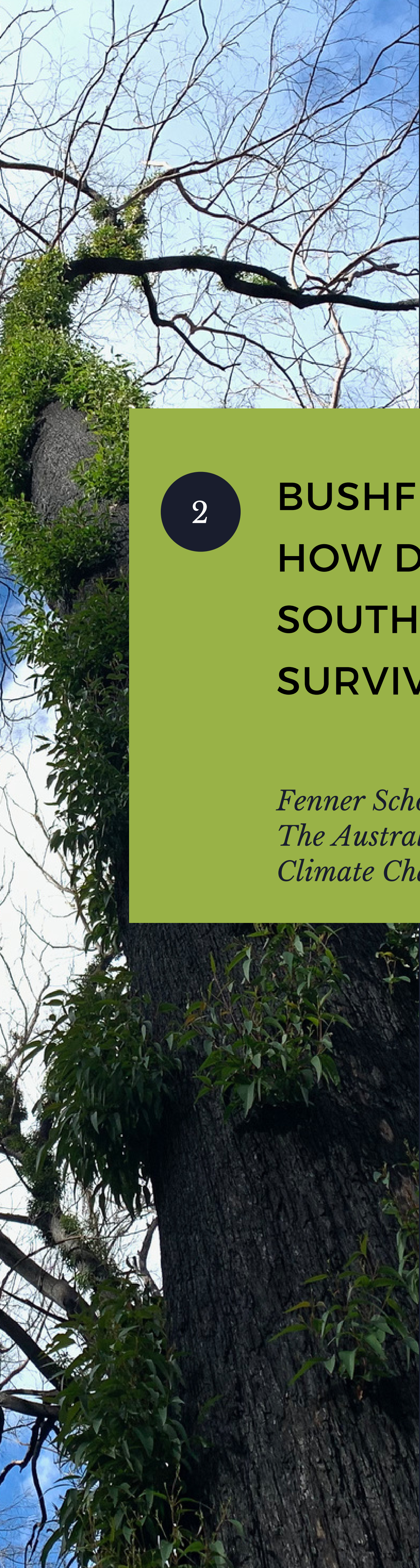

# BUSHFIRE RECOVERY PROJECT

2

## BUSHFIRE SCIENCE REPORT NO. 2: HOW DO THE NATIVE FORESTS OF SOUTH-EASTERN AUSTRALIA SURVIVE BUSHFIRES?

*Fenner School of Environment & Society, The Australian National University; and Griffith Climate Change Response Program, Griffith University*

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This report is one of a series of Bushfire Science Reports prepared by the Bushfire Recovery Project (see www.bushfirefacts.org ). The reports aim to present the latest evidence from the peer-reviewed scientific literature about bushfires, climate change and the native forests of southern and eastern Australia.

Reports in the Bushfire Science series are:

No. 1 How does climate affect bushfire risks in the native forests of south-eastern Australia?

No. 2 How do the native forests of south-eastern Australia survive bushfires?

No. 3 What are the relationships between native forest logging and bushfires?

No. 4 What are the ecological consequences of post-fire logging in the native forests of south-eastern Australia?

No. 5 What is the role of prescribed burning of native forests in reducing the risk of infrastructure loss to bushfires?

The Bushfire Recovery Project is a collaboration between the Fenner School of Environment & Society, The Australian National University, and Griffith Climate Change Response Program, Griffith University, 2020.

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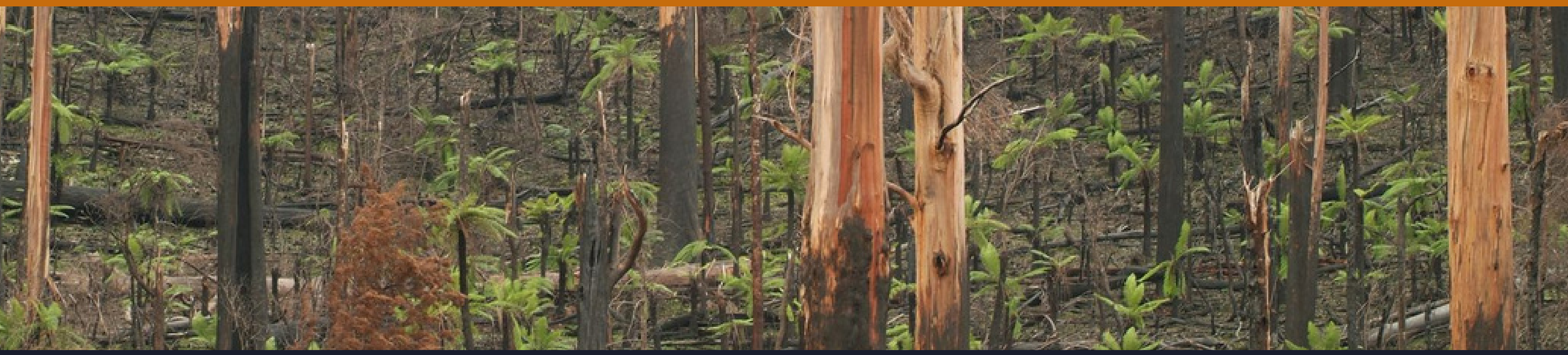
# INTRODUCTION

