approach

Carbon retention can be quantified as the stock of carbon recorded in an ecosystem over an accounting period, which is as proxy indicator for ecosystem service flow. The *impact* of the bushfires on carbon retention can be quantified using DISER's estimates. The change in carbon retention due to the bushfires is equal to the net change in carbon sequestration): 55.1 megatonnes of carbon across the three RFA regions in 2020.

However, total supply of carbon retention services in 2020 cannot be estimated as carbon stock estimates are not available beyond 2016 (for the whole of Victoria) or 2017 (for above-ground biomass on public land).

Table 39 Impact of the bushfires on carbon stocks in 2020 (megatonnes of carbon)

RFA region	Reductions to carbon stock	Additions to carbon stock	Net change in carbon stock
East Gippsland	-36.2	0.1	-36.1
Gippsland	-10.5	1.2	-9.3
North East	-10.0	0.3	-9.7
Total	-56.7	1.7	-55.1

Source: Department of Industry, Science, Energy and Resources
Note that additions to carbon stock may include regrowth attributable to bushfires prior to 2019-20, such as bushfires which occurred in Gippsland in 2018-19.
Note carbon stocks do not include methane emissions.

89. Department of Industry, Science, Energy and Resources 2020, *Estimating greenhouse gas emissions form bushfires in Australia's temperate forests: Focus on 2019-20*, Commonwealth Government, Canberra.

Valuation of impact

Carbon sequestration approach

Carbon sequestration can be valued using a market price approach by applying a suitable value to each tonne of carbon dioxide equivalent (CO2e). Tonnes of carbon emitted/removed can be converted to equivalent tonnes of carbon dioxide using a factor of 3.664.[90] Values consistent with scenarios in the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report[91] can be applied, with the values converted into Australian dollars for the relevant year using an average annual exchange rate and then escalated to the relevant year using an Australian GDP deflator.[92] Based on a scenario that would provide a likely chance of limiting global temperature increases to below 2°C above pre-industrial levels, the value per tonne of CO2e in 2020 is $71 (in AUD2019).[93,94] It should be noted that the IPCC values do not represent actual prices observed from carbon markets, rather they are derived from hypothetical (modelled) abatement scenarios.

Carbon prices are generally projected to increase over time. This presents a complexity when assessing the impact of bushfires on net carbon sequestration as, depending on the discount rate used, the value of carbon losses in the year a disturbance (such as a bushfire) occurs may be outweighed by the value of carbon sequestration in future years due to post-fire regrowth. That is, the net present value of future flows of carbon sequestration is greater *when a bushfire occurs.* This is another limitation of the carbon sequestration approach.

Carbon retention approach

Valuing carbon retention requires determining an appropriate unit value for the storage of a tonne of carbon for an accounting period (a year). This is different to unit values for a tonne of CO2e emitted/removed (discussed above) which, if simply multiplied by the quantity of carbon stocks, would provide a value of the asset (carbon stock) rather than annual service flow (carbon retention service).

A definitive method for valuing carbon retention has not yet been established in ecosystem accounting literature or practice. A proposed approach is to use standard capital accounting techniques to estimate an annual flow value.[95] For example, by valuing the carbon stock and using an annuity approach to create an annual flow value.

Supply of carbon retention services in a year (year t) can be valued using an annuity approach as follows:

90. One tonne of carbon is equal to 3.664 tonnes of CO2e. Department of the Environment and Energy 2017, *National greenhouse accounts factors: Australian national greenhouse accounts*, Commonwealth of Australia, Canberra.
91. Intergovernmental Panel on Climate Change 2014, 'Working Group III Contribution to the Fifth Assessment Report, Climate Change 2014—Mitigation', Cambridge University Press, Cambridge, p.450.
92. Conversion indices used are from the World Bank's World Development Indicators published in the Bank's online databank. World Bank Databank, World Development Indicators, Official exchange rate (LCU per US$, period average): Series code PA.NUS.FCRF, GDP deflator (base year varies by country): Series code NY.GDP.DEFL.ZS, http://databank.worldbank.org/data/
93. This IPCC scenario assumes global action is taken to keep global temperature rises to below 2°C and is maintained out to 2050. Values are derived from the mean of carbon prices that have been assessed by the IPCC as providing a greater than 66 per cent chance of keeping global temperature increases to below two degrees by 2100 – consistent with atmospheric concentrations of carbon dioxide equivalent to 430-480 ppm.
94. Values consistent with this IPCC scenario have previously been applied in Victorian Government analysis and decision-making. For example, see Department of Environment, Land, Water and Planning 2020, 'Appendix 12', *Regulatory Impact Statement: Victorian Energy Efficiency Target Amendment (Prescribed Customers and Targets) Regulations 2020*, State of Victoria, Melbourne, pp. 20-22.
95. Authors unknown 2020, Discussion paper 3.2: Treatments for selected ecosystem services and related flows for the revised SEEA EEA. February 2020, p. 19.

- Carbon stock in year t is converted to CO2e and valued by using a suitable carbon value for year t. Carbon values consistent with scenarios in the IPCC's Fifth Assessment Report (discussed above) can be applied.
- The carbon stock value is converted into a series of uniform annual payments using a discount rate of 4 per cent[96] over an infinite time period. The annual payment represents the value of ecosystem service flow in year t.
- This can be repeated to value ecosystem service flow in year t+1 and beyond, based on carbon stock in year t+1 and a suitable carbon value for year t+1.

By applying this approach to the estimated decrease in supply of carbon retention in 2020 (55.1 megatonnes of carbon across the three RFA regions in 2020), the value of this ecosystem service loss is estimated at $574 million in 2020.[97] This includes a loss of $376 million in East Gippsland, $96 million in Gippsland and $101 million in the North East.

96. Consistent with Victorian Department of Treasury and Finance guidance on discount rates. Department of Treasury and Finance 2013, *Economic evaluation: Technical guidance*, State of Victoria, Melbourne, pp. 24-27.

97. As discussed previously (see footnote 13), this differs from the approach taken in a study published by WWF-Australia in early 2020, which quantified and valued permanent carbon stock losses from the bushfires across south-east Australia. This study quantifies and values the impact of the bushfires on the ecosystem service of global climate regulation (carbon retention) in Victoria in 2020. This approach is consistent with an ecosystem accounting framework and aligns with the assessment of other ecosystem services. As the studies address different questions, they consequently yield different results. However, the underlying estimates of carbon emissions from the bushfires across south-east Australia broadly align. Emissions estimates discussed in the WWF-Australia study range from 400 to 1,000 Mt CO2, while the Department of Industry, Science, Energy and Resources estimated emissions of 850 Mt CO2.

Cultural services

Opportunities for recreation and tourism

Description of ecosystem service and users

Forests in Victoria provide diverse opportunities for recreation and sightseeing. The user of this ecosystem service is the Victorian community (households) as well as interstate and international visitors. The tourism industry may also directly use this ecosystem service as an input to tour operations in parks and state forests.

People visit forests for a wide range of experiences that are supported or enhanced by the environmental amenities that forests provide. That is, forest ecosystems contribute to the benefit visitors receive along with non-environmental amenities such as walking tracks of picnic facilities.

People gain benefits from visiting forests, such as enjoyment and improved health and wellbeing. There is a large and increasing body of evidence showing that contact with nature and forests provides a wide range of physical and mental health benefits, both from physical activity and passive experience of forests.

Impact of fire on ecosystem service

Provision of this ecosystem service is expected to initially decrease as a result the 2019-20 bushfires. As fire burns vegetation cover, this reduces the aesthetic experience people get from visiting and recreating in forests. Post-fire forests are also hazardous to visitors, with increased risk of falling trees and erosion. Areas of parks and state forests are often closed after bushfires to protect visitor safety and support forest regeneration. Bushfires also impact built assets such as signage, picnic and camping facilities and walking and mountain biking trails.

The impact of the bushfires on this ecosystem service is evident in a recent study of state forest visitation undertaken over 2019 and 2020. The study found that each of the DELWP regions saw an increase in state forest visitation over the spring/summer period except for Gippsland, likely due to the bushfires.[98] DELWP districts that saw decreases in visitation in the spring/summer period were all districts in the vicinity of the bushfires, such as Upper Murray, Snowy, Ovens and Latrobe.[99]

However, the overall impact on forest-based recreation and tourism in Victoria will depend on people's behavioural response to the bushfires. Although there may be a decrease in visitation to fire-affected forests, this may not result in an equivalent decrease across the whole of Victoria, as people may instead visit forests in other parts of the state. Consequently, other forests may supply *increased* recreation services as a result of the bushfires.

