Criterion 3

Maintenance of ecosystem health and vitality

Beerburrum State Forest, Queensland.

Criterion 3 Maintenance of ecosystem health and vitality

Sustainable forest management aims to maintain ecosystem health and vitality while maintaining the productive capacity of native and plantation forests to provide the goods and services required by society.

This criterion contains two indicators that together aim to cover the range of agents and processes that affect the health and vitality of native forests and commercial plantations. The first indicator considers the scale and impact of vertebrate and invertebrate pests, pathogens and weeds, as well as environmental factors such as drought and extreme weather events. The second indicator considers the impacts of forest fire, and presents data on the area of forest burnt by planned and unplanned fires.

Forest health

Agents that affect forest health and vitality and that are considered in Indicator 3.1a include browsers, invertebrates (mainly insects), pathogens and weeds. Other potentially damaging processes that are considered include drought, extreme climatic events such as wind storms or cyclones, and climate change.

Australia's forests are adapted to and recover from many of these disturbances, particularly those that occur periodically where impacts are followed by periods of recovery.

Forest health surveillance is mainly undertaken in plantations, with the aim of detecting and identifying the extent of forest health issues such as disease, insect and vertebrate pests, weeds, and nutrient deficiencies, while monitoring the impacts of these on tree survival and growth. Detailed data on pathogens and areas affected are available for commercial plantations. Assessments for conservation reserves and multiple-use public native forests are mainly ratings of scale and impact of damage. Active management of agents affecting forest health is directed mainly at the protection of commercial values in multiple-use public and private native forests and plantations, and the protection of biodiversity and other forest values in all forests.

Ants feeding on lerps.

Fire

Fire is an intrinsic part of Australia's landscape, and affects biodiversity and other environmental values, as well as having important social and economic consequences. Eucalypt forests, in particular, accumulate large amounts of flammable fuel, and most eucalypt forest ecosystems burn naturally with a characteristic frequency, seasonality, and intensity (known collectively as the 'fire regime'), followed by regeneration and regrowth.

Indicator 3.1b outlines the ecological role of fire, the factors that affect fire frequency, seasonality and intensity across Australia, and reports the areas of planned and unplanned fire (bushfire) that occurred in each year of the reporting period 2011–12 to 2015–16. Because some areas of forest, especially in northern Australia, were burnt in multiple years of this period, the indicator reports separately the cumulative area of forest fire (the sum of the annual forest fire areas) and the total area of forest burnt (in which areas burnt multiple times are reported only once). The data sources and methods used to derive these values for SOFR 2018 have been significantly updated compared to those used for SOFR 2008 and SOFR 2013, and therefore the results cannot be directly compared across these reports.

Fire is also an important forest management tool in Australia's forests. Fire management experts generally consider that planned burning is an effective way to reduce fuel loads, promote forest regeneration after wood harvesting, promote the health of forest stands, maintain ecosystem processes and achieve other desired forest management outcomes. However, some people and community organisations have concerns for the effects of planned fire on flora and fauna, visual amenity, air quality and other values. Indicator 3.1b therefore also explains the role of planned fire, and provides a case study about the National Burning Project, which developed guidelines and frameworks for planned fires for use by Australia's fire management authorities.

This icon indicates data, maps or graphics from *Australia's State of the Forests Report 2018* that are available for electronic download. Data used in figures and tables in this criterion, together with higher resolution versions of maps, are available via www.doi.org/10.25814/5bda8e8ad76d6 and www.doi.org/10.25814/5be3bc4321162.

Indicator 3.1a

Scale and impact of agents and processes affecting forest health and vitality

Rationale

This indicator identifies the scale and impact on forest health of a variety of processes and agents, both natural and human-induced. Through the regular collection of this information, significant changes to the health and vitality of forest ecosystems can be monitored and measured.

Key points

- The agents having the greatest impact on forests over the period 2011 to 2016 differed between jurisdictions and forest types, and for some species between broad climatic regions.
  - A total of 25 introduced vertebrate pest species, and a total of 110 weed species, were reported as having an adverse effect on forests in one or more jurisdictions.
  - Introduced vertebrate pests with widespread adverse impacts on forests in more than one jurisdiction were deer, cats, rabbits, pigs, foxes and cane toads.
  - Weed species with widespread adverse impacts on forests in one or more jurisdictions were Gamba grass, bridal creeper, Mission grass, lantana, St Johns wort, prickly pear, and blackberry.
  - In most jurisdictions, a greater number of vertebrate and weed species were reported as damaging to forests in reserves and multiple-use forests than to plantations.
- Targeted control measures were implemented for feral goats, deer, cats, rabbits, pigs and foxes in forests in reserves in multiple jurisdictions during the reporting period. Control measures were applied in reserves for between 12 and 40 weed species in each of the six states and territories that provided data for forest in reserves.
- The range of native and established introduced pathogens and insect pests active during the period 2011–16 is comparable with previous reporting periods. However, for several of the insect pests of plantations previously reported to be most damaging, there were sharp declines over this period in the number of populations that required management.
- Myrtle rust (*Austropuccinia psidii*) is now present in all eastern states of Australia and in the Northern Territory. Currently, 380 native Australian species of the family Myrtaceae are known to be hosts of this pathogen.
  - The impact of myrtle rust is rapid and severe on species that are susceptible to the pathogen. Subtropical wet sclerophyll forest and rainforest communities that have mid-storey and understorey layers rich in species of the Myrtaceae family are being severely altered by myrtle rust.
  - Preliminary determinations have been made to list two widespread species of the Myrtaceae, *Rhodamnia rubescens* and *Rhodomyrtus psidioides*, as Critically Endangered under the New South Wales *Biodiversity Conservation Act 2016* due to the rapid decline of their populations after local arrival of the myrtle rust pathogen.
- Giant pine scale (*Marchalina hellenica*) was detected for the first time in Australia at two locations (Adelaide and Melbourne) in October 2014.
  - An eradication response was initiated in early 2015 under the Emergency Plant Pest Response Deed, and all known infested trees in the Adelaide incursion were destroyed by mid-2016.
  - However, eradication of the much larger Melbourne incursion was unsuccessful, and a decision to transition to management was made in October 2016.
- Forests affected by the extended drought that persisted in southern Australia until 2010 are showing signs of recovery. The activity of secondary pests and pathogens that attacked drought-stressed trees has also declined. There were no new instances of drought-related forest health impacts reported during the period 2011–16.
- The period 2011–16 continued the trend of increasing mean annual temperatures for Australia, with each year between 2013 and 2016 setting a new record for annual average temperature. Observations at carbon flux sites across southern Australia during the record heatwave of January 2013 showed that major forest and woodland ecosystems were resilient to that event.

Continued

Continues

Key points

- Most of the forests that suffered extensive damage from tropical cyclone Yasi in 2011 had shown strong signs of recovery two years later. In February 2015, tropical cyclone Marcia caused significant damage to pine plantations in the Byfield area, Queensland, with 600 thousand cubic metres of logs salvaged from damaged plantations.
- Extensive areas of mangrove along the southern coast of the Gulf of Carpentaria suffered rapid dieback and mortality in late 2015. The event coincided with unusually low sea-levels and several climate anomalies, which in combination are thought to have produced hypersaline conditions that were beyond levels tolerated by the mangrove species.
- Australia has developed a Plantation Forest Biosecurity Plan and a National Forest Biosecurity Surveillance Strategy Implementation Plan to strengthen surveillance systems and minimise the threats from forest pests and pathogens.

This indicator addresses the factors affecting the health and vitality of Australia's native forests and plantations. It focuses on the impacts of vertebrates, invertebrates, pathogens and weeds on forest health, but also covers other potentially damaging processes, such as drought, extreme climatic events and climate change. The active management of these agents in forests is directed mainly towards protecting commercial values in multiple-use public and private native and planted forests, and biodiversity and other forest values in all forests. It is important to note that many pests and diseases, particularly native ones, show cyclical patterns of impact, and while occasionally present in outbreaks are generally of minor concern.

Forest health and biosecurity

Australia has biosecurity strategies and systems to minimise the introduction of pests not currently in Australia[137], and to reduce the adverse impacts of new pest invasions, of exotic species that have become established in Australia, and of native species that regularly or periodically reach damaging population levels. Australia's Intergovernmental Agreement on Biosecurity (IGAB)[138] provides the overarching framework for formulating priorities and measures to reduce the adverse impact of pests on Australia. The recent National Forest Biosecurity Surveillance Strategy seeks to provide greater coordination between government and industry to minimise the threat to national biosecurity from pests and pathogens in forests and strengthen surveillance systems for early detection of new incursions of exotic pests and pathogens, and led to development of a National Forest Biosecurity Surveillance Strategy Implementation Plan[139]. Forest health surveillance activities relate to endemic (native) pests or established non-indigenous pests; biosecurity surveillance activities (for example at and around ports) relate to exotic pests not established in Australia.