The catastrophic impacts of the 2019-2020 mega-fires of eastern and southern Australia received extensive media coverage, with smoke blanketing the major cities of the east coast and surrounding regions for months. Many people seeing the stark images of blackened forest landscapes thought these environments were "completely destroyed" by the bushfires. Here we assess the published peer-reviewed scientific literature to address five related questions:

1. Are bushfires a natural part of the Australian forest environment?
2. How do forests persist in the face of recurrent bushfires?
3. How do animals and fire sensitive ecosystems persist in fire-prone landscapes?
4. Are bushfires ecologically destructive?
5. How do bushfires interact with other disturbances?

# KEY POINTS

- Fire has exerted a selective force on Australian vegetation for at least 60 million years. Australia's plants and animals are therefore well adapted to "fire regimes", i.e., the typical patterns of fires occurring in a landscape.
- Most of the plants in the eucalypt forests of southern Australia have traits that enable them to tolerate infrequent, high intensity fires and recurrent low to moderate intensity fires. The two main fire response strategies are resprouting and seeding.
- Most of the eucalypt forests are dominated by tree species that can recover quickly after bushfire by resprouting, providing structural and ecological stability to the forests.
- Some eucalypt forests are dominated by tree species that respond to crown scorch by releasing seeds. These seeder trees need long fire-free periods in which to grow and mature.
- The survival and recovery of many animal populations depends on unburnt patches.
- Fire regimes are expected to change as a consequence of climate change. Altered fire regimes, including increasing frequency and intensity of fires, can change the composition and structure of forest ecosystems.
- The persistence of rainforest patches within the fire-prone landscapes of southern Australia is at risk and in need of special management interventions.



# 1.Are bushfires a natural part of the Australian forest environment?

Fire has been an intrinsic part of the environment globally through much of terrestrial plant evolution [*1-4*]. As combustion can occur when oxygen levels in the atmosphere exceed 13%, the variation in atmospheric oxygen levels throughout Earth's history correlates with the presence of fire activity [*2*]. Fire influences vegetation distribution ]and structure, the carbon cycle, and climate [*2,3*].

Fire has exerted a selective force on Australian vegetation for at least 60 million years [*5,6*]. Although there is a long evolutionary history of fire, Australia's plants and animals are more accurately described as being adapted to fire regimes rather than fire adapted [*1,7*]. A "fire regime" is described by: the type of fire (i.e., crown, surface or below ground), and the typical fire intensity, seasonality and frequency of fire experienced at a given location. Fire intensity is defined as the amount of energy released from a fire over a period of time in a given area, whereas fire severity is defined as the impact that a fire has on vegetation [*8*]. The interval between consecutive fires is particularly important ecologically and influences the rates of growth, reproduction and mortality of both plant and animal species [*9*].