The longer-term impact of the bushfires on visitation to fire-affected forests is difficult to predict. Visitor numbers may continue to be reduced if people are dissuaded by recollections of the bushfires or form new habits (e.g. visiting forests elsewhere in Victoria or Australia or doing other recreational activities). Alternatively, visitor numbers may increase if people are motivated to visit fire-affected forests (e.g. to see the post-fire regeneration or because the fires drew attention to particular areas).

98. Quantum Market Research 2020, *Understanding state forest visitation and tourism – Wave 2 (spring/summer 2019-20)*, report prepared for the Department of Environment, Land, Water and Planning, March 2020, p. 18.
99. Quantum Market Research 2020, *Understanding state forest visitation and tourism – Wave 2 (spring/summer 2019-20)*, report prepared for the Department of Environment, Land, Water and Planning, March 2020, p. 18.

A 2020 study of state forest visitation found that 83 per cent of state forest visitors would like to visit regions impacted by the bushfires, although there was still some hesitation (with 26 per cent expressing hesitancy).[100] However, it is unclear how much this sentiment would translate into use of the ecosystem service (actual visits to bushfire-affected forests) rather than just visiting bushfire-affected regions. Hesitancy was driven by concerns for personal safety and expectations that the experience could cause emotional distress.[101] Over half (52 per cent) of state forest visitors said they were a little or a lot more likely to visit state forests in the next 12 months, with 10 per cent saying they were a little or a lot less likely to visit, and 38 per cent saying there was no change to their likelihood.[102] However, it is unknown how these intentions would translate into actual visitation behaviour, and in reality people's visitation behaviour in 2020 will be strongly influenced by the COVID-19 pandemic.

Quantification of impact

Ideally, the impact of the bushfires on this ecosystem service would be quantified as the reduction in forest visitation in 2020 and beyond that can be attributed to the bushfires. However, this is difficult to estimate due to the availability of location specific forest visitation data.

The number and area of parks and state forests burnt in the 2019-20 bushfires can be used as a proxy indicator for the impact of the bushfires on recreation and tourism. Most of the forests burnt were on public land in state forests, parks or reserves. Overall, 49 state forests, 14 parks and 83 reserves were impacted by the bushfires (see Table 40), with 1 million hectares of forest burnt across these three categories (see Table 41). A further 160,000 hectares of 'unlabelled' forest was burnt, which is mostly state forest.

Table 42 lists the ten parks and state forests with the largest area burnt in the bushfires. The Alpine National Park, spanning the East Gippsland, Gippsland and North East RFA regions, had the largest area burnt (over 120,000 hectares), although this is only around a fifth of the park. The Snowy River National Park and Croajingolong National Park in East Gippsland had 115,000 hectares (63 per cent) and 90,000 hectares (81 per cent) burnt respectively.

While visitation data is not available for individual state forests, annual visitation estimates are available for some individual parks and reserves. Table 43 lists the estimated annual visits, where available, of parks and reserves impacted by the bushfires. All these parks and reserved were fully or partially closed due to the bushfires. Collectively they are estimated to receive around 2 million visits per year. Not all parks and reserves impacted by the bushfires will see a 100 per cent reduction in visitation due to the bushfires. For example, areas of iconic parks such as the Alpine National Park, and even the significantly fire affected Croajingolong National Park and Snowy River National Park, are open to the public.

100. Quantum Market Research 2020, *Understanding state forest visitation and tourism – Wave 2 (spring/summer 2019-20)*, report prepared for the Department of Environment, Land, Water and Planning, March 2020, p. 43.
101. Quantum Market Research 2020, *Understanding state forest visitation and tourism – Wave 2 (spring/summer 2019-20)*, report prepared for the Department of Environment, Land, Water and Planning, March 2020, p. 44.
102. Quantum Market Research 2020, *Understanding state forest visitation and tourism – Wave 2 (spring/summer 2019-20)*, report prepared for the Department of Environment, Land, Water and Planning, March 2020, p. 46.

Table 40 Number of state forests, parks and reserves, and other public land burnt in the 2019-20 bushfires

	East Gippsland	Gippsland	North East	Total
State forests	30	24	4	49
Parks (national, state and regional)	10	1	5	14
Reserves	61	8	17	83
Water frontages	45	16	24	84
Plantations	0	0	8	8
Other	5	3	2	10
Total	151	52	60	248

Total is less than the sum of the three RFA regions, as some parks and state forests span multiple RFA regions. Plantations are areas of public land leased for plantations. Other includes education areas, historic areas, cemeteries and reservoirs.

Table 41 Area of state forests, parks and reserves, and other public land burnt in the 2019-20 bushfires

	East Gippsland	Gippsland	North East	Total
State forests	423,823	198,120	168,704	790,647
Parks (national, state and regional)	248,762	64,065	79,843	392,670
Reserves	16,918	5,734	1,614	24,265
Water frontages	1,277	410	1,239	2,926
Plantations	-	-	5,546	5,546
Other	972	820	1	1,794
Total	691,752	269,149	256,948	1,217,849

Plantations are areas of public land leased for plantations. Other includes education areas, historic areas, cemeteries and reservoirs.

Table 42 Ten parks and state forests with largest area burnt in the 2019-20 bushfires

	Area burnt (ha)	Total area (ha)	% burnt	RFA region(s)
Alpine National Park	122,313	662,291	18	EG, G, NE
Snowy River National Park	72,594	114,674	63	EG
Croajingolong National Park	71,580	88,469	81	EG
Yowen-burrun State Forest	39,654	49,502	80	G
Coopracambra National Park	36,144	38,491	94	EG
Wingan State Forest	35,162	43,379	81	EG
Buldah State Forest	34,502	37,523	92	EG
Drummer State Forest	32,820	36,478	90	EG
Haunted Stream State Forest	30,193	32,156	94	G
Yalmy State Forest	26,101	28,420	92	EG

Table 43 Annual visitation of parks and reserves burnt in the 2019-20 bushfires

	Area burnt (ha)	% burnt	Annual visits
Alpine National Park	122,313	18	1,320,618
Croajingolong National Park	71,580	81	289,928
Mount Buffalo National Park	7,938	29	131,473
Snowy River National Park	72,594	63	59,928
Cape Conran Coastal Park	6,914	60	43,340
Errinundra National Park	22,041	55	32,863
Buchan (AT) Cave Reserve	271	92	31,904
Stony Creek Streamside Reserve	5	85	24,202
Lind National Park	1,271	94	23,766
Burrowa - Pine Mountain National Park	18,810	99	13,347
Alfred National Park	2,812	93	9,619
Wabba Wilderness Park	18,756	97	4,193
Bald Hills Road Bushland Reserve	17	95	3,944
Coopracambra National Park	36,144	94	2,999
Cann River Bushland Reserve	4	39	2,176
Mount Elizabeth Nature Conservation Reserve	4,897	94	1,536
Bemm River Scenic Reserve	497	80	38

Visitation estimates are from 2014. Note the confidence of visitation estimates varies.