The National Forest Biosecurity Surveillance Plan complements the earlier Plantation Forest Biosecurity Plan (version 2)[140] which was formally endorsed by the Plantation Forest Industry in November 2012, and the Australian Government and all state and territory governments in January 2013. Both documents list 20 exotic forest pests not currently present in Australia, deemed to be of high risk to Australian plantation forests (high-priority threats), and likely to cause significant damage if introduced. Formal active surveillance programs and national diagnostic protocols have been or are being developed for these 20 species.

Metrics for scale and impact, and extent of control

The key agents (such as pests, weeds and pathogens) that adversely affected forest health and vitality during the period 2011–16, and their scale and impact, were assessed by states and territories in each of the following categories: mammals; birds; amphibians and fish; insects and mites; plants, including weeds; and pathogens and diseases. Forest health experts within each state and territory nominated which agents were listed, and provided separate assessments for plantations, multiple-use public native forests and nature conservation reserves. The metric used to assess scale/impact (Table 3.1) combined the scale of distribution of the agent across the jurisdiction (restricted or widespread) with the overall impact across that affected area. For each agent listed by a jurisdiction, the extent of the control program used as a management response was also assessed (Table 3.1).

Agents not reported by a jurisdiction were either not present in that jurisdiction, or were present but not considered a key agent affecting forest health and vitality during the period 2011–16, or there was insufficient information available for their status to be assessed. The scores provide an indication of relative importance only, and should not be taken as absolute measures across states and territories.

[137] A pest is any species, strain or biotype of plant, animal or pathogenic agent that is injurious to plants or plant products.

[138] www.agriculture.gov.au/biosecurity/partnerships/nbc/intergovernmental-agreement-on-biosecurity

[139] www.planthealthaustralia.com.au/wp-content/uploads/2018/03/National-Forest-Biosecurity-Surveillance-Strategy.pdf

[140] ausfpa.com.au/wp-content/uploads/2016/02/Plantation-forest-biosecurity-plan.pdf

Table 3.1: Metrics used to assess scale/impact of damage by key agents affecting forest health and vitality in forests, and extent of control program

Scale/impact		
Scale	**Impact within the affected area**	**Score**
None or no response[a]	No or lesser impact by that agent	–
Restricted (<25%)	Adverse	1
Widespread (>25%)	Localised adverse	2
Widespread (>25%)	Widespread adverse	3
Control program		
Extent of control program		**Colour**
None or agent not listed		
Ad hoc (unplanned)		
Limited targeted		
Widespread targeted		
Widespread general		
Eradication		

[a] Pest agents where the jurisdiction either gave no response or did not indicate a significant impact.

Vertebrate pests

Vertebrate animal pests include both introduced species that have become established as wild populations, and native species that can be damaging in some situations.

Many of the introduced vertebrate species have colonised large tracts of Australia to become nationally significant pests (West 2011). Their adverse impacts in forests include preying on, or competing with, native fauna; providing a vector for pathogens; digging that contributes to soil erosion and the spread of weeds; and direct damage to plants by browsing, trampling or rubbing. A small number of native species that feed on plants can also have adverse impacts when their populations increase beyond the carrying capacity of their habitat or when they feed on young planted trees.

Table 3.2 gives the total number of vertebrate species reported as damaging by six jurisdictions for different forest areas, and their average scale/impact score based on species with a score of 1, 2 or 3 within that jurisdiction. Many vertebrate pest species were reported across several jurisdictions; the distributions of others such as Asian water buffalo, camel, cane toad and starling reflected broad climatic regions or jurisdictions where the species has a significant impact within forests. The scale/impact metric for damage caused by vertebrates reported by jurisdictions was generally greatest for forests in reserves, and least for plantations (Table 3.2).

Introduced vertebrate species

Across jurisdictions, 25 introduced vertebrate species were reported as key agents causing damage to forests. With the exception of hare, camel and tilapia (various species of cichlid fish), all species had a scale/impact score of 2 or 3 in at least one jurisdiction. Table 3.3 lists the 20 introduced vertebrate species that were assessed as having the greatest impact in forests in reserves in the 2011–16 reporting period. Limited or widespread targeted control measures were applied to feral goats, deer, cats, rabbits, pigs and foxes in forest reserves in multiple jurisdictions during the reporting period. Ad hoc or no control measures were applied to other key vertebrate species. In New South Wales, wild dogs are actively managed across all land tenures, because of their wide-ranging movement and their damage to sheep grazing and other farming properties. Some species such as house mouse (*Mus musculus*) and black rat (*Rattus rattus*) are more widespread than apparent from Table 3.3, but caused impact on forests in only some jurisdictions.

Wild populations of many of these species have been present in Australia for more than a century. With the exception of targeted eradication programs on some islands, management is focused on protection of forests from ongoing damage rather than removal of the pest species, and in conservation forests management is focused on protection of biological

Table 3.2: Scale/impact of damage by vertebrate pests in public forests

	ACT	NSW	NT	Qld	SA	Vic.
Number of vertebrate species with a scale/impact score of 1, 2 or 3.						
Plantation	2	7	4	7[a]	15[b]	4
Multiple-use public native forest	n.d.[c]	1	11[d]	14	n.d.[e]	13
Nature conservation reserve	8	13	11	20	15	16
Average scale/impact score of the above species						
Plantation	1.0	1.0	1.0	1.0[a]	1.9[b]	1.5
Multiple-use public native forest	n.d.[c]	1.0	2.0[d]	2.0	n.d.[e]	2.0
Nature conservation reserve	2.1	2.1	1.9	1.9	2.1	1.7

n.d., no data.

[a] Response from HQPlantations.

[b] Plantations in South Australia have multiple permitted uses including recreational access, and may be on multiple-use public forest tenure.

[c] No separate response received for multiple-use public native forest in the Australian Capital Territory.

[d] Data for public native forests not in nature conservation reserves (there are no multiple-use public native forests in the Northern Territory).

[e] No separate response received for multiple-use public native forest in South Australia.

Notes:

Species numbers, scale/impact scores and tenures are as reported by jurisdictions and agencies. The rating system is explained in Table 3.1. Data were not received from Tasmania or Western Australia. Values shown are the total number of vertebrate species reported with a scale/impact score of 1, 2 or 3, and the average scale/impact score of those species.

This table, together with other data for Indicator 3.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

Table 3.3: Scale/impact of damage to forests in reserves caused by key introduced vertebrate species, and extent of control

Latin name	Common name	EPBC listing	ACT	NSW	NT	Qld.	SA	VIC
Mammals								
Bos taurus	Cattle (feral / stray)		–	–	2	3	–	–
Bubalus bubalis	Asian water buffalo		–	–	2	–	–	–
Canis lupus familiaris	Wild dogs (not dingoes)		–	–	1	1	–	3
Capra hircus	Feral goat	T	–	3	–	2M 2I	2	2
Cervus spp	Deer (including sambar and red deer)		2	3	–	1	2	3
Dama dama	Fallow deer		2	3	–	1	2	3
Equus asinus	Donkey		–	–	2	–	–	–
E. caballus	Horse		–	1	2	1	–	2
Felis catus	Feral cat	T	3	3	3	3	2	3
Lepus capensis	Hare		–	1	–	–	1	1
Mus musculus	House mouse		–	–	–	1I	3	1
Oryctolagus cuniculus	Rabbit	T	2	3	-	1	3	2
Rattus rattus/R. norvegicus	Introduced rats	TI	–	–	–	1I	3	1
Sus scrofa	Feral pig	T	2	3	3	3	1	2
Vulpes vulpes	Fox	T	3	3	–	3	3	3
Birds								
Passer domesticus	Sparrow		–	–	–	–	2	–
Sturnus vulgaris	Starling		–	–	–	–	2	–
Fish								
Cyprinus carpio	Carp		–	–	–	2	–	–
Gambusia affinis	Mosquito fish		–	1	1	2	–	–
Amphibians								
Rhinella marina	Cane toad	T	–	1	3	3	–	–

T, species listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); M, mainland scale/impact only; I, offshore island scale/impact only.

Notes:
Numerical values show scale/level of impact; cell shading shows extent of control (see Table 3.1).
Species listed are the 20 introduced vertebrate species (or taxa, or taxa groups) with the highest sum of scale/impact scores across the five responding jurisdictions.
Source: data and assessment from states and territories. Data were not received from Tasmania or Western Australia.

This table, together with other data for Indicator 3.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

assets. The impacts of seven of the introduced species listed in Table 3.3 are currently listed as a Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and Threat Abatement Plans have been prepared for each of these seven species.