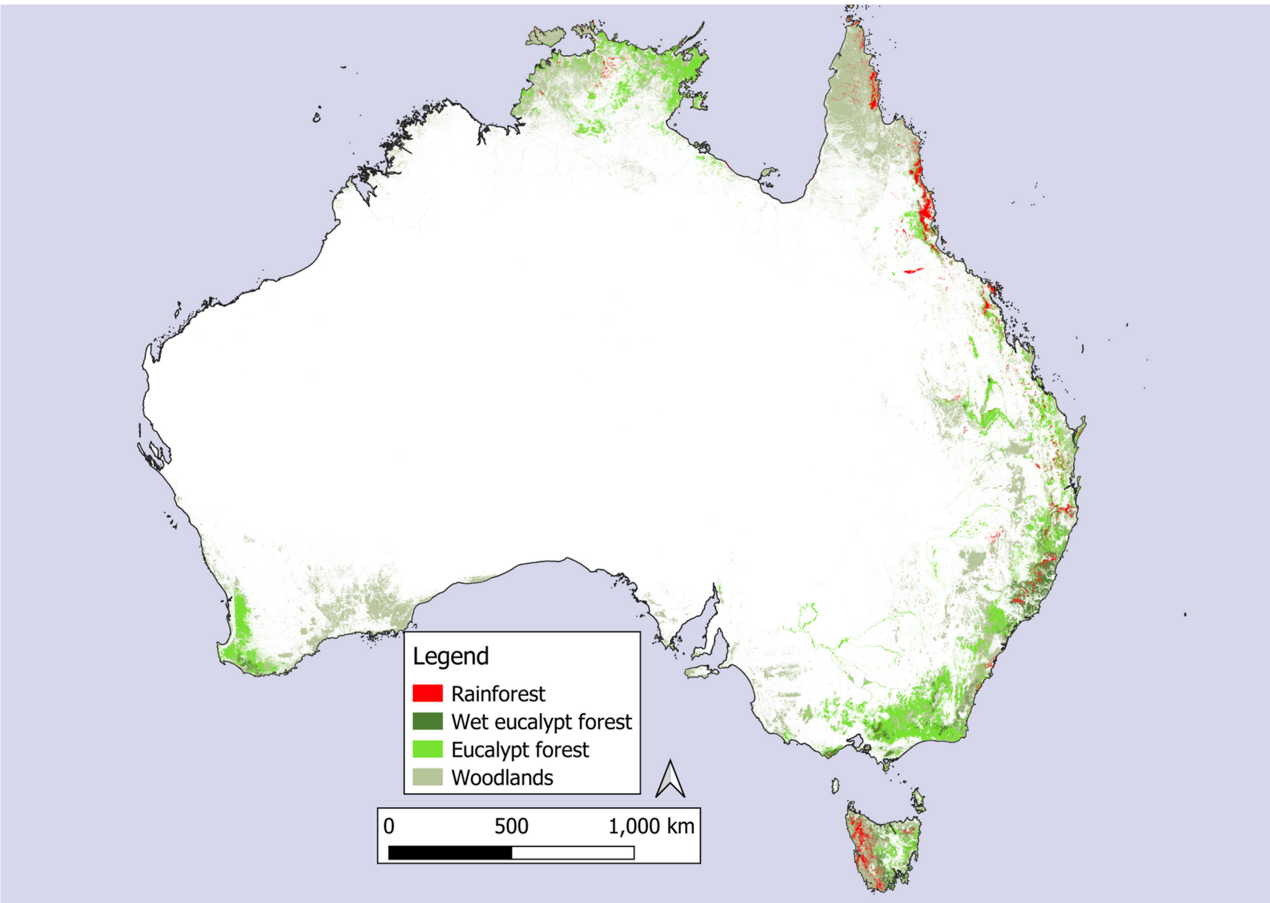



Figure 1 Forests and woodlands together cover 70,655,650 hectares of Australia. This is a huge area but still less than 10% of the land area. Of this, 4.7% is rainforest, 5.4% is wet eucalypt forest, 24.7% is eucalypt forest and 37.4% is eucalypt woodland. The remaining 27.8% is all other kinds of forest and woodland including Acacia, Callitris, Casuarina and Melaleuca forests and woodlands. Note that our data are from a combination of the National Vegetation Information System (NVIS)[*10*] and the global forest change dataset in which forests are defined as < 5 metres tall [*11*].

Australia has over 70 million hectares of native forests and woodlands (Figure 1). The plant genus *Eucalyptus* is extremely prevalent in much of the woody vegetation of Australia and includes over 800 species [*12,13*]. A eucalypt is any species within the genus *Eucalyptus* or the closely related genera *Corymbia* and *Angophora*. Eucalypts dominate the forests and woodlands of the coastal regions of Australia and vast areas of its drier inland regions. Here we use the term eucalypt forest to include all vegetation formations that are dominated by trees in the genera *Eucalyptus*, *Corymbia* or *Angophora*. This includes the wet eucalypt forest (also referred to as wet sclerophyll forest, or tall-open forest), eucalypt forest (also referred to as dry sclerophyll forest, and open forest) and their various understorey formations including grassy and shrubby understoreys. Most woodlands in Australia are also dominated by eucalypts. We use the term rainforest to include closed forests that are dominated by genera other than *Eucalyptus*.

## 2. How do eucalypt forests persist in the face of recurrent bushfires?

In spite of the stark imagery of blackened landscapes, and contrary to media reports, the ecological reality is that eucalypt forests are not "destroyed" by bushfire [*14*]. Plants have a range of traits that enable them to persist in the face of recurrent fire. These can be grouped into two main response strategies (1) resprouters; and (2) seeders [*7,15*].

### Resprouters

Resprouting is the initiation of new shoots from recovery buds after fire (Figure 2). Above-ground recovery buds are protected by thick or insulating bark [*16*] (Figure 2). Resprouting from above-ground recovery buds on stems and branches is referred to as epicormic resprouting. Many resprouting species have their recovery buds located underground where they are insulated by the soil, e.g., lignotubers in many *Eucalyptus* spp; bulbs, corms and tubers (in orchids and lilies); and rhizomes (in ferns and reeds) [*16*]. These are referred to as basal resprouters [*13*]. Palms, cycads, grass trees and tree-ferns can resprout from buds located at the top of a plant that have been protected from the heat of fire by compact leaf bases [*7,15,17*]. These are called apical resprouters.

Figure 2 Forms of resprouting (a) epicormic sprouts emerging from the charred trunk of a Swamp Mahogany; (b) Swamp Fern resprouting from rhizomes following fire; and (c) apical resprouting in a Cabbage Palm.