Figure 28 State forests, parks and reserves impacted by the 2019-20 bushfires

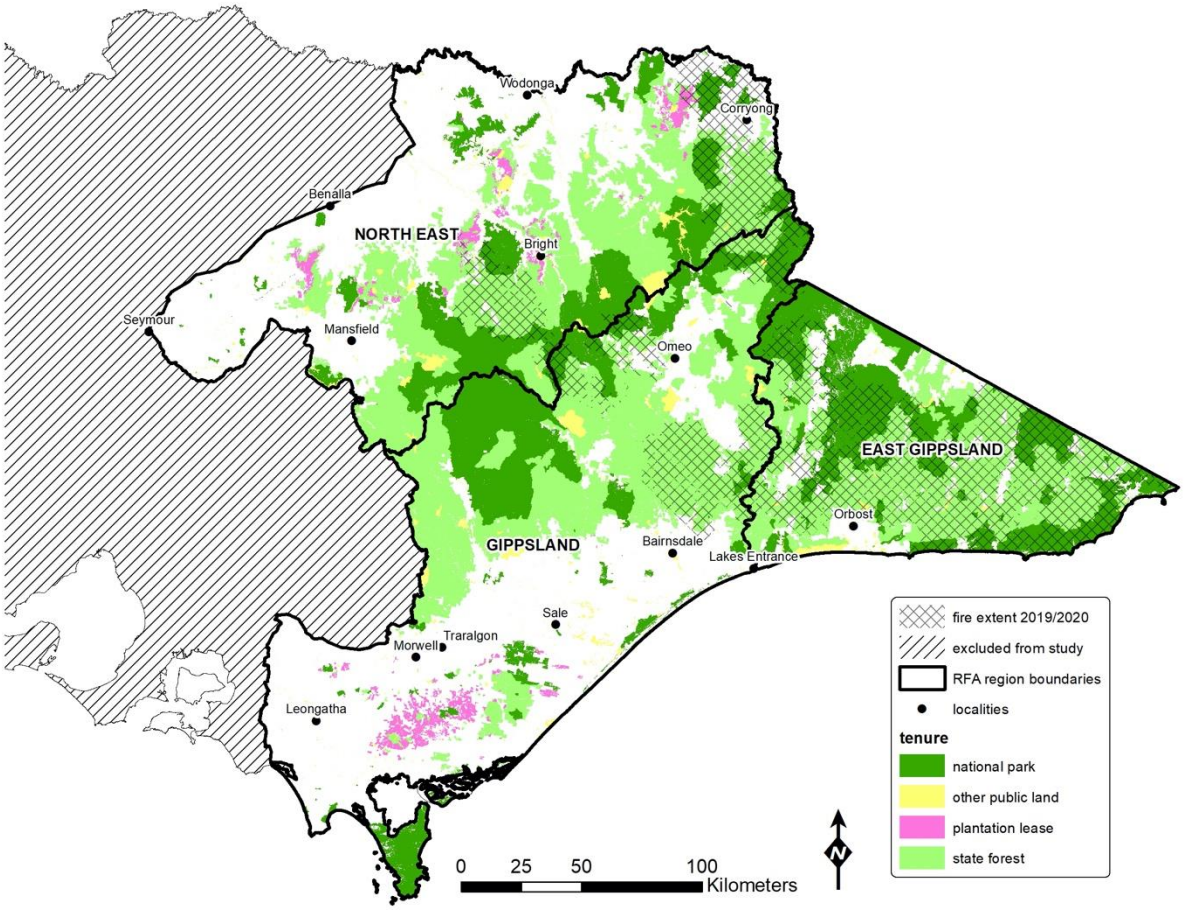


Figure 29 State forests, parks and reserves impacted by the 2019-20 bushfires – East Gippsland RFA region

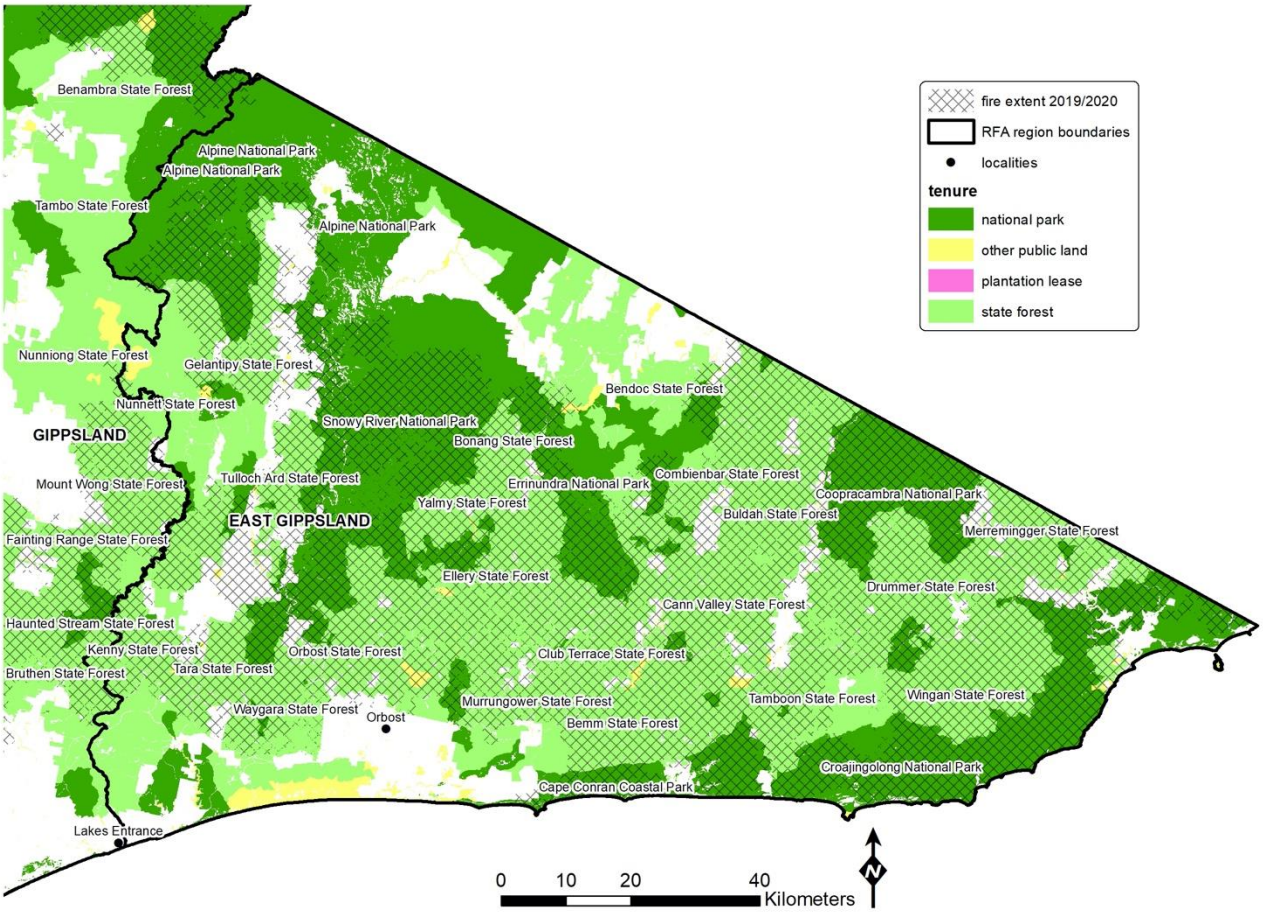


Figure 30 State forests, parks and reserves impacted by the 2019-20 bushfires – Gippsland RFA region