Actions to reduce or mitigate the effect of feral predators such as foxes and cats on forest fauna are undertaken in several states. Since 1996, the Western Shield program in Western Australia[141] has involved the aerial and ground deployment of baits containing the naturally occurring plant toxin 1080 (sodium fluoroacetate), and more recently a new bait attractive to feral cats (Eradicat®). In 2016, the annual program applied baits to 2.4 million hectares of forests on public lands. The success of the program has led to a reduction of at least 55% of the number of foxes in baited areas in the south-west of Western Australia, with populations of at least 53 threatened mammal, bird and reptile species remaining in existence in baited areas. Since 1998, a range of physical items were collected in Tasmania that indicated fox activity in that state which, along with reports of fox sightings from members of the public, led the Tasmanian Government to run a fox eradication program from 2006 to 2014. No physical evidence of fox activity has been collected in Tasmania since July 2011.

Management targeted at these introduced vertebrate pests is generally integrated management using a suite of tools, and depending on the pest is either localised or widespread. A collection of resources and tools available to support this management was developed by the Invasive Animals Cooperative Research Centre (CRC) and is maintained by the Centre for Invasive Species Solutions[142]. The Invasive Animals CRC is developing new tools to augment those already available, including the recent development of a new strain of rabbit haemorrhagic disease virus (Wishart and Cox 2016) for release in 2017.

[141] www.dpaw.wa.gov.au/management/pests-diseases/westernshield

[142] See the *PestSmart Connect* portal, www.pestsmart.org.au

Native vertebrate species

Adverse impacts from kangaroos, wallabies and brushtail possums in the period 2011–16 were mainly restricted to plantations in Tasmania, Victoria and southern NSW, and multiple-use forest in Tasmania, as well as on some islands. The scale/impact of damage was similar to that in previous reporting periods, and was primarily associated with shoot browsing of young trees, bark stripping of 3–6 years-old *Pinus radiata* by wallabies, and upper stem girdling of mid-age trees by brushtail possums. The scale and impact of damage by possums and wallabies is considered higher in Tasmania than in Victoria and NSW.

Over-abundant populations of the aggressively territorial Noisy Miner (*Manorina melanocephala*) and Bell Miner (*M. melanophrys*) continue to have adverse impacts in altered native forest ecosystems in eastern Australia. Those adverse impacts include the direct effect of reduced avian diversity, and the indirect effect of declining forest health associated with increased defoliation because of depleted populations of insectivorous birds. In 2014, over-abundance of the Noisy Miner was listed as a Key Threatening Process under the EPBC Act[143]. In 2008, forest eucalypt dieback associated with over-abundant psyllids and Bell Miner was listed as a Key Threatening Process under the NSW *Threatened Species Conservation Act 1995*[144]. A review of the status of Bell-Miner-Associated Dieback (BMAD) was recently completed (Silver and Carnegie 2017).

A high population density of koalas in the Cape Otway area, Victoria, between 2011 and 2013 caused severe defoliation and death of manna gum (*Eucalyptus viminalis*) in several hundred hectares of woodland. By the end of 2013, the koala population had suffered high mortality from starvation (Whisson et al. 2016).

Invertebrate pests

A great diversity of native invertebrates (mostly insects), and a smaller number of introduced species, inhabit forests and can periodically increase in population to cause extensive damage. The populations of most pest species fluctuate in response to climate, particularly drought events, and to a suite of natural enemies. For the most damaging pest species, active management to prevent adverse impacts is needed. Such management, which is mainly restricted to plantation situations, can involve the use of natural enemies of the pest, silvicultural treatments, or the use of pesticides.

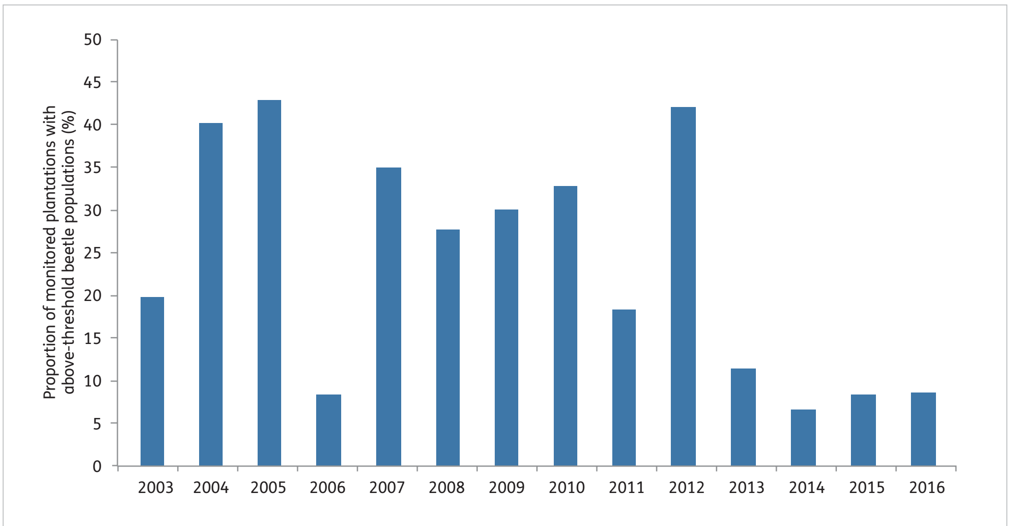
Insect pests affecting hardwood plantations

Chrysomelid leaf beetles remain the most widely reported invertebrate pest of eucalypt plantations. In Tasmania, *Paropsisterna bimaculata* is the main species of leaf beetle and is managed using an Integrated Pest Management strategy. This involves monitoring to detect damaging populations and to inform decisions on the need for control with chemical insecticides if natural controls prove insufficient. Populations in 2012 were high and comparable with those of the previous 5-year period, but in 2013 and subsequent years there was a sharp drop in the proportion of populations exceeding the threshold for triggering control actions, particularly in plantations in northern Tasmania (Figure 3.1). The reasons for this decline have not been established. Another leaf beetle species, *Paropsisterna m-fuscum*, is widespread in young (1–2 year-old) southern blue gum (*Eucalyptus globulus*) plantations in Western Australia, but causes little damage because routine soil injection with the insecticide Clothianidin deters the insect from feeding on planted seedlings.

CRITERION 3

3.1a

Figure 3.1: Proportion of annually monitored eucalypt plantations on public land in Tasmania that had populations of leaf beetles (*Paropsisterna* spp.) that exceeded the economic injury threshold



Note: Extensive bushfires contributed to the low proportion for 2006.

Source: Annual Stewardship Reports, Sustainable Timber Tasmania[145]

The data used to create this figure, together with other data for Indicator 3.1a, are available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

143 www.environment.gov.au/system/files/pages/a564219c-dd63-4187-a578-6e3cddc7ca31/files/noisy-miner-ktp-advice.pdf

144 Now subsumed into the New South Wales *Biodiversity Conservation Act 2016*.

145 Until July 2017, Forestry Tasmania.

Gonipterus "unnamed species 2" is widespread in the western region of the Western Australian hardwood plantation estate. Plantations in the lower productivity areas of this region require protection with insecticide between the ages of 2–5 years to prevent substantial reductions in growth. *G. platensis* has caused severe defoliation on the driest sites in localised areas in Tasmania and Western Australia.

Spring beetles (*Liparetus* and *Heteronyx* species) caused severe damage to young (1–2 year-old) eucalypt plantations in Western Australia in localised areas adjacent to poorly managed native forest remnants that have a grassy understorey. Autumn gum moth (*Mnesampela privata*) has caused little damage in Western Australia and only localised small outbreaks in Tasmania. Christmas beetles (*Anoplognathus* spp.) caused severe damage to many Dunn's white gum (*E. dunnii*) plantations in northern NSW in 2015–2016. Damage from stem-boring insects (*Aenetus* and *Poracantha*) was present in about 10% of the area of young eucalypt plantations in northern NSW.

Insect pests affecting softwood plantations

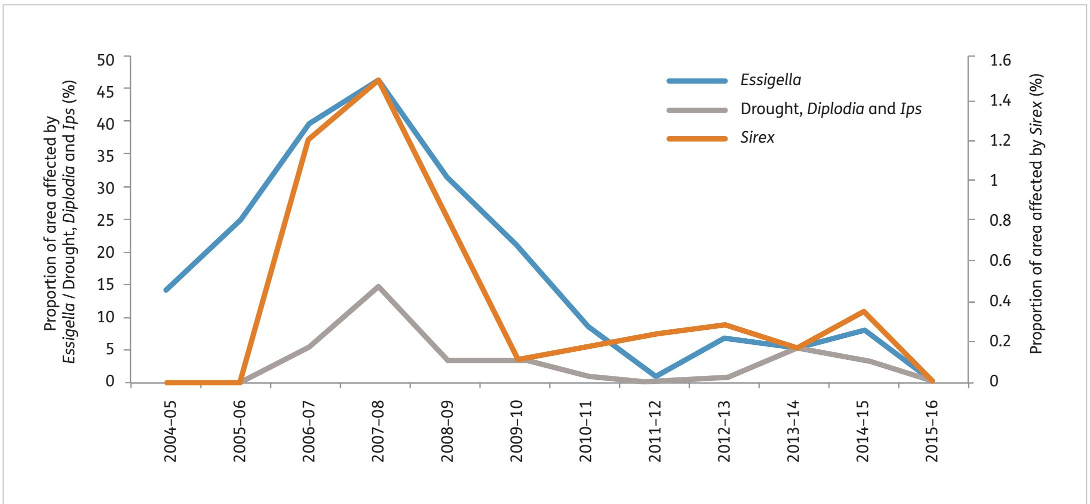
Three introduced insect pests caused extensive damage to radiata pine (*Pinus radiata*) plantations in the eastern states: sirex wood wasp (*Sirex noctilio*), five-spined bark beetle (*Ips grandicollis*) and Monterey pine aphid (*Essigella californica*). The activity of these pests is tightly linked to drought events. The extended drought between 1996 and 2010 in eastern Australia, which peaked in 2006, was associated with a sharp increase in the area of *P. radiata* plantations that suffered damage from each of these pests (Figure 3.2). Since drought-breaking rains in 2010 and 2011, the area of *P. radiata* plantation suffering damage has reduced to low levels (Figure 3.2).