Once they are mature, resprouters can survive fire by protecting recovery buds, although it may take many years before they develop fire resistant structures such as lignotubers, thick bark and protective leaf bases [*16*], or sufficient height to avoid exposure to intense heat [*18*]. Resprouting is stimulated when the vegetation canopy is removed [*19*]. Stored carbohydrate reserves, which are often below ground, enable resprouters to initiate growth almost immediately after the passage of a bushfire [*20*]. Satellite imagery of eucalypt forests dominated by epicormic resprouters in the Sydney Basin has shown that the canopy can recover substantially within two years of a bushfire [*21*]. Rapid canopy recovery following fire provides critical food and shelter resources for recovering fauna populations [*22*]. For example, koalas migrating into a burnt forest from an unburnt forest can live entirely off a newly developing canopy within months of a fire [*23*].

Nearly all eucalypts can recover from bushfire by resprouting despite having all of their canopy scorched [*24*], but eucalypts are not the only resprouters. Many non-eucalypt forest plants also can resprout, with 70% of the plant species in eucalypt forests having the ability to resprout following fire (Table 1) [*17*]. The eucalypts are conspicuous, however, in their ability to resprout epicormically following crown fire [*13*]. Resprouter tree species within the genera *Eucalyptus*, *Corymbia* and *Angophora* physically dominate the eucalypt forests and woodlands of southern Australia [*17*].

Figure 3 Epicormic resprouting following bushfire

Where the typical fire regime is recurrent low to moderate intensity surface fires, resprouters are advantaged [*17,25,26*]. Resprouters can occupy the same site for hundreds to thousands of years with minimal changes in population size [*27,28*]. The longevity and physical dominance of epicormic resprouters confers a high degree of structural and functional stability to eucalypt forests in response to both drought and fire. In terms of forest structure, regrowth from the ground level is not required because the vegetation canopy can recover from above-ground recovery buds. The ability to resprout also enables temperate eucalypt forests to function as robust carbon sinks [*29*].

Table 1. Proportions of fire responses and resprouting types among Australian vegetation communities (values are rounded) from Clarke et al [*17*]. Obligate seeders are unable to reproduce by resprouting. Facultative resprouters are also capable of seeding.

| Ecosystem | Fire type | # species assessed | % Fire response | | | | % Resprouting type | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Obligate resprouters | Obligate seeders | Facultative resprouters | Fire avoiders | Apical | Epicormic | Basal | Undergro und |
| Rainforest (temperate and tropical) | Surface | 232 | 62 | 5 | 16 | 18 | 3 | 6 | 91 | <1 |
| Eucalypt forest (wet and dry sclerophyll) | Crown / surface | 1153 | 21 | 27 | 49 | 3 | 4 | 24 | 68 | 4 |
| Savanna (tropical and temperate | Surface | 235 | 40 | 7 | 48 | 5 | 2 | 59 | 37 | 1 |
| Eucalypt shrubland (mallee) | Crown | 215 | 3 | 57 | 35 | 4 | 0 | 7 | 84 | 9 |
| Acacia shrubland (brigalow) | Surface | 184 | 47 | 12 | 16 | 26 | 0 | 16 | 75 | 9 |
| Heath (wet and dry heath) | Crown | 621 | 11 | 47 | 42 | 1 | 3 | 11 | 80 | 6 |

## Seeders

In contrast to resprouters, seeders are killed by total canopy scorch. Seeders are able to persist in fire-prone landscapes because they have the ability to produce a fire-resistant seed bank that germinates profusely after fire [*15*]. One seeder mechanism is to retain seeds in woody capsules that protect the seed and hold it in a dormant condition until stimulated to open by fire [*18*].

Examples of this mechanism are found in species of *Banksia*, *Hakea*, *Leptospermum* and *Callistemon* [16]. Another strategy, common amongst *Acacia* species (wattles), is to produce hard seeds that are stored in the soil and stimulated to germinate when heated by fire [*7*].

In the case of obligate seeders, fire is needed for regeneration i.e., seeding is their only post-fire strategy. Bushfire provides the cue for seed release and germination, while simultaneously reducing competition for light, water and nutrients and creating the open space necessary for slow growing seedlings to survive [*30*]. In eucalypt forests, 27% of species are obligate seeders [*17*], and most of these have a shrub growth form. For these species, the length of time between consecutive fires is important. If the time between fires is too long, there are few opportunities to release seed. Conversely, if the interval between fires is too short, and plants have not had the opportunity to mature and produce seed, then local extinction can occur [*16*].

Ten species of obligate seeders can grow into tall trees (25–100+ m) in the wet eucalypt forests of eastern Australia [28]. Normally, these species are co-dominant with resprouters [*17*] but striking exceptions to this are the forests dominated by ash-type eucalypts. Across Victoria, the ash forest area, which is dominated by obligate seeders, was mapped in 2013 and found to be approximately 547,000 ha or 7% of Victoria's total forest area [*31*]. High severity fire can cause high mortality of canopy trees in these forests, and the resulting germination event produces even-aged stands. However, spatial variation in fire severity, topography, severity of the preceding fire and the length of time since the previous fire can all alter the mortality rate and contribute to the development of multi-aged forest stands [32] with up to four age classes present in an ash forest [*33*]. Multi-agedness can therefore be quite prevalent, even in forests dominated by obligate seeder trees.