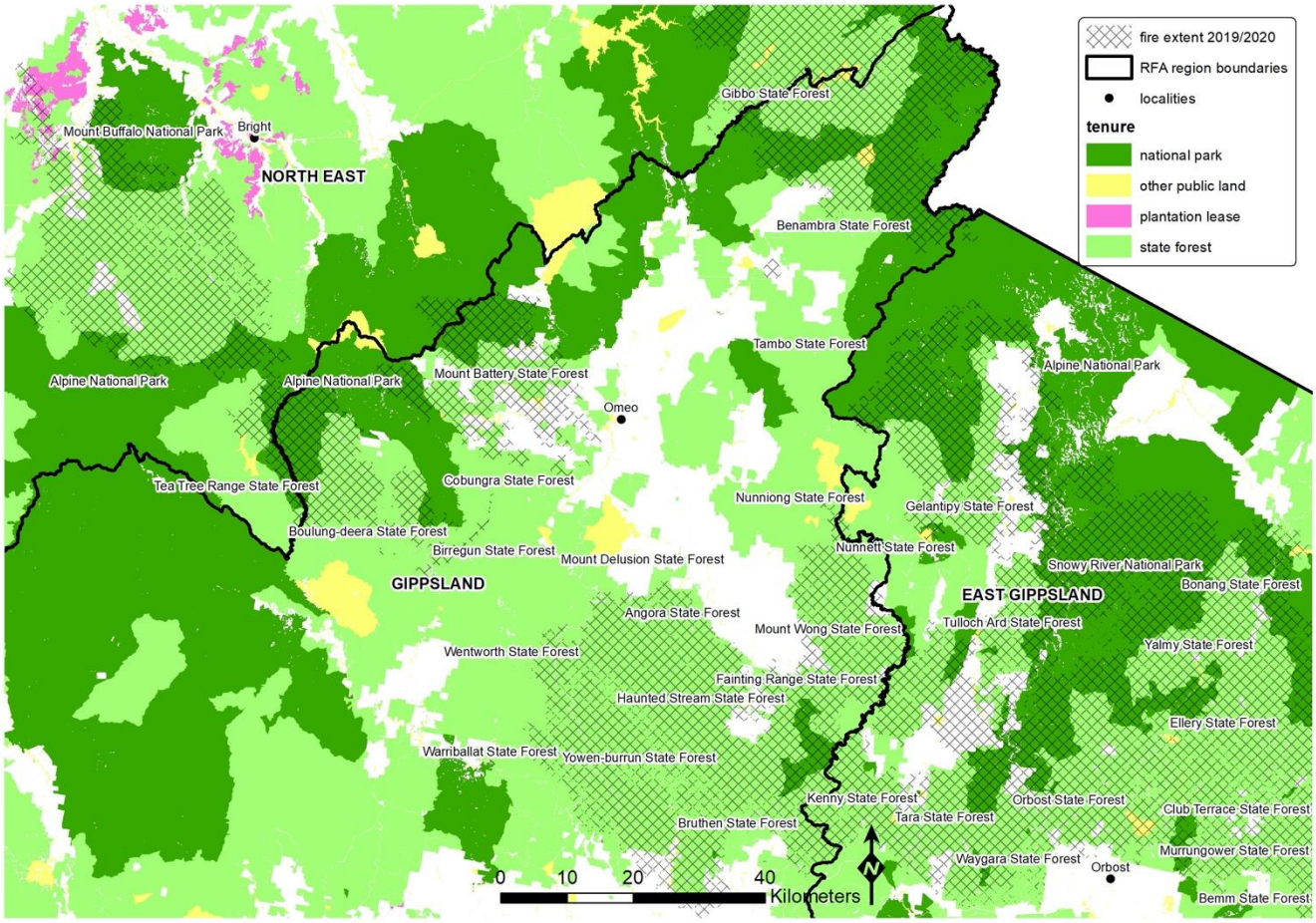
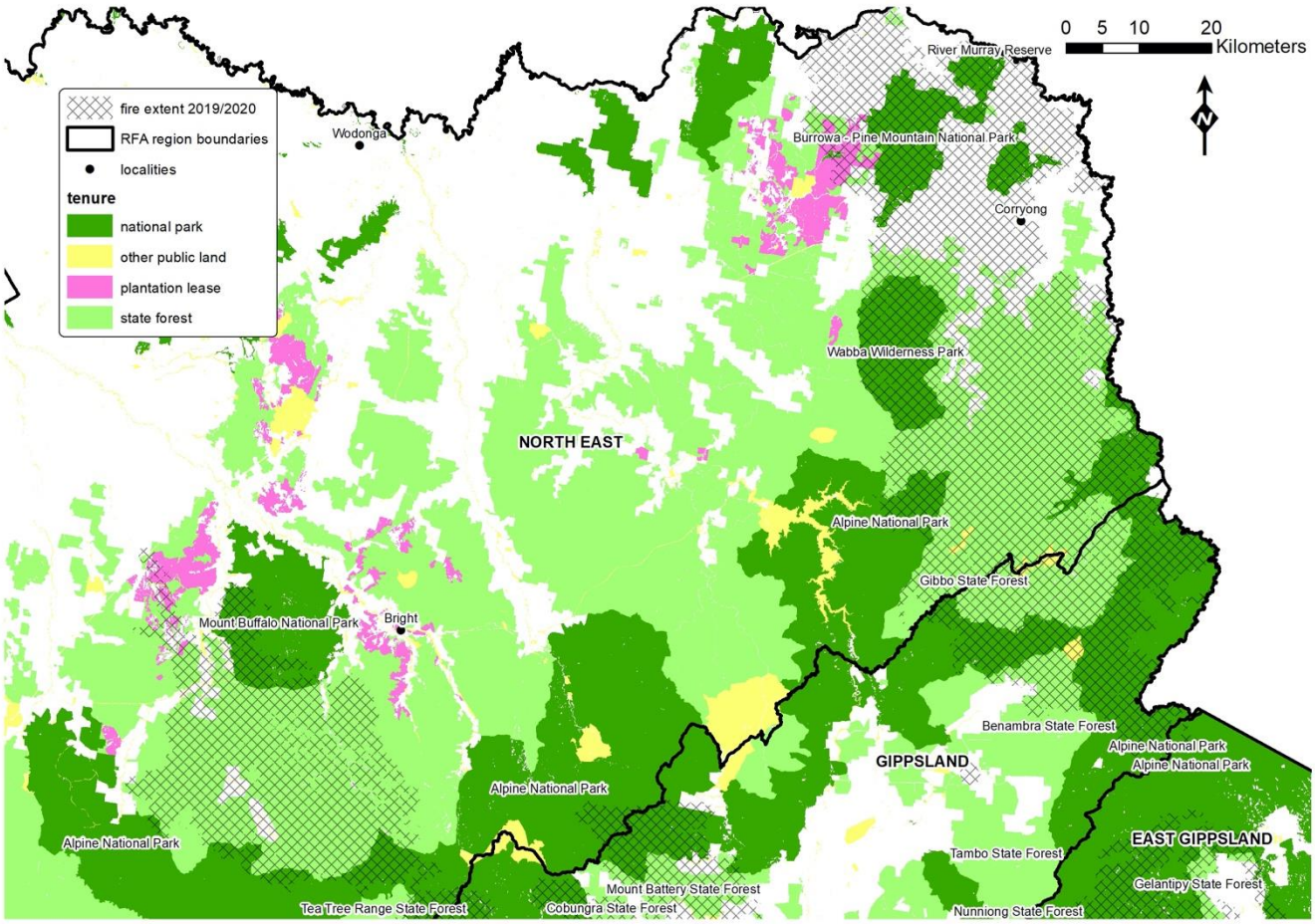


Figure 31 State forests, parks and reserves impacted by the 2019-20 bushfires – North East RFA region



Appendix B: Technical summary

The following section outlines the biophysical modelling and spatial data analysis approaches undertaken and datasets used to deliver the ‘Ecosystem services from Forests in Victoria – Impact of the 2019-2020 bushfires report. Only those services that required biophysical modelling and/or spatial analysis are detailed.

Background

The objective of the biophysical modelling and spatial data analysis undertaken was to provide collated data by either RFA region, land tenure, land cover class, catchment type or burn severity class which then enabled valuations to be undertaken.

The ecosystem services that required biophysical modelling and/or spatial data analysis, the software used to produce the output and the output generated are detailed in Table 44 .

Table 44 Ecosystem services requiring biophysical modelling and/or spatial data analysis, dataset and software utilised and output generated.

	Spatial and temporal datasets used, file name and source	Software used	Raster or vector analysis	Output generated
Extent & Condition	- Forest Extent, Forest_mask_13 (VFMP) - Public Land Management, PLM25 (CSDL) - Fire History, Fire_History (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL)	ArcGIS	Vector	Area of forest impacted by fire and fire severity class per RFA region and tenure class. Frequency of forest burnt in last 5, 10 and 15 years per RFA region.
Water provision	- Designated Water Supply Catchments, PWSC100 (CSDL) - Melbourne Water Catchments (Melbourne Water) - Public Land Management, PLM25 (CSDL). - Sustainable diversion limit catchments, SDL_catch (CSDL) - Ecological Vegetation Class, NV1750_EVC (CSDL) - Regional Forestry Agreement regions, RFA100 (CSDL) - Forest Extent, Forest_mask_13 (VFMP) - Victorian Digital Elevation Model, DEM25 (CSDL) - Victorian Water Storages (CSDL) - Patched Point Climate Data (SILO) - Victorian Landsystems, Landsystem250 (CSDL) - Water Trading Zones for Victorian Declared Water Systems (Victorian Water Register) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL) - Ash forest extent, VMVEG (CSDL) - Forest age, EastVIC_SppAge_14Oct2016 (Forest Taskforce)	Biosim, and ArcGIS	Raster and Vector	Average annual catchment water yield (0.6 annual recharge + surface runoff + lateral subsurface flow) ML/Ha (2008-2018) for fire and no-fire scenario. Summed per RFA region, catchment zone, tenure/land cover and burn severity class.
Biomass for timber	- Plantation extent, AustraliasPlantations_2016 (ABARES) - Regional Forestry Agreement zones, RFA100 (CSDL) - Forest Extent, Forest_mask_13 (VFMP) - Public Land Management, PLM25 (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL)	ArcGIS	Vector	Area (Ha) of plantation per RFA region, catchment zone, tenure/land cover and burn severity class.
Biomass for fodder	- Public Land Management, PLM25 (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL) - Forest Extent, Forest_mask_13 (VFMP)	ArcGIS	Vector	Area (Ha) of agricultural licensed/leased land per RFA