Silvicultural treatments (primarily thinning of plantation stands) and introduced biological controls are used to minimise adverse impacts from *Sirex*, *Ips* and *Essigella*. The parasitoids *Roptrocerus xylophagorum* and *Dendrosoter sulcatus* were introduced into Australia in the 1980s to limit numbers of *I. grandicollis*. The parasitoid *Diaeretus essigellae* was released in Australia in 2009 to reduce numbers of *E. californica*, and by 2014 had successfully established in three of the five major *P. radiata* plantation regions in NSW and five of the eight regions in Victoria. Several parasitic wasps (*Ibalia leucospoides*, *Megarhyssa nortoni*, *Rhyssa* spp. and *Schlettererius cinctipes*) and the parasitic nematode *Beddingia siricidicola* have been introduced to limit numbers of *Sirex noctilio*. The *Sirex* biological control program requires ongoing management, particularly to maintain virulent cultures of the nematode, and is coordinated through the National Sirex Coordination Committee[146]. *Sirex* populations are regularly checked to monitor the levels of nematode parasitism. Recent checks found the *Ibalia* parasite in 30% and 60% of *Sirex* wasps in Victoria and NSW, respectively. Background populations of the parasitic nematode persisted in most eastern states, although levels of parasitism were low in Victoria.

Damage to plantations at Byfield, Queensland, from tropical cyclone Marcia resulted in a sharp rise in populations of native and exotic bark beetles (Scolytidae) that attacked wind-blown trees. Galleries (tunnels) of wood-boring insects and their associated blue-stain fungi impacted on wood quality.

Giant pine scale (*Marchalina hellenica*), a sap-sucking pest that attacks the trees in the family Pinaceae including *P. radiata*, was first detected in Australia in October 2014 at two locations, Adelaide and Melbourne. An eradication response made under the Emergency Plant Pest Response Deed was initiated in early 2015, and all known infested trees at the Adelaide incursion were located and destroyed by

Figure 3.2: Proportion of the annual area of *Pinus radiata* plantation on public land in New South Wales that was affected by drought, pests and pathogens between 2004–05 and 2015–16



Source: FCNSW (2016d)

The data used to create this figure, together with other data for Indicator 3.1a, are available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

[146] australiansirex.com.au/

mid-2016. The Melbourne incursion was much larger and it was deemed neither technically feasible nor cost-effective to remove and destroy infested trees. Giant pine scale has not been found in other parts of Australia, nor has it been detected in any pine plantations. However, it poses a threat to Australia's softwood plantation industry. As a result, a decision to transition to management was made in October 2016.

Insect pests affecting native forests

The scale and impact of insect pests in native forest was much lower in the 2011–16 reporting period than the previous reporting period of 2006–11.

Psyllids (*Cardiaspina* spp.) were the most damaging insect pest affecting native forests in 2011–16. Large populations caused severe defoliation in river red gum (*Eucalyptus camaldulensis*) forests in many parts of Victoria and South Australia. High *Cardiaspina* populations led to Bell-Miner-Associated Dieback of wet sclerophyll forests in northern NSW.

The large outbreak of gum-leaf skeletoniser (*Uraba lugens*) that severely defoliated about 250 thousand hectares of jarrah (*E. marginata*) forest in Western Australia in 2010–11 abated, and forests have since recovered (Wills and Farr 2016). That and previous outbreaks of *U. lugens* in jarrah forests occurred in the wetter parts of the forest after the breaking of prolonged droughts (Wills and Farr 2016). The large *Phoracantha semipunctata* outbreak that killed many jarrah and marri (*Corymbia calophylla*) trees following the severe drought in 2009–10 restricted to the areas most severely affected by drought-related canopy dieback: populations of the beetles did not subsequently spread onto trees that were not dieback-affected from the drought (Seaton et al. 2015). The outbreaks of cup-moth (*Doratifera*) in Victoria and Tasmania that commenced in the 2006–11 reporting period abated, and the forests have recovered well by the end of the current 5-year period.

Pathogens

Pathogens affecting hardwood plantations

Species of *Teratosphaeria* (formerly *Mycosphaerella*) causing leaf disease were the pathogens most commonly reported in *Eucalyptus* plantations. Kirramyces leaf disease (*T. eucalypti*), which caused extensive severe defoliation of shining gum (*Eucalyptus nitens*) in Tasmania and Victoria in the wet summers of 2010–11 and 2012–13, became much less prevalent between 2014–16 as lower rainfall conditions returned. Severe defoliation was restricted to localised areas of the north-eastern highlands of Tasmania and the Gippsland and Otway regions of Victoria that continued to experience moist conditions more regularly than the broader plantation estate. Some plantations in the central north of Tasmania that suffered complete defoliation in the 2010–11 epidemic failed to recover, resulting in the death of several hundred hectares of mid-rotation trees (Figure 3.3).

Leaf disease of young (<3 year-old) *E. globulus* plantations associated with a suite of *Teratosphaeria* species is becoming more prevalent in Western Australia. Contributing to this is the establishment of new plantations closer to the coast (between Margaret River and Albany) where rainfall is higher. Disease is also present at higher rates in large plantation blocks on sand plains where a mix of age classes maintains an ongoing source of inoculum to infect new plantations soon after they are planted.

Myrtle rust (*Austropuccinia psidii*[147]) caused little damage in blackbutt (*E. pilularis*), flooded gum (*E. grandis*) and Gympie messmate (*E. cloeziana*) plantations in northern NSW. Only 5% of young (6 month-old to 2 year-old) plantations were infected, and in these plantations infection incidence was less than 1% of trees. Disease was not detected in plantations beyond 3 years of age.

Phytophthora root-rot of *E. nitens*, due to *Phytophthora cinnamomi*, became much less prevalent in northern Tasmania in the 2011–16 period. The decline in prevalence was attributed to lowland sites being increasingly replanted with the less-susceptible species *E. globulus*. *Eucalyptus nitens* plantations in the Otway and Gippsland regions of Victoria continued to suffer mortality from phytophthora root-rot.

Canker diseases were much less prevalent during the period 2011–2016. The most significant was a scattered low incidence of cankers caused by *Holocryphia eucalypti* (formerly *Endothia gyrosa*) associated with attack by stem-boring insects in drought-stressed mid-rotation *Eucalyptus nitens* plantations in northern Tasmania. A total of 480 hectares was affected over the 5-year period.

Figure 3.3: Mortality in a mid-rotation *Eucalyptus nitens* plantation in northern Tasmania following complete defoliation by *Kirramyces* leaf disease

[147] Previously referred to by the names *Puccinia psidii* and *Uredo rangelii*.

CRITERION 3

3.1a

Pathogens affecting softwood plantations

The suite of pathogens affecting softwood plantations remained unchanged from previous reporting periods.

Spring needle cast (SNC) caused by the fungus *Cyclaneusma minus* continues to be the most damaging pathogen impact on *Pinus radiata* in Tasmania. An increasing proportion of the Tasmanian plantation estate now has planting stock with higher resistance to SNC. SNC is also the most widespread pathogen in Victoria and South Australian plantations, and is affecting an increasing area of *P. radiata* plantations in the Tumut area of NSW.

Diplodia canker (*Sphaeropsis sapinea*) was widespread in *P. radiata* plantations in all eastern states, but at reduced levels compared with the previous 5-year period. In Victoria, localised outbreaks were primarily associated with damage from hail and storms.

In north-east Victoria, up to 3,000 hectares of plantation have been treated for Dothistroma needle blight (caused by *Dothistroma septosporum*) each year since 2011. Elsewhere levels of Dothistroma needle blight in *P. radiata* remained generally low, but outbreaks that required chemical control occurred in localised "hot-spots", mainly in the Northern Tablelands of NSW and in fog-prone valleys in the Noojee area of Victoria. Small outbreaks also occurred in the Otway Ranges of Victoria, but no treatment is carried out in this region.