The fire response classifications (resprouters and seeders) are potential responses and are not true of all individuals all the time. How an individual plant responds to a given fire depends on the developmental stage and vigour of the plant, the fire severity, the interval between fires, the season of burning, microhabitat differences and seasonal conditions [*7,16,34,35*]. For example, lignotubers need time to develop or replenish sufficient carbohydrate reserves to support resprouting and if exposed to fire too soon or too often, individual plants may lose the ability to resprout, and die [*36*].

## 3. How do animals and fire sensitive ecosystems persist in fire-prone landscapes?

Fire-prone ecosystems dominate the vegetation cover over most of the Australian continent [*17*]. The persistence of many plant and animal species within fire-prone landscapes often depends on fire refuges [*37*]. Each fire creates a mosaic of intensities that leaves some areas unburnt and burns the vegetation in other areas entirely [*20*]. The size and location of unburnt areas varies from one fire to another [*38*]. Fire weather and drought are the main drivers of the occurrence of unburnt patches. When fire weather is moderate, there are more unburnt patches than when fire weather is severe [*39*]. Under severe fire weather, unburnt patches may make up as little as 1% of the total burnt area [*39,40*].

Echidna emerging after fires pass through Murramarang National Park, New South Wales.

### Animals

The likelihood of individual animals surviving a fire is strongly dependent on the fire intensity. This is particularly the case for animals that live in the vegetation canopy. In the case of low intensity fires, large mammals such as wallabies can move through a fire front [*41*]. However, finding refuge, either in a habitat feature that provides protection from heat and flames or in an unburnt patch of forest, is the main strategy for many animals to survive the passage of a fire [*23,42-45*].

Relatively large unburnt patches can occur in topographically sheltered gullies and other landscape locations where conditions are wetter and cooler than the surrounding landscape [*40,46,47*]. These are important refuges during fire for mammals and birds [*48-50*]. However, a fire refuge can be any feature that enables the survival of individuals in the face of an event that would otherwise result in mortality. Depending on the intensity and duration of the fire, small animals may be able to survive the fire *in situ* by sheltering in drainage lines, under rocks, underneath bark, in hollow logs, in tree hollows, within compacted leaf bases or in burrows [*45,51,52*]. A range of animal species have been recorded in wombat burrows and there are anecdotal reports of animals sheltering in wombat burrows during fire.

Low intensity fires that are small and patchy might give many individual animals the opportunity to avoid being killed [*18,53*]. However, when fires are large and intense, high mortality rates can be expected for most species. Whether animals are able to access refuge from fire will depend on the species' size, biology and mobility; their geographic distribution in relation to potential fire refuges; and where individuals are at the time of a fire. Burrowing animals have a better chance of surviving a bushfire than animals which do not make or use burrows [*54*]. However, having survived the passage of a bushfire, many more individuals will be lost due to dehydration, predation, or starvation in the altered post-fire environment [*18,43,55*].

In the weeks, months and years after the passage of a bushfire, the spatial pattern and rate of recovery of populations will be unique for each species and will depend on the spatial distribution of individuals and populations that survived the fire in situ; each species' life history attributes [*56*]; and the changing availability of plant-based resources including food and shelter [*51,53,57,58*]. It may take more than 100 years for key habitat resources to re-develop [*59*].

For many species, their population recovery will be driven by individuals surviving in unburnt areas [*23,57,60*]. Unburnt areas within the fire perimeter are important for the recovery of *in situ* populations [*42,44,45,61*]. Large unburnt areas outside the fire perimeter are also important, as colonisation from *ex situ* populations can be significant for post-fire recovery of fauna [*61,62*]. Gullies, and the key habitat resources that they protect, may be key to the survival and resilience of many fauna species [*37,63-65*]. Unburnt patches are important for the persistence of fire sensitive species across forested landscapes globally [*39*]. Irrespective of their function as fire refugia, locations where nutrients and moisture accumulate are also critical to the persistence of many animals in the Australian landscape [*66*].

The persistence of plants and animals depends on many factors of which the fire regime is just one. Other factors that determine a species' ability to persist at a location include: matching niche requirements [*67*]; life history attributes such as means of reproduction [*68*] and dispersal ability [*69-71*]; climatic and weather conditions between fires [*35,72*]; landscape connectivity [*73,74*] and species interactions including competition and predation [22,63]. Interactions between these factors mean that a species’ response to fire can vary between populations, between sites and between fires. Over time, the composition of the community (i.e., which species are part of the ecosystem), and the community structure will depend on the outcomes of these interactions [*9*].