	- Ecological Vegetation Class, NV1750_EVC (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL)			region, burn severity class and license/lease type.
Erosion Control	- Designated Water Supply Catchments, PWSC100 (CSDL) - Melbourne Water Catchments (Melbourne Water) - Public Land Management, PLM25 (CSDL). - Sustainable diversion limit catchments, SDL_catch (CSDL) - Ecological Vegetation Class, NV1750_EVC (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL) - Soil and Landscape Grid National Soil Attribute Maps - Bulk Density, (CSIRO) - Patched Point Climate Data (SILO) - Victorian Landsystems, Landsystem250 (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL) - Factor Increase in erosion rate post fire, factor_change_yr1python.tif (Alluvium Consulting)	Biosim, and ArcGIS	Raster and Vector	Gross and net annual erosion (m^3 and t) per RFA & catchment zone (2020 & 2021) for fire and no-fire scenario.
Water flow regulation	- Public Land Management, PLM25 (CSDL) - Ecological Vegetation Class, NV1750_EVC (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL) - Forest Extent, Forest_mask_13 (VFMP) - Victorian Land-systems, Landsystem250 (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL) - Locality Boundaries, Locality Boundaries Property (VMADMIN) - Victorian Landuse Mapping, VLUIS (DJPR) - Digital Elevation Model, DEM25 (CSDL)	ArcGIS	Vector	Number, catchment area, burn area and burn severity area of localities with catchment impacted by fire.
Pollination	- Victorian apiary sites, Apiary (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL) - Public Land Management, PLM25 (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL)	ArcGIS	Vector	Number of apiary sites (count) and area of apiary range impacted by fire and fire severity classes.

Recreation and tourism	- Public Land Management, PLM25 (CSDL) - Burn Severity Mapping, BUSHFIRE_SEVERITY_EAST_AND_NORTHEAST_VICTORIA_2019-20 (CSDL) - Regional Forestry Agreement zones, RFA100 (CSDL)	ArcGIS	Vector	Total area, burn area and burn severity class areas of named parks/reserves. Area of named park/reserve within each RFA region. Area burnt of named park/reserve within each RFA region.

General descriptions of models and datasets

Forest extent

VFMP forest mask data was used to define the extent of forested areas for ecosystem services assessed spatially.

Areas on public land mapped as shrubland, grassland or wetland by EVC group classification, were also included in the assessment, knowing they were likely areas of native vegetation albeit not 'forested' vegetation, that were still capable of providing ecosystem services.

Tenure

For crown land areas, data is provided from the PLM25 dataset and classified using the MMTGEN field. The following field attributes have been aggregated for clearer reporting:

- Commonwealth Land, Other Public Land, Not Classified or unattributed were grouped and reported collectively as 'other public land'
- Other Conservation Reserves & National Parks Act and Nature Conservation Reserves were grouped and collectively called 'National Park'

Tenure classification is therefore reported as:

- National park
- State forest
- Plantation lease (note this is plantation tenure on crown land, many parts of this tenure type support native vegetation, road infrastructure and fallow areas not necessarily planted to plantation timber)
- Other public land and;
- Private land

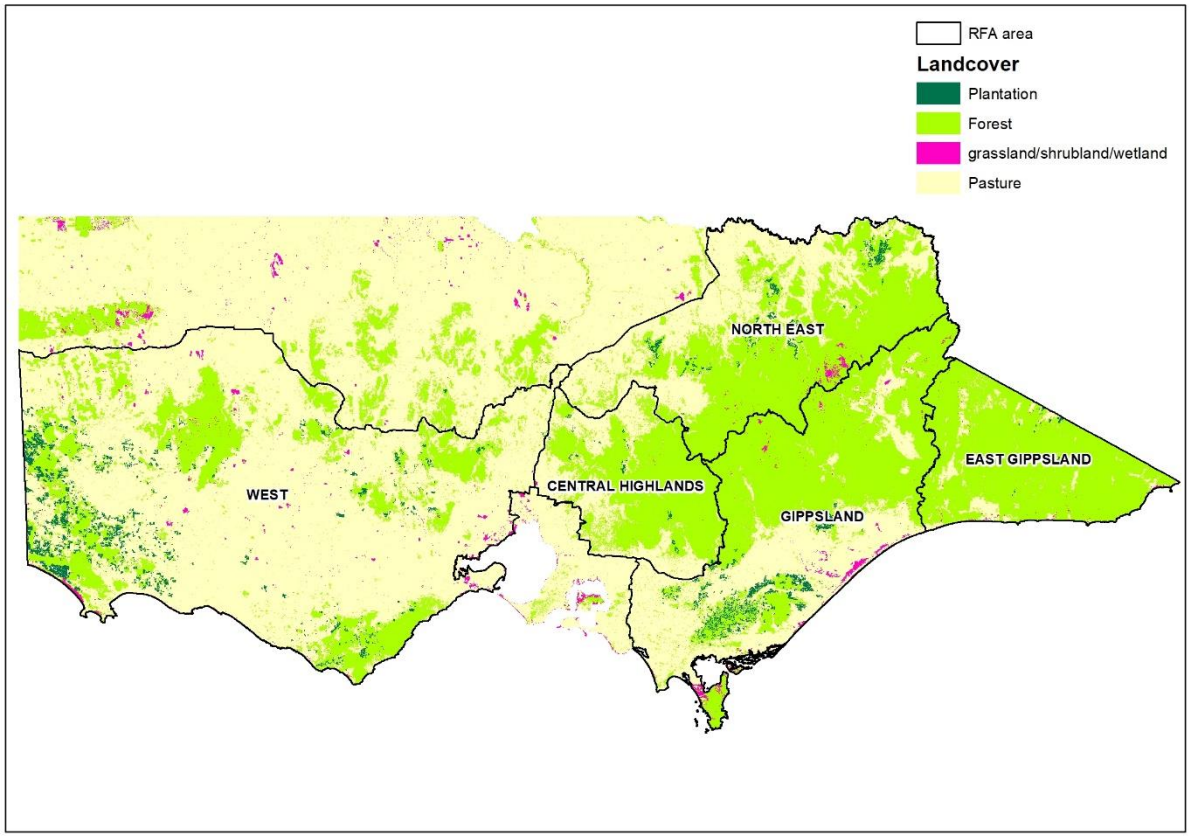
Landcover mapping

A suite of aggregated data was generalised to form a customised landcover map for this project. The whole state of Victoria was divided into the following four broad landcover classifications (refer to Figure 32):

- Forest - Forest extent mapping from VFMP determined forested areas, the 'EVC1750' dataset then disaggregated the forest areas into detailed forest types.
- Grassland/shrubland/wetland – for public land areas based on EVC group classification
- Plantation - Mapped plantation areas using the 'VMVEG_plantation' dataset that were coincident with the VFMP forest extent mapping were designated as plantation.
- Pasture - All other areas are assumed to be pasture/cropping.

Although this methodology excludes land uses such as urban, industrial, roading etc for the scale at which this assessment was undertaken it was deemed that including such land uses would have added extra complexity to the model and lengthened the model run times whilst not contributing any further clarity to the required output, that being the quantification of hydrological forest ecosystem services.

Figure 32 Aggregated landcover mapping classes



Ensym

EnSym[103] is a modular software platform that facilitates the use of a suite of environmental modelling tools. It enables easy and rapid evaluation of environmental outcomes due to changes in land management and climatic conditions. It contains several toolboxes that deal with different aspects of the environment including land based biophysical process, groundwater dynamics, spatial and contextual connectivity and finally a set of tools for systematic spatial and temporal reporting. It has been developed by the Victorian Government.