Pathogens affecting native forests

The introduced pathogens *Phytophthora cinnamomi* (phytophthora root-rot) and *Austropuccinia psidii* (myrtle rust) are the most damaging diseases in native forests because of the broad suite of highly susceptible species that they affect. Native pathogens, by comparison, damage a narrow range of susceptible species, and their host plants have higher levels of resistance (presumably as a result of co-evolution).

Myrtle rust (*Austropuccinia psidii*) remains the most significant pathogen threat to native forests. The pathogen spread rapidly northwards along the eastern seaboard of NSW and Queensland in the 1–2 years following its arrival in 2010, and now occupies much of its predicted climatically optimal range. In the 2011–16 period, the number of known host species increased considerably, and marked changes occurred in the composition and structure of some forest communities after infection. Currently, 380 native Australian species of the Myrtaceae family are known to be hosts of this pathogen (Berthon et al. 2018), and impact on the more susceptible species is both rapid and severe. A detailed description of the impacts of myrtle rust is provided in Case Study 3.1.

Mapping of phytophthora dieback in publicly managed native forest in Western Australia is updated annually and targets areas where timber harvesting plans are being prepared. At the end of 2016, the cumulative total area mapped as dieback-affected based on standard protocols (DEC 2009) was 274 thousand hectares, with 78% of that area being multiple-use public native forest, 20% nature conservation reserves, and 2% other Crown land. Basic mapping through testing and field surveillance is carried out in Victoria, where a model has been developed to help land managers assess the risk of management activities and determine the recommended hygiene conditions. Elsewhere in Australia, the forest area affected by *P. cinnamomi* is not mapped; overall, the extent and impact were reported to be little different from the previous reporting period of 2006–11. In Tasmania, only one significant new extension of *P. cinnamomi* into native forest was reported, namely the Peter Murrell Nature Reserve, which is within a large suburban area and has high levels of public use, and was therefore at greater risk of accidental introduction of the pathogen.

Root-rots and butt-rots caused by *Armillaria* species, notably *A. luteobubalina*, are widespread in tall, closed forests in south-western Western Australia, Victoria and Tasmania. Patch mortality from spread of the fungus between trees occurs in localised areas, particularly in karri (*E. diversicolor*) forests in Western Australia. However, scattered mortality of individual plants, often during the first 1–2 years after forest regeneration, is more typical. There were no reports of elevated levels of *Armillaria* for the period 2011–16.

Mortality of myrtle beech (*Nothofagus cunninghamii*) due to myrtle wilt (*Chalara australis*) is the only significant pathogen impact in temperate rainforests of Tasmania and Victoria. Since 2012, an increase in the levels of mortality in *N. cunninghamii* has been observed throughout Tasmania. Assessment of a long-term monitoring plot (Arve Loop) in 2015 recorded 11% recent mortality (Jeörg Parschau, unpublished data) after two decades of low mortality rates (as reported in Packham et al. 2008). No significant change in the status of myrtle wilt in Victoria was reported, other than detections around new roads.

In south-western Western Australia, regular monitoring of a canker disease of marri (*Corymbia calophylla*) caused by the

Myrtle beech (*Nothofagus cunninghamii*) tree killed by myrtle wilt, cool temperate rainforest, Liffey Falls State Reserve, Tasmania.

native fungus *Quambalaria coyrecup* was conducted between 2001 and 2014. The extent of the disease increased over the period, with 10% of trees becoming infected and 7% being killed by girdling cankers (Paap et al. 2017).

Dieback and other syndromes in native forests

A wide range of chronic or episodic crown dieback syndromes occur to some degree in native forests in all states and territories, often causing significant tree mortality and consequential ecosystem impacts. These events are usually caused by combinations of factors such as climatic stresses, poor land management practices, defoliating insect outbreaks, and an imbalance in insect predator levels. Canker-causing fungi such as *Holochryphia eucalypti* (formerly *Endothia gyrosa*) and *Botryosphaeria* species, and stem-boring insects such as *Phoracantha* species, can have a secondary role. In most cases, there is considerable uncertainty as to the actual mechanism by which the various proposed causal factors combine to produce the dieback syndrome.

Bell-Miner-Associated Dieback of moist sclerophyll forests in New South Wales and Victoria has been observed for more than a century. The syndrome is linked to forest areas that have high populations of Bell Miner birds (*Manorina melanophrys*) and elevated populations of psyllids. The most significant damage is found in Sydney blue gum (*Eucalyptus saligna*) forests in northern New South Wales (Silver and Carnegie 2017). The NSW Department of Primary Industries (Forest Science) has undertaken extensive aerial surveys to update mapping of the extent of Bell-Miner-Associated Dieback.

A syndrome known as Monaro dieback has resulted in the dieback and mortality of substantial areas of *E. viminalis* over the past decade in the Monaro region of southern New South Wales. The affected area in 2013 was 2,000 square kilometres (Ross and Brack 2015) at the drier limit of the natural distribution of *E. viminalis*, but drought is unlikely to be the sole causal factor because symptoms continued to develop after the wet years of 2010–12. Other possible contributing factors examined included populations of *Gonipterus* weevils, grazing history, burning history, and forest structural complexity.

Extensive dieback and mortality of *E. viminalis* was also reported in northern Tasmania. Symptoms first became evident in 2014, and the affected trees showed copious bleeding of gum on their stem. Similar symptoms were seen in *E. globulus* plantations in the same general area, and with affected plantation trees having large gum pockets in the growth ring of the previous growing season (2012–13), which was a period of record heatwave. It has not been established whether the syndrome in *E. viminalis* is the same as that in *E. globulus*, nor whether high temperatures alone can trigger such symptoms.

A severe dieback and mortality event affecting mangrove along the southern coast of the Gulf of Carpentaria occurred in late 2015. This event is described in Case Study 3.2.

Weeds

More than 2,800 exotic plant species have become established as pests in Australia[148]. Species such as blackberry (*Rubus fruticosus* and other *Rubus* spp.) and lantana (*Lantana camara*) compete with native flora and can become locally dominant, reducing biodiversity and other values; they can also affect tree establishment, growth and product yield in commercial forest plantations and production native forests. Exotic grasses such as gamba grass (*Andropogon gayanus*) and buffel grass (*Cenchrus ciliaris*) greatly elevate the severity of fires in northern Australia; changes to fire regimes due to these grass species have the potential to affect forest stands in the region[149].

Across jurisdictions, 110 weed species were reported as key agents causing damage to forests, including introduced grasses, herbs, vines and aquatic plants, and native and introduced tree and shrub species. Table 3.4 gives the total number of weed species reported by five jurisdictions by forest tenure, and average scale/impact scores for species with a score of 1–3 within that jurisdiction. The species reported by each jurisdiction reflected weed distributions and broad climatic regions. Species reported by more than one jurisdiction included kikuyu grass (*Pennisetum clandestinum*), serrated tussock (*Nassella trichotoma*), willow (*Salix* spp.), blackberry, sweet briar (*Rosa rubiginosa*), Scotch broom (*Cytisus scoparius*) lantana, African boxthorn (*Lycium ferocissimum*), rubber vine (*Cryptostegia madagascariensis*) and cat's claw vine (*Dolichandra unguis-cati*).

The five states and territories that provided data reported some level of control measure in forest in nature conservation reserves for between 12 and 40 key weed species for each jurisdiction. Few weed species were the subject of widespread control or eradication measures. Within forest in nature conservation reserves, widespread general control measures were applied to Crofton weed (*Eupatorium* spp.) in New South Wales, to briar (*Rubus* spp.) and *Nassella trichotoma* in the Australian Capital Territory, and to bellyache bush (*Jatropha gossypiifolia*) in the Northern Territory. Eradication measures were applied to water hyacinth (*Eichhornia crassipes*), orange hawkweed (*Hieracium aurantiacum*), honey locust (*Gleditsia triacanthos*) and bitou bush (*Chrysanthemoides monilifera*) in Queensland, and to Leucaena (*Leucaena leucocephala*) within forest on reserves on islands.