Green refugia in the Yarra Ranges National Park after 2009 'Black Saturday' fires, Victoria

## Fire sensitive ecosystems

Rainforests are distributed as an archipelago of patches of varying size among the widespread and dominant eucalypt forests of eastern and southern Australia. Relatively large intact blocks of rainforest remain in south-eastern Queensland, northern and central coastal New South Wales and Tasmania. Patches naturally decline in size in southern New South Wales and Victoria where rainforest occurs as many small discrete patches in sheltered locations (Figure 4).

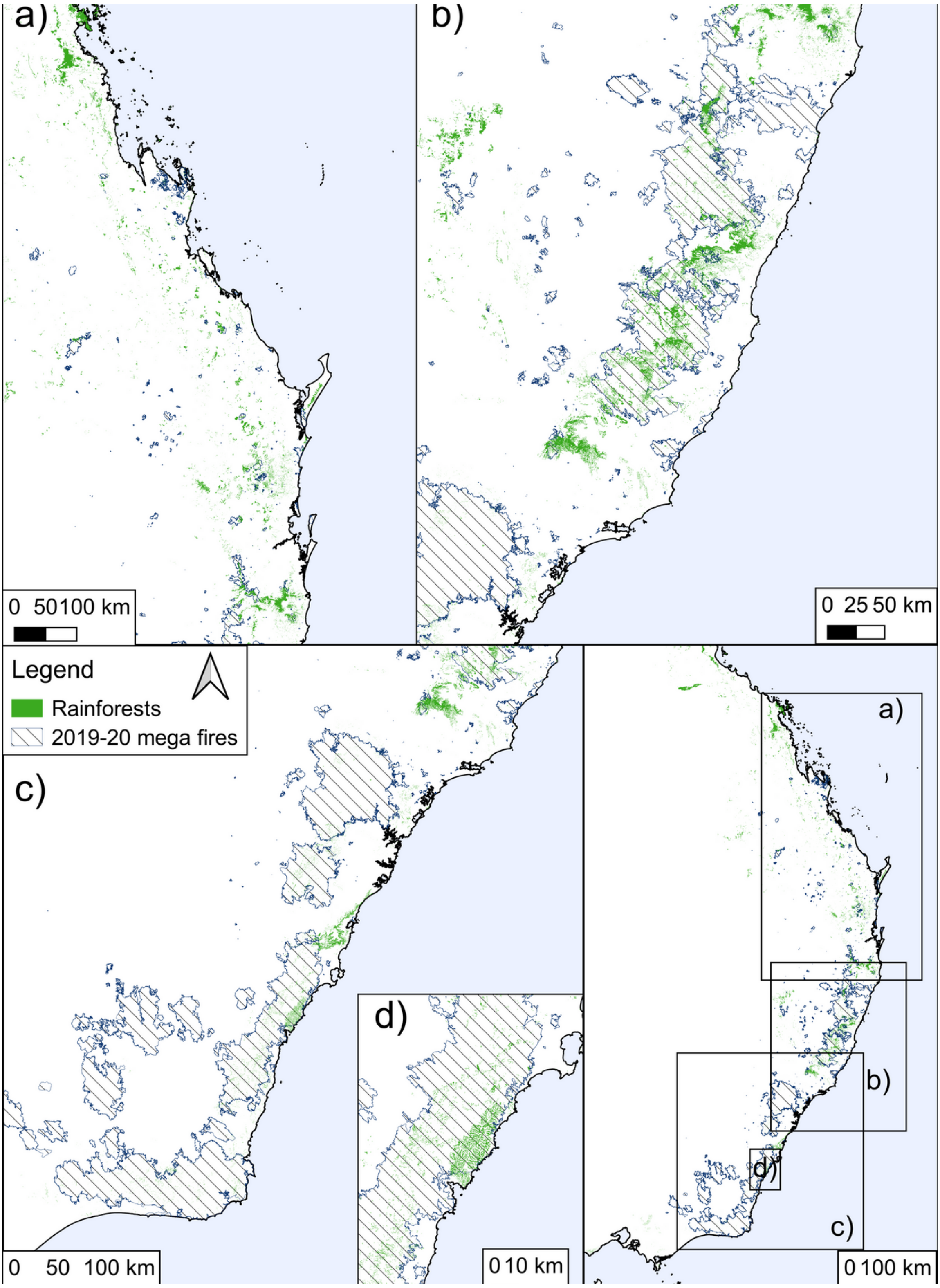



Figure 4 The distribution of rainforest vegetation in eastern Australia showing its occurrence as many small, discrete remnants in (a) south-eastern Queensland, (b) northern coastal New South Wales, (c) southern coastal New South Wales and (d) enlargement of section of southern coastal New South Wales.