Biosim

Biosim is the biophysical modelling toolbox of Ensym, designed to simulate all major biophysical components. Biosim simulates daily soil/water/plant interactions, overland water flow process, soil loss and carbon sequestration. Biosim can be applied to any combination of soil type, climate, topography and land practice. Biosim has been developed by DELWP and preceding departments since 2000[104].

[103] https://ensym.biodiversity.vic.gov.au/cms/

[104] Beverly, C. 2007. Technical Manual - Models of the Catchment Analysis Tool. Victorian Department of Sustainability and Environment.

Details, limitations and assumptions on modelling approach and spatial data analysis

Water Supply

Catchment water yield is defined as the quantity of water derived from a unit area of watershed. For this project we report water yield as available megalitres of flow per day from a given water catchment. Potential maximum catchment water yield has been modelled using the Biosim model within the Ensym modelling framework. Modelled daily surface runoff, lateral subsurface flow and a proportion of recharge have been summed to give total annual catchment water yield. This study has used 60 per cent of recharge as a calculated estimate of groundwater flow that discharges to stream (baseflow) the remaining 40 per cent is lost to evapotranspiration and groundwater throughflow. The 60 per cent groundwater flow discharge rate is based on a calibrated Biosim surface water model at the Bright gauge (403205), which is a similar environment (local groundwater flow system) to the states upland RFA regions.

Water yield post fire has been assumed to remain unchanged for mixed forest areas that regenerate by re-sprouting. This is in line with recent research undertaken in North East Victoria by Gharun et al (2013) following the Black Saturday Fires, where the following was concluded:

"*it was discovered that after three years, forests that regenerate after fire by sprouting do not use more water than unburnt forests. Furthermore, since the canopy in the recovering forest closely resembled mature, undisturbed forest, the research team proposes that water use in this regenerating forest should not increase dramatically as the forest continues to move towards maturity.*"

Ash forest areas however are well known to use high volumes of water whilst regenerating post disturbance, thus yield impacts post fire have been estimated for all Ash forest areas impacted by the 2019/2020 fires in Victoria.

Potential maximum catchment water yield in Ash forests is assumed to occur at forest maturity from 150 years of age. Thus, to take account of the impact fire has on Ash forest age and therefore catchment yield the following steps and assumptions have been made:

- Fire severity classes 5 (canopy scorch) & 6 (canopy burn) were assumed to create a stand replacing event. In Alpine Ash and Mountain Ash forests, Vivian et al. (2008) found that fire severity classes of canopy consumption and severe canopy scorch resulted in 98.9 per cent tree mortality and lower severity classes resulted in only 17.5 per cent tree mortality, with much of the pre-fire stand surviving.
- Mapped forest stand age and mapped Ash forest extent were used to assign an age and spatial extent to all Ash forest areas in the study area. Using the Kucerza curve[105], annual relative changes to the modelled potential maximum catchment water yield were made allowing estimates of catchment water yield through to the year 2169 for a fire and no-fire scenario.
- The 'fire scenario' models the impact of the 2019/2020 fires plus all other prior mapped stand replacing events for Ash forests (fire and harvesting) and then no further disturbance from 2020 onwards.
- The 'no-fire scenario' models the impact of all prior mapped stand replacing events for Ash forests (fire and harvesting) and then no further disturbance from 2020 onwards.

[105] Kuczera, G 1987, 'Prediction of water yield reductions following bushfire in Ash-mixed species eucalypt forest', Journal of Hydrology, volume 94, pp. 215-236.

The impact of the 2019/2020 fires on catchment water yield has been expressed as the difference between the 'fire' and 'no-fire' scenarios as described above over a 150 year period assuming every year sees average annual rainfall[106], this is a theoretical maximum impact given average climate conditions and is not designed to be an accurate forecast, rather an indicative quantity useful for general impact analysis. Clearly there will be annual variations in future climate and climate change impacts have not been considered in the 150 scenarios. As noted above these two scenarios assume no further disturbance to Ash forests over the next 150 years, clearly there will be further disturbance events, the timing and frequency of which will alter the impact on water yield related to the 2019/2020 fires. Repeat fire events in Ash forests over short time frames that initiate a succession in forest type further complicates catchment water yield calculations and attribution of change in catchment water yield to individual events. There has been no allowance made for Ash forests that have not regenerated due to prior disturbance events or won't regenerate due to the 2019/2020 fires.

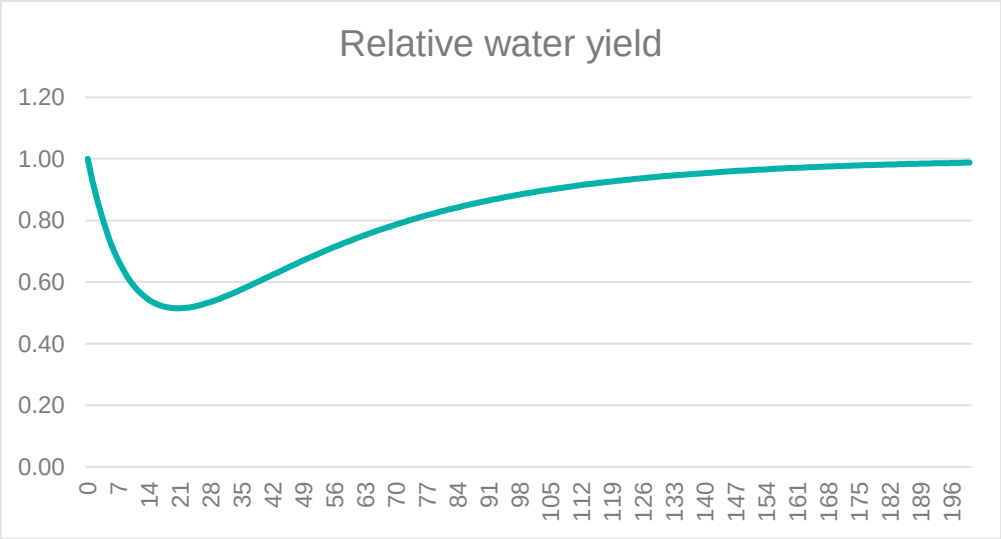
The Kuczera Curve (Figure 33) has been represented using the following mathematical equation:

$$y(x) = 1 - e^{-bx}(1 - e^{-cx})$$

where:

y(x) = water yield, x = forest stand age, b = 0.022 (curve shape control) and c = 0.07 (curve shape control).

Figure 33 Relative change in water yield in Ash forest post disturbance over 200 years



The Kuczera curve doesn't account for a short-term increase in water yield post fire when cover has been reduced and prior to the new Ash seed bed germinating. Research by Feikema et al (2013), has shown that for most post fire recovery situations in Ash forests there is no short-term increase in water yield.

[106] The 11 year period from 2008 – 2018 was used to calculate average annual rainfall.

"We conclude, therefore, that the likelihood of an increase in streamflow after severe wildfire is low, because even if post-fire rainfall is above average, a substantial soil water deficit must largely be removed before appreciable increases in streamflow will occur."

Ash forests are classified as a 'wet forest' and typically exhibit well developed soils with higher organic matter contents and infiltration capacities, thus they respond very differently post fire to 'dry forest' areas that typically display poorer levels of soil development and lower levels of infiltration. Thus, for the purposes of this report, it is assumed that Ash forest areas will not produce a short-term increase in catchment water yield post fire.

For catchment water yield valuation purposes, RFA regions were divided into the following catchment zones:

Regulated catchments (catchment areas supplying reservoirs)

- Melbourne Water catchments
- Irrigation zone supply catchments (supply to trading zones, refer to Figure 35)
- Other regulated catchments (non-trading zones)

Un-regulated catchments

- SDL catchments
- Non-SDL catchments

Contributing areas to reservoirs were either calculated using ArcGIS hydro tools or sourced using SDL, PWSC or AHGF pre-determined catchment boundaries.