The 25 introduced weeds identified as having the most impact in Australia's forests in nature conservation reserves over the period 2011–16 are listed in Table 3.5. Eleven of these 25 weeds are included on the national list of Weeds of National Significance[150], and nationally co-ordinated strategic plans have been developed for the management of each of these Weeds of National Significance. Three introduced grasses present in northern Australia and listed in Table 3.4 (gamba grass, mission grass and para grass) were also listed as a Key Threatening Process under the EPBC Act in 2009[151], and a

148 soe.environment.gov.au/science/soe/2011-report/8-biodiversity/3-pressures/3-9-invasive-species

149 www.environment.gov.au/biodiversity/threatened/threat-abatement-advices/invasive-pasture-grasses-introduction

150 www.environment.gov.au/biodiversity/invasive/weeds/weeds/lists/wons.html

151 www.environment.gov.au/biodiversity/threatened/threat-abatement-advices/invasive-pasture-grasses-introduction

Table 3.4: Scale/impact of damage by weeds in public forests

	ACT	NSW	NT	QLD	SA
Number of weed species with a scale/impact score of 1, 2 or 3					
Plantation	6	10	3	5[a]	19[b]
Multiple-use public native forest	n.d.[c]	n.d.[c]	26[d]	44	n.d.[e]
Nature conservation reserve	12	35	20	46	22
Average scale/impact score of the above species					
Plantation	2.5	1.4	1.0	2.0[a]	1.4[b]
Multiple-use public native forest	n.d.[c]	n.d.[c]	1.4[d]	1.4	n.d.[e]
Nature conservation reserve	1.8	1.7	1.4	1.2	1.4

n.d., no data.

a Response from HQPlantations.

b Plantations in South Australia have multiple permitted uses including recreational access, and may be on multiple-use public forest tenure.

c No separate response received for multiple-use public native forest in the Australian Capital Territory or New South Wales.

d Data for public native forests not in nature conservation reserves (there are no multiple-use public native forests in the Northern Territory).

e No separate response received for multiple-use forest in South Australia.

Notes:

Species numbers, scale/impact scores and tenures are as reported by jurisdictions and agencies. The rating system is explained in Table 3.1. Data were not received from Tasmania or Western Australia. Values shown are the total number of weed species reported with a scale/impact score of 1, 2 or 3, and the average scale/impact score of those species.

This table, together with other data for Indicator 3.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

Table 3.5: Scale/impact of damage to forests in reserves of the 25 weeds of highest scale/impact, by jurisdiction

Latin name	Common name	ACT	NSW	NT	QLD	SA
*Andropogon gayanus**	Gamba grass	–	–	3	2	–
*Asparagus asparagoides**	Bridal creeper	–	2	–	–	3
Baccharis halimifolia	Groundsel	–	2	–	1	–
Cenchros polystachios	Mission grass (perennial)	–	–	3	2	–
*Chrysanthemoides monilifera**	Boneseed	–	2	–	1	2
*Cytisus scoparius**	Scotch broom	1	2	–	–	2
Echium plantagineum	Paterson's curse	2	2	–	–	1
Genista monspessulana	Cape broom	–	–	–	–	2
Hyparrhenia hirta	Coolatai grass	–	2	–	2	–
Hypericum perforatum	St Johns wort	2	3	–	–	–
*Lantana camara**	Lantana	–	3	1	3	–
Leucaena leucocephala	Coffee bush	–	–	1	2[M] 1[I]	–
*Lycium ferocissimum**	African boxthorn	–	2	–	1	2
*Nassella trichotoma**	Serrated tussock	2	2	–	–	–
Opuntia spp*	Prickly pear	–	3	–	–	1
Pinus spp	Pines	–	2	–	1	1
Rosa rubiginosa	Sweet briar	1	2	–		–
*Rubus anglocandicans / R. fruticosus**	Blackberry	–	3	–	1	2
Rubus spp	Briar	3	–	–	–	–
Salix spp*.	Willows	–	2	–	–	2
Sporobolus spp.	Giants rat's tail grass	–	1	–	2	1
Themeda quadrivalvis	Grader grass	–	–	1	2	–
*Ulex europaeus**	Gorse	–	1	–	–	2
Urochloa mutica	Para grass	–	-	2	1	–
Xanthium occidentale	Noogoora burr	–	2	2	–	–

*, Weeds of National Significance; I, island populations; M, mainland populations.

Notes:

Numerical values show scale/level of impact, and cell shading shows extent of control (see Table 3.1).

Species listed are the weed species (or taxa, or taxa groups) ranked highest by the sum of their scale/impact scores across the five responding jurisdictions.

Source: data and assessment from states and territories. Data were not received from Tasmania, Victoria or Western Australia.

This table, together with other data for Indicator 3.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

Threat Abatement Plan has been prepared (Commonwealth of Australia 2012)[152].

Management to reduce the impact on forests of established weeds is usually coordinated regionally through Natural Resource Management regions, and funded through competitive grants such as those awarded through the Caring for our Country program[153]. For example, African boxthorn was added to the list of Weeds of National Significance in 2012, and a large control program for this species in the Yorke Peninsula in South Australia was conducted using aerially applied granular herbicide.

For established weeds, priority is given to preventing spread into areas that are currently largely free of the weed. An example of this has been the response to the first detection of buffel grass (*Cenchrus ciliaris*) in Victoria in 2014. Delimiting surveys, treatment of known infestations and public awareness campaigns have been implemented in response to the detection (James et al. 2016) to prevent the establishment of buffel grass in north-western Victoria where it would threaten mallee ecological communities.

For potentially invasive species that have not become widely established, eradication may be feasible. The National Four Tropical Weeds Eradication Program in Queensland and NSW is an example[154]. This eradication program commenced in 2001 and targets five species (*Limnocharis flava*, *Mikania micrantha* and three *Miconia* species) in Queensland and NSW that are invasive in waterways and rainforest. Surveillance and monitoring of known infestations has intensified since 2010, and the detection rate of mature plants has declined from 2.5 plants per 100 hectares searched in 2010, to 0.6 plants per 100 hectares searched in 2016 (Jeffrey and Brooks 2016).

Climatic events and climate change

Drought

There were no damaging drought events reported for the period 2011–16.

Areas of the northern jarrah forests that suffered dieback and mortality following the severe drought in 2009–10 showed good recovery four years later (Matusick et al. 2016). In the 1–2 years following the drought event, a higher proportion of *Eucalyptus marginata* than *Corymbia calophylla* had died or were showing advanced dieback (Ruthrof et al. 2015). However, four years after the event, a combination of seedling regeneration and resprouting from surviving, dieback-affected trees resulted in the affected areas having a similar species composition to that prior to the drought (Matusick et al. 2016) although forest structure was greatly altered.

Wind and storm damage

Tropical cyclone Marcia (February 2015) caused extensive damage to 12 thousand hectares of mid-rotation southern pine plantations in the Byfield area, central Queensland (Figure 3.4). Approximately 600 thousand tonnes of logs were salvaged from affected plantations in the 18 months after the cyclone, and some were exported, primarily to China[155]. Native forest in the Byfield National Park and in the Shoalwater Bay Training Area also suffered severe wind damage, particularly on Townshend Island where trees were completely defoliated[156].

Cyclone Yasi caused extensive and severe damage to forests in the Mission Beach–Tully area in February 2011. Data from reconnaissance flights conducted by the Queensland Parks and Wildlife Service in 2011 and 2013 (Holloway 2013) showed that most forest communities had recovered well, but there were four communities experiencing longer-term consequences.

- Canopy damage to open eucalypt forests fringing rainforests resulted in rainforest species invading the understorey, making it more difficult to conduct the prescribed burns needed to maintain eucalypt forest.
- Patches of lowland rainforests have been extensively colonised by native *Calamus* (lawyer cane) and exotic *Rubus* species.
- There has been little regeneration in melaleuca woodlands in swales behind beaches that experienced extensive blow-down but were not subsequently burnt.
- Lastly, mangrove communities in riverine estuaries suffered extensive post-cyclone mortality, possibly as the result of inundation beyond normal tolerances during storm surges.

[152] www.environment.gov.au/system/files/pages/99dfad7e-9feb-4da1-826b-fdf5740ffa5e/files/northern-australia-introduced-grasses.pdf

[153] The Caring for our Country program was combined with the National Landcare Program in 2013. www.nrm.gov.au/news-and-resources/resources/previous-programmes

[154] www.daf.qld.gov.au/business-priorities/plants/weeds-pest-animals-ants/weeds/four-tropical-weeds-eradication-program

[155] *Queensland Times* 27 June 2017.

[156] www.bom.gov.au/cyclone/history/marcia.shtml#winddmg

CRITERION 3

3.1a

Figure 3.4: Wind-damaged pine plantation at Byfield, Queensland, following Cyclone Marcia

Climate change

Australia is predicted to experience warmer temperatures, altered rainfall patterns, more severe droughts, more intense rain events and more heatwaves over the course of the 21st century (CSIRO and Bureau of Meteorology 2015). The long-term consequences for Australia's forests of these predicted changes in climate is yet to be understood, but monitoring of and research on responses to individual climate events or changes may provide some early indications.

The period 2011–16 continued the trend of increasing mean annual temperatures for Australia, which commenced around 1950 (Figure 3.5). Each year between 2013 and 2016 set a new record for mean annual temperature, and heatwave conditions occurred on several occasions, most notably during January 2013, which was Australia's warmest month on record (Bureau of Meteorology 2014). Measurements made at several flux sites operated through the Terrestrial Ecosystem Research Network[157] (Figure 3.6) tracked the responses of the main forest ecosystems in southern Australia during this heatwave (Van Gorsel et al. 2016). The measurements showed that forests at all the sites were resilient to the heatwave, although the water-limited woodland sites became net sources of CO_2 during the heatwave event.