The persistence of rainforests within the largely fire-prone landscapes of Australia, both in larger intact blocks and the small patches, is a remarkable feature of forest ecology in Australia. The evolution of these rainforests pre-dates Australia's eucalypt forests and they are refuges to many plant and animal species with ancient origins in Gondwanaland [*75*]. A high proportion of rainforest plant species have some capacity to resprout but they are mostly basal resprouters and require long fire free intervals to recover the ability to reproduce. They are therefore unable to persist in locations where there is recurrent fire [*76*]. Their persistence within fire-prone landscapes is maintained by multiple interacting factors including climatic conditions, topography, soils, moisture and fire history [*40,46,47,76-78*].

For larger rainforest patches, vegetation "feedbacks" are involved whereby the rainforest canopy maintains a humid, cool, shady microclimate which makes these forests less fire-prone [*76,77,79*]. Animal activity, such as foraging in the leaf litter layer by the Superb Lyrebird, also can modify fuel characteristics and further reduce the likelihood of burning [*37,80-82*]. These conditions favour plant species that are less flammable than adjacent eucalypt dominated vegetation. For smaller rainforest patches, topographic sheltering creates gullies where conditions are wetter and cooler than the surrounding landscape, providing protection from most fires [*40,47*].

As long as fire weather conditions are not severe, non-flammable rainforest vegetation can suppress fire [*77,79*]. When low intensity fire reaches rainforest, the changes in microclimate and fuel characteristics are often sufficient to prevent the fire from spreading, although repeated fires cause steady attrition of the forest boundary [*46*]. However, gullies are not immune to burning, and after prolonged and severe drought the capacity of rainforest stands in normally damp gullies to extinguish fire is greatly reduced [*39*].

As we discuss in Report No. 1 of this Bushfire Science Report series (see www.bushfirefacts.org), there are observed and projected increases in extreme fire weather conditions as evidenced by the unprecedented 2019-2020 mega-fires. Increased severity of fire weather and increased drought conditions are likely to lead to a reduction of fire refugia across the forests of southern Australia. Intervention to protect topographic areas that able to support fire refugia will be an important step towards maintaining the ecological integrity of forests under future climate change [*39*].

# 4. Are bushfires ecologically destructive?

From an ecological perspective, bushfires are not completely destructive. Bushfires, including those of high severity, are one form of ecological disturbance that has an important role in maintaining biodiversity within the eucalypt forests of southern Australia [*14*]. Bushfires provide an important cue for regeneration of many plant species and have a structuring role in plant communities in fire-prone environments [*9,16*]. As outlined above, it is the fire regime, rather than a single fire event, that is important for forest ecology. Over time, fire regimes have helped to shape plant characteristics and the composition and structure of Australia's forests. However, large bushfires that burn the entire geographic area occupied by a species are clearly a threat to fauna. In addition, inappropriate fire regimes can cause population declines or local extinction even in species with traits that give them the potential to survive fire [*16*].

Inappropriate fire regimes include fires that are too intense, not intense enough, too frequent or too infrequent. As noted above, the climate is changing rapidly, extreme fire weather conditions are increasing and fire regimes are projected to change [*83,84*]. One aspect of changing fire regimes that has particular ecological significance, is the frequency of fires, especially the length of time between two consecutive fires at a given location.

Fire frequency is a key driver of vegetation composition and structure because of the effects of fire in relation to plant life cycles [1*6,85*]. Forests dominated by obligate seeder tree species such as Mountain Ash and Alpine Ash provide a striking example. In these ecosystems, fire stimulates the release of canopy-stored seed and regeneration of a new cohort of trees [*33*]. However, if the next fire occurs before trees have become reproductive (<20 years), or after seed is no longer produced (>350 - 500 years), then demographic collapse can occur [*86*]. Increasing fire frequency poses the risk of demographic collapse of Mountain Ash forests and Alpine forests [*87-89*]. In recent years, two fires in rapid succession have caused complete regeneration failure in large stands of Alpine Ash in the Australian Alps [*88*].

High fire frequency also can be a problem for resprouter species that are normally considered to be fire tolerant, including the trees that dominate Australia's eucalypt forests.


The Alps, New South Wales.

As resprouters have long juvenile periods, high fire frequency can change stand structure in forests dominated by resprouters by killing juvenile plants, reducing the capacity of established trees to produce seed, and exhausting the capacity of mature trees to vegetatively recover [*36,90*].

Conversely, if fires are too infrequent to stimulate the production or release of seeds, plants may die without reproducing [*30*]. Exclusion of fire from open eucalypt forests can result in the competitive exclusion of shade intolerant species [*91*].

A single high intensity fire can cause long term changes in plant community composition and structure, even in ecosystems that are tolerant of low to moderate fires. In some vegetation communities, a single high severity fire can cause population collapse of species less tolerant of fire [*92*]. A single high intensity fire can cause local extinction of seeder species that are normally fire tolerant, and high mortality rates of resprouting species which would normally have high resistance to fire [*90,93-95*]. In the Karri forests of Western Australia, for example, a single large and intense bushfire in 2015 caused almost twice as much mortality of Karri trees and complete elimination of a normally dominant shrub species compared to sites where the bushfire was less intense [*95*].