Figure 34 Water yield catchment valuation zones

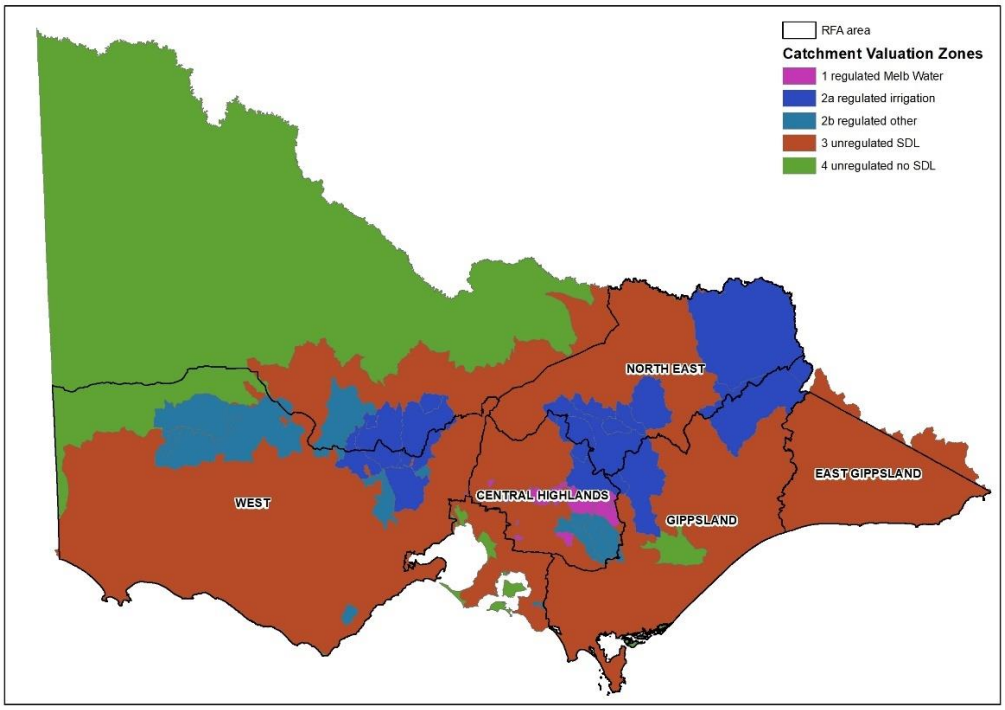


Figure 35 Registered Trading Zones[107]

Trading Zone	Trading Zone description
1A	**Greater Goulburn** Lake Eildon; Goulburn River from Lake Eildon to Goulburn Weir; Lake Nagambie; Shepparton, Central Goulburn, Rochester and Pyramid-Boort irrigation areas except the Boort irrigation area.
1B	**Boort** Boort irrigation area
1L	**Loddon Weir Pool**
2	**Broken: Nillahcootie to Casey's Weir** Lake Nillahcootie; Broken River from Lake Nillahcootie to top of Casey's Weir pool; Casey's Weir pool; Broken River from Casey's Weir pool to the Goulburn River; Upper Broken Creek from Broken River to Waggarandall Weir, including Major Creek.
3	**Lower Goulburn** Goulburn River downstream of Goulburn Weir.
4A	**Campaspe** Lake Eppalock; Campaspe River from Lake Eppalock to Waranga Western Channel; Campaspe irrigation district.
4B	**Coliban channel system** Coliban channel system.
4C	**Lower Campaspe** Lower Campaspe River, from downstream of the Waranga Western Channel to the River Murray
5A	**Loddon** Tullaroop Reservoir; Tullaroop Creek from Tullaroop Reservoir down to Loddon River; Cairn Curran Reservoir; Loddon River from Cairn Curran Reservoir down to top of Loddon Weir Pool; Serpentine Creek system upstream of Bear's Lagoon.
5B	**Bullarook** Hepburns Lagoon, and downstream to Bullarook Creek; Newlyn Reservoir; Bullarook Creek from Newlyn Reservoir to Creswick Creek.
6	**Vic Murray Dartmouth to Barmah** Lake Hume; River Murray from Lake Hume to Barmah Choke; Lake Dartmouth; Mitta Mitta River below Lake Dartmouth; Murray Valley irrigation area, excluding Lower Broken Creek.
6B	**Lower Broken Creek** Lower Broken Creek downstream of Katamatite.
7	**Vic Murray Barmah to SA** River Murray from Barmah Choke to the South Australian border; Torrumbarry irrigation area; Tresco irrigation district Nyah irrigation district; Robinvale irrigation district; Red Cliffs irrigation district; Merbein irrigation district; First Mildura irrigation district (Note – this now includes the previous trading zone 8)
9A	**Ovens** Lake Buffalo; Buffalo River downstream of Lake Buffalo; Ovens River downstream of the confluence with the Buffalo River.
9B	**King** Lake William Hovell; King River downstream of Lake William Hovell.
9C	**Lower Ovens** Ovens River downstream of the confluence of King River.
10	**NSW Murray above Barmah Choke** River Murray from Lake Hume to Barmah Choke, including Murray Irrigation Ltd areas and Wakool Irrigation District
11	**NSW Murray below Barmah Choke** River Murray from Barmah Choke to SA border (including the Edwards/ Wakool system and the Western Murray Irrigation District).
12	**South Australian Murray** River Murray in SA and Trust districts
13	**Murrumbidgee** Murrumbidgee Irrigation and Colleambally Irrigation areas; Murrumbidgee and Tumut below Burrinjuck and Blowering reservoirs (including Yanko, Colombo and Billabong Creek systems)
14	**Lower Darling** Menindee Lakes and the Darling River downstream of the Menindee Lakes

Biomass for timber

Plantation areas were defined using the 'Australia's plantations 2016 dataset' produced by the Australian Bureau of Agricultural and Resource Economics and Sciences – (ABARES) which provides attribute information on plantation type classified into hardwood, softwood and unknown, mixed species, fallow classes.

Comparison was made against the Victorian 'Plantation' dataset within in the 'VMVEG' feature data class which reports a smaller area of plantation. This is likely because small plantations are not included in the Victorian data however on investigation, by comparing aerial imagery in North East Victoria, we found numerous areas stated as plantation, in the ABARES dataset, that were clearly not. So, it could also be a factor that the ABARES dataset overestimate plantation area, thus the correct area could be somewhere in the middle of the ABARES and Victorian Government data. Regardless we have used the ABARES dataset to ensure consistency with national approaches.

Biomass for fodder

Information on agricultural grazing licenses/leases on public land were sourced from the 'PLM25' dataset which is housed within the CSDL. The number of agricultural grazing licenses/leases intersecting with each tenure type has been calculated using ArcGIS. Only licenses and leases that contain forested areas were included in the assessment. Any non-forest areas of agricultural licenses or leases are

[107] https://waterregister.vic.gov.au/images/documents/Trading%20Rules%20%20updated%2030%20June%202014.pdf

excluded. Forested areas were defined using the VFMP forest extent dataset. The following PLM25 tenure classes are classified as 'agricultural' and included in the assessment.[108]

ALPINE CONTIGUOUS GRAZING
ALPINE GRAZING LICENCE
BUSH GRAZING - SEASONAL
CONSERVATION LICENCE - WF
CULTIVATION/GARDEN LICENCE
GRAZING - SOFTWOOD PLANTATION OPS
GRAZING LICENCE
GRAZING LICENCE - NON PRIM PRODUCERS
GRAZING LICENCE (CROPPING APPROVED)
GRAZING LICENCE (W)
INDUSTRIAL/COMMERCIAL LICENCE
MISCELLANEOUS (GENERAL) LICENCE
RECREATION/AMUSEMENT LICENCE
RESERVE (DIR MGT) BUSHLAND
RESERVE SEC 17D (NOT EXTRACTIVE)
RIPARIAN MANAGEMENT LICENCE
UNUSED ROAD LIC. - BLUE GUM PLANTATION
UNUSED ROAD LICENCE - AFFORESTATION
UNUSED ROAD LICENCE - NON PRIM PROD
UNUSED ROAD LICENCE - NON PRODUCTIVE
UNUSED ROAD LICENCE - PRIMARY PROD
WATER FRONTAGE LICENCE - BOX IRON BARK
WATER FRONTAGE LICENCE - NON PROD
WATER FRONTAGE LICENCE - PRIM PROD
WATER FRONTAGE LICENCE - RECREATION

Water Quality

Net sediment discharge in mass/time is used as a metric for water quality. Alluvium Consulting mapped fire severities and modelled post-fire erosion risk for the extent of the 2019/2020 fires[109], drawing on recent research on bushfire hydrology in collaboration with the University of Melbourne and their HydroFire model, Alluvium Consulting created the following datasets which have been used in this analysis:

- Background average annual hillslope erosion rates without fire measured in tonnes/ha/yr
- Annual hillslope erosion rates in the first year after a bushfire measured in tonnes/ha/yr
- Annual hillslope erosion rates in the second year after a bushfire measured in tonnes/ha/yr

[108] https://discover.data.vic.gov.au/dataset/public-land-management-plm25
[109] Alluvium Consulting 2020, 'Regional scale mapping of fire severity and erosion risk', https://www.alluvium.com.au/news/river-impacts-and-recovery-after-fire

Post-bushfire erosion risk is modelled using the Revised Universal Soil Loss Equation (RUSLE) with modifications to the vegetation cover (C factor) and soil erodibility (K factor) based on empirical data and literature review by the University of Melbourne. As noted in the Alluvium Consulting documentation[110]

"*the estimates of annual erosion rates are generated for areas where we have no data on post-fire erosion. Therefore, the maps should be used as a qualitative indicator of erosion risk and regional assessment of soil loss and potential changes to sediment regimes. The metrics are not suitable as quantitative input into detailed analyses and modelling of catchment processes and risks. They should, however, help inform where more intensive modelling and data-driven risk assessment should be prioritised*."

Using the Alluvium Consulting data to provide an indicative range of net sediment delivery to inform sediment retention ecosystem service estimates at RFA region and catchment zone scale is considered an appropriate application given the above limitations.

The RUSLE model does not model sediment attenuation processes such as in stream sediment storage and deposition processes prior to the catchment discharge point. To account for sediment attenuation processes the application of a sediment delivery ratio (SDR) has been used to provide net sediment discharge expressed in mass/time. SDR is defined as the ratio of sediment delivered at the catchment outlet (or some other defined location in a catchment) to gross erosion within the catchment, to take account of the sediment storage on route to a catchment outlet. Two SDR values have been used to take account of a range of possible sediment delivery rations. SDR's of 0.18 and 0.36 have been applied, this is in line with hydrological analysis undertaken by Alluvium Consulting for the Valuing Victoria's Parks project[111] and with research undertaken by CSIRO on SDR's within the Murray Darling Basin[112] (Figure 36).

Ensym calculates gross erosion in mass (tonnes) on a daily timestep. To convert from a mass (tonnes) to a volume (m^3), estimates need to be made on the average particle bulk density. The Soil and Landscape Grid of Australia[113] bulk density dataset was used to calculate average bulk density for each RFA zone (Table 45).

It is worth noting that the erosion estimates provided by Alluvium Consulting and then used in this report account for standard post fire hillslope erosional processes only. Post fire runoff generated debris flows can create an order of magnitude higher sediment loads and the impacts from such have not been included, thus the erosion estimates should be seen as a lower bound.

[110] https://www.alluvium.com.au/news/river-impacts-and-recovery-after-fire

[111] Annexure C in Marsden Jacob Associates (2014): Valuing the water services provided by Victorian Parks, prepared for Parks Victoria.

[112] Lu, H., Moran, C., Prosser, I., (2003), Modelling Sediment Delivery Ratio over Murray Darling Basin, International Congress on Modelling and Simulation 2003, Modelling and Simulation Society of Australia and New Zealand Inc.

[113] Viscarra Rossel, Raphael; Chen, Charlie; Grundy, Mike; Searle, Ross; Clifford, David; Odgers, Nathan; Holmes, Karen; Griffin, Ted; Liddicoat, Craig; Kidd, Darren (2014): Soil and Landscape Grid National Soil Attribute Maps - Bulk Density - Whole Earth (3" resolution) - Release 1. v5. CSIRO. Data Collection. http://www.clw.csiro.au/aclep/soilandlandscapegrid/index.html

Figure 36 Sediment delivery ratio (SDR) values for the Murray Darling Basin, Lu et al (2003)

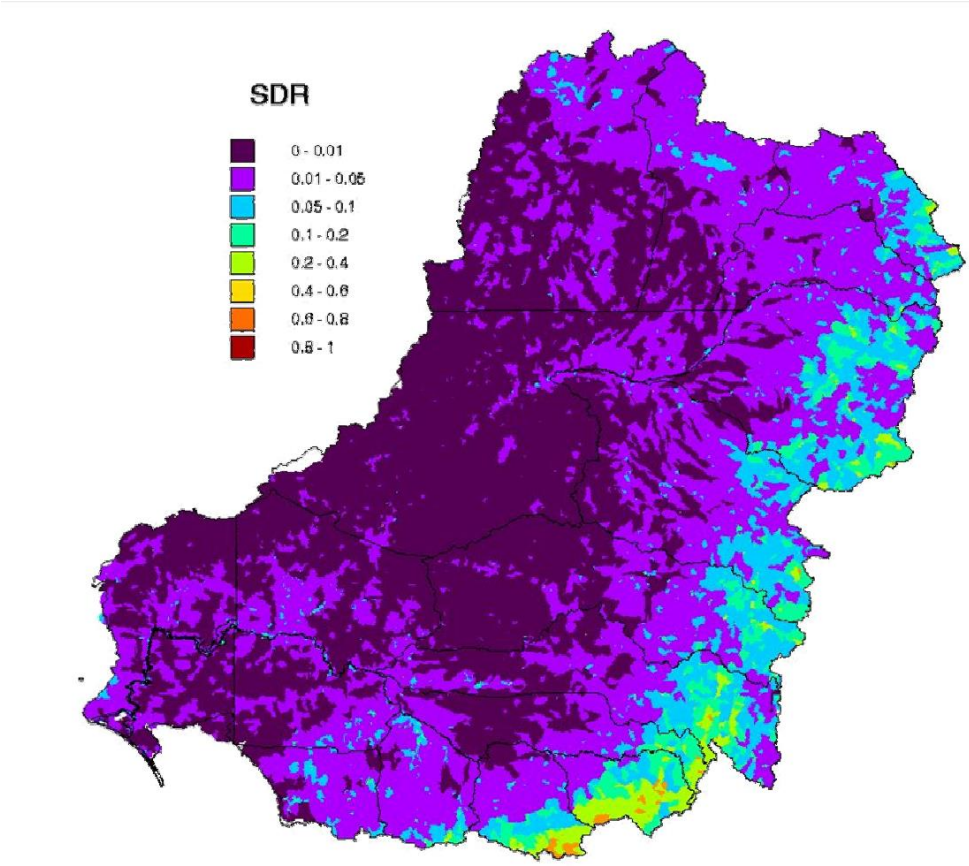


Table 45: Mean bulk density values per RFA area

RFA	Mean bulk density (gm/cm^3)
East Gippsland	1.103445
Central Highlands	1.08404
Gippsland	1.127852
West	1.28175
North East	1.113689

Flood Regulation

Flood regulation services were expressed as the proportion of contributing area burnt at differing severities for localities that contain residential, commercial or industrial classified land within the 1 in 100 year flood extent area (annual recurrence interval (ARI) of 100 years), noting that higher severity burns create proportionally more runoff. This assessment doesn't however account for the variation in runoff post fire that is determined by slope, soil type and aridity. Improvements could be made to this assessment by incorporating a spatially varying runoff ratio factor, as described in Noske et al (2020).

Pollination

Each Victorian apiary site as contained in the CSDL Apiary dataset was buffered by 1.6km to reflect a standard bee forage range[114]. Area and intensity of fire on this foraging range was reported.

General Limitations

Although each of the Ensym modules have undergone extensive testing and calibration and proved their capabilities, Biosim has not been specifically calibrated for this project. The outputs created are useful for catchment scale, relative assessment. For more detailed site-specific data where absolute vales calibration and validation should be a priority.

The water yield modelling outputs are made on the assumption that 60 per cent of recharge returns to stream as baseflow, this will be more accurate in the highland areas where groundwater flow systems are short and relatively shallow however less accurate in lower relief areas where groundwater flow systems are much larger and it would be expected that larger volumes of groundwater would leave the catchment by discharge into other aquifers. The majority of the 2019/2020 fires however occurred in highland areas with short groundwater flow systems.

Linking Ensym to a groundwater flow model such as Modflow would alleviate this issue however adds an extra level of complexity and time commitment.

[114] DJPR Apiculture on public land standard operating procedures

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