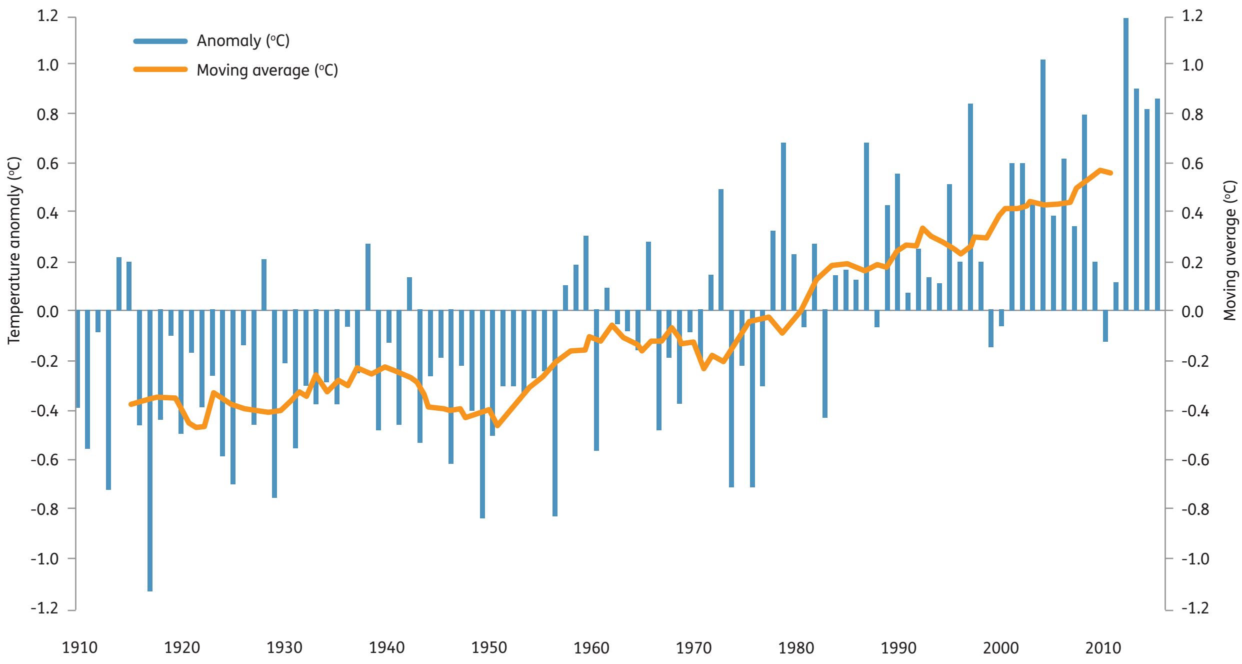
Generally, predictions of the changes in productivity and vulnerability of Australia's forests under predicted future climates have, to date, relied on predictions from process-based models (e.g. Battaglia et al. 2009). More recently, analysis of data from forest inventory plots with a long-term history of measurement has found that the maximum productivity of eucalypt native forests on mesic (non-water-limited) sites occurred at cooler sites, suggesting that warming temperatures would reduce productivity of these forests (Bowman et al. 2014). This is supported by early results from three flux sites in tall, wet eucalypt forests (Warra in southern Tasmania, Wallaby Creek in the Victorian Highlands and Tumbarumba in southern NSW), which have showed a strong latitudinal gradient (north to south) of declining productivity with increasing temperatures[158].

The effects of the prolonged drought experienced in southern Australia between 1996 and 2010 (the Millennium Drought) were reported in SOFR 2013. That drought caused widespread mortality and secondary insect attack in both eucalypt native forests and pine plantations. In the northern jarrah forests of south-western Western Australia, dieback and mortality was greater in jarrah (*Eucalyptus marginata*) than in marri (*Corymbia calophylla*), suggesting that marri might replace jarrah if such events were to become more frequent (Ruthrof et al. 2015). However, resprouting and regeneration during 2011–16 resulted in no shift in species composition although forest structure was greatly altered (Matusick et al. 2016). In other areas, species composition has

[157] www.tern.org.au/

[158] Tim Wardlaw, University of Tasmania, unpublished data.

Figure 3.5: Australia's mean annual temperature anomaly from 1910–2016



Bars show the temperature anomaly: the difference between each annual average temperature and the 1961–90 average temperature.
Solid line shows 11-year moving average of the temperature anomaly.
Data source: www.bom.gov.au/climate/current/annual/aus/2016/#tabs=Temperature (see Bureau of Meteorology 2017).

The data used to create this figure, together with other data for Indicator 3.1a, are available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

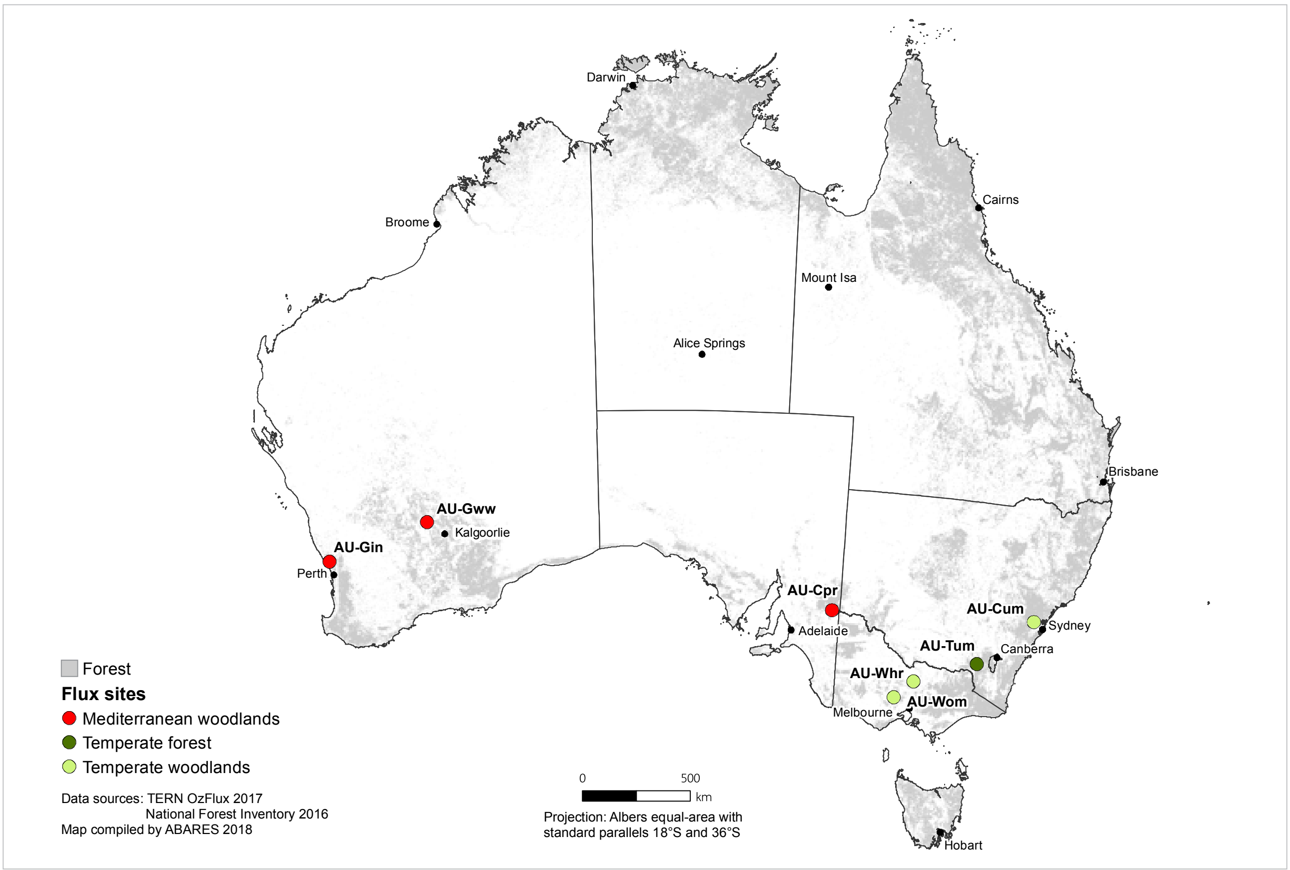
changed in response to prolonged lower rainfall. Sustained lower rainfall conditions between 1970–1996 in south-eastern Australia resulted in increased dominance of more drought-tolerant species, notably *Allocasuarina* spp. in some eucalypt woodlands (Zeeman et al. 2014), with the intense drought between 1996–2010 amplifying the shift towards *Allocasuarina* spp.