Frequent high intensity fire has the potential to cause transitions to more open, simplified forest structure even in systems dominated by resprouters [*96-98*]. The combined impacts of more frequent fire and warmer, drier conditions can lead to reduced rates of recruitment, growth and survival of woody plants and changes in vegetation composition and structure [*35,99*].

# 5. How do bushfires interact with other disturbances?

The mega-fires of 2019-2020 were unprecedented in their spatial extent and severity [*100*]. Furthermore, these bushfires were superimposed on ecosystems and wildlife populations already under significant stress from multiple pressures including: direct impacts of climate change, clearing and fragmentation of native ecosystems, invasive species, predation by exotic pests, habitat degradation, overexploitation of natural resources such as timber and water, disease and pollution [*101-105*]. For example, extreme temperatures associated with climate change are causing mass mortality of flying foxes, a key species for pollination in eucalypt forests [*106*]. The combined impacts of land clearing and drought have also caused significant declines in the distribution and population of koalas [*107*]. The 2019-2020 mega-fires may have exacerbated the situation by abruptly and severely reducing population sizes and rendering habitat unsuitable for many years [*108*].

The ecosystem-level consequences of multiple different and compounding human and natural disturbances are unpredictable [*109*]. We know, however, that interacting disturbances can have profound effects on biodiversity and ecosystem properties, especially those related to ecological maturity [*110*]. While our understanding of the ecological effects of interacting disturbances is far from complete, there are many specific examples of effects. For example, habitat fragmentation prevents re-colonisation of burnt areas by fauna that have survived fire in unburnt areas, especially of species with poor dispersal ability [*111*]. Feral cats are able to hunt more effectively in a post-fire landscape where shelter for surviving wildlife has been removed by fire [*112*]. Some species within the plant family Myrtaceae, including resprouting species of *Eucalyptus* and *Angophora*, are more vulnerable to infection by the invasive pathogen myrtle rust following fire [*113*]. Feral herbivores can also affect plant recovery following fire [*111*]. Interactions between changed fire regimes, invasive species and changing land use have contributed to significant declines in Australian mammals and birds and presumably other animal and plant groups [*103*].

The 2019-2020 mega-fires were beyond anything that had been anticipated in conservation planning and management for biodiversity [*111*]. The fires urnt much of the conservation network including habitat for 832 native vertebrate species (378 birds, 254 reptiles, 102 frogs, 83 mammals, and 15 freshwater fish) [*108*], and were of a scale that had not been factored into recovery plans for threatened species [*111*]. The fires overlapped with the habitat of 107 threatened vertebrate taxa. Seventy species had more than 30% of their habitat burnt, and of these, 21 species were already listed as threatened with extinction [*108*].

Many species that were not previously considered to be threatened, also suffered significant losses. Initial assessments have identified 119 animal species as high priority for urgent management attention comprising 17 bird, 20 mammal, 23 reptile, 16 frog, 22 crayfish, 16 freshwater fish species and 5 invertebrate species [*114*]. Data are particularly lacking for invertebrates, but 191 invertebrate species are known or assumed to have been severely affected by the 2019-20 mega-fires [*115*]. For invertebrates, to date only butterflies, land snails, beetles and flies have been assessed and numbers are likely to be much higher when a more complete analysis can be completed that includes moths, spiders, crickets and other groups. As many as 709 plant species are at high risk and in urgent need of management intervention as a result of the 2019-20 mega-fires [*116*].

# CONCLUSION

The eucalypt forests of southern Australia are resilient to disturbance by bushfire. Nearly all eucalypts and many non-eucalypt forest plants can recover from bushfire by resprouting, with 70% of the plant species in eucalypt forests having the ability to resprout following bushfire. However, the combined impacts of high intensity large-scale bushfire with multiple other pressures mean that we should not be complacent about forest recovery.

In the short term, the best chance for forest recovery combines a number of strategies that: (1) allow natural forest regeneration processes to take place; (2) do not disturb burnt areas any further (see also Report No. 4 of this Bushfire Fact series (www.bushfirefacts.org); (3) reassess the extinction risk of fire-impacted species; (4) assist the recovery of fauna populations in both burnt and unburnt areas; and (5) address the multiple threats to native animal populations wherever they pose a barrier to recovery. The range of recovery actions required is broad and needs to be informed by each species' sensitivity to fire and the suite of threatening processes that affect it.

In the longer term, significant investment in the conservation and recovery of Australia's ecosystems is needed to increase the resilience of native plant and animal populations. In relation to fire, there is a need for improved protection, planning and response to ensure the retention of unburnt patches, particularly topographically sheltered gullies that are critical to the survival and subsequent population recovery of the biota in fire-prone landscapes. Improved protection, fire planning and fire response are also needed for fire sensitive, key biodiversity areas such as the Gondwana Rainforests [*117*]. Importantly, urgent action on climate change mitigation is needed to reduce further global warming and ongoing increases in extreme fire weather conditions, and to help avoid repeated events of this type.

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