There is also a direct effect of increased atmospheric CO_2 concentration on forests. The commissioning in 2012 of Australia's EucFACE facility[159] in a mature forest red gum (*E. tereticornis*) woodland at Cumberland Plains, New South Wales, allowed this to be studied. Initial results are that the forest shows greater water-use efficiency under elevated CO_2, but consequential productivity gains are not realised because of phosphorus limitation. Different patterns of loss to herbivory are also expected, as the abundance of several arthropod groups declined under elevated CO_2 conditions.

The sustained shift in the Australian climate since 1970 has prompted work to develop adaptation strategies to help mitigate adverse effects. Many adaptation options are based on stronger deployment of existing forest management practices. Interventionist management in protected areas would require societal and policy shifts (Keenan and Nitschke 2016). The AdaptNRM initiative[160] makes extensive use of tools to predict vulnerabilities in future climates at fine spatial scales, and focuses on restoration plantings to assist natural migration as local climates change (CSIRO and Bureau of Meteorology 2015). Coupling the prediction of future climate with species distribution records can map where the climatic range of a species may occur in the future (Williams et al. 2015), allowing planning of strategic approaches such as vegetation corridors to assist migration (Prober et al. 2015b). An alternative approach is active translocation of selected genotypes of species to areas that match future climates, and eucalypts are a particular current focus for this approach (Prober et al. 2015a; Prober et al. 2016; Harrison et al. 2017).

159 www.westernsydney.edu.au/hawkesburyinstitute/facilities/EucFACE
160 adaptnrm.csiro.au/

Figure 3.6: Flux measurement sites in the TERN OzFlux facility that observed forest function during the 2013 heatwave



Red dots, sites in Mediterranean woodlands; light green dots, sites in temperate woodlands; dark green dot, site in temperate forest. Forest types as described by OzFlux. Map reproduced from Van Gorsel et al. (2016).

A higher resolution version of this map, together with other maps for Indicator 3.1a, is available via www.doi.org/10.25814/5be3bc4321162

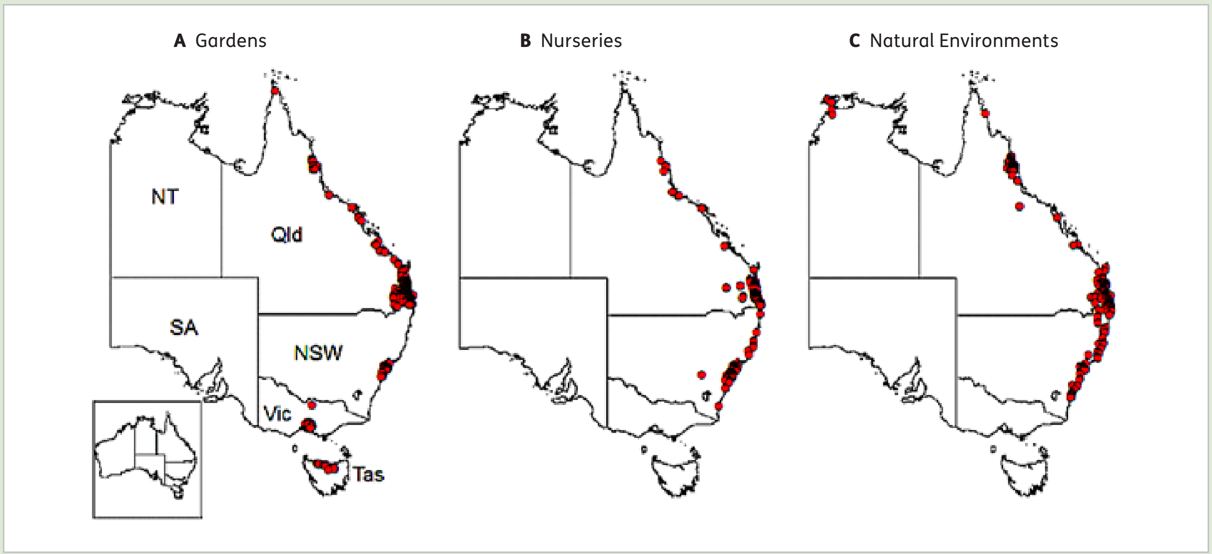
Case study 3.1: Myrtle rust

Myrtle rust (*Austropuccinia psidii*), a strain of guava or eucalypt rust, was detected for the first time in Australia in April 2010 on the central coast of New South Wales (Carnegie et al. 2010). After an initial emergency response, eradication of the rust was determined to be not technically feasible and a decision to transition to management was made in December 2010. SOFR 2013 detailed the spread and effects of myrtle rust in the first 1–2 years after its arrival in Australia. In the five years since, the spread of myrtle rust along the eastern seaboard has stabilised, but new infections have been detected in Tasmania and the Northern Territory (Figure 3.7). The myrtle rust detections in Tasmania, like those in Victoria, currently remain confined to cultivated plants in gardens and nurseries.

When myrtle rust first arrived in Australia, there was considerable uncertainty as to its identity and relatedness to *Puccinia psidii* in South America (Carnegie and Lidbetter 2012). Knowing the identity of a rust is fundamentally important, as it underpins biosecurity measures, provides stable input for breeding programs for rust resistance, and allows effective prioritisation of management efforts. It is now known that the Australian strain of myrtle rust is the same as that found in South America, and is unrelated to other species of *Puccinia*. A new genus, *Austropuccinia*, was subsequently created to accommodate the species (Beenken 2017). A single strain of *A. psidii* is present in Australia, and isolates taken from a range of infected sites are genetically identical (Sandhu et al. 2016). The Australian strain is the same as one present in Hawaii, China, New Caledonia and Indonesia (Machado et al. 2015). This strain has only recently been identified in South America (Granados et al. 2017) and it remains unclear whether it originates from there.

Research and monitoring is measuring the impact that myrtle rust has on populations of individual species in natural ecosystems, and on the composition of forest communities. Preliminary determinations have been made to list two widespread species, *Rhodamnia rubescens* and *Rhodomyrtus psidioides*, as Critically Endangered under the New South Wales *Biodiversity Conservation Act 2016* because of the rapid impacts and ongoing threat from myrtle rust, which has caused large reductions in their population size[161]. Both species were common understorey shrubs or small trees in rainforests and wet sclerophyll forests along the coastal hinterland extending from central New South Wales to southern Queensland. Carnegie et al. (2016) found that myrtle rust was present in all 43 sampled stands of *Rhodamnia rubescens* and all 18 sampled stands of *Rhodomyrtus psidioides*, and that healthy *Rhodamnia rubescens* were killed in less than 18 months after exposure to myrtle rust. In two stands surveyed, all *Rhodomyrtus psidiodes* individuals had died (Figure 3.8).

Figure 3.7: Known infections of *Austropuccinia psidii* in Australia as at June 2016



Maps reproduced from Berthon et al. (2018) with permission.

Continued

161 www.environment.nsw.gov.au/resources/threatenedspecies/determinations/PDRhodrubesCR.pdf; www.environment.nsw.gov.au/resources/threatenedspecies/determinations/PDRhodpsidCR.pdf

Continues

Myrtle rust can also alter the composition and structure of the plant communities more broadly, with extensive damage to several rust-infested subtropical wet sclerophyll forests that are rich in species of Myrtaceae (Pegg et al. 2017). Rapid loss of the most rust-susceptible species of the Myrtaceae that dominate the mid- and understorey layer creates gaps that are being filled by less-susceptible species, including noxious weeds such as lantana (Figure 3.9).

Singh et al. (2016) found that 7.8% of Australia's hardwood plantation estate was located in areas climatically suitable for myrtle rust. However, in contrast with the severe disease seen in natural forests, myrtle rust currently has minimal impact in eucalypt plantations. Carnegie (2015) surveyed 55 plantations less than 2 years old in regions climatically suited to the disease. Myrtle rust was found in less than 10% of plantations, and only in those that were adjacent to rust-affected native forests. Only a small proportion of trees (<1%) showed disease symptoms, and disease did not persist once the plantations grew beyond three years of age. The strain of *Austropuccinia psidii* present in Australia can cause severe disease in many eucalypt species when artificially inoculated in greenhouse environments, but it appears that it has limited capacity to cause disease by natural infection in eucalypt plantations (Carnegie and Lidbetter 2012; Morin et al. 2012; Potts et al. 2016). The evidence gathered in the first seven years after the introduction of myrtle rust into Australia indicates a greater threat to conservation values than to wood production in plantations. This conclusion relies on maintaining strong biosecurity measures to reduce the risk of other strains of *A. psidii* becoming established in Australia.

A better understanding, and prioritisation, of the species and communities most at risk from the current strain of myrtle rust will also be required to manage the threat to conservation values. There is currently information on the susceptibility of approximately one-sixth of the 2126 species of the Myrtaceae family in Australia. A total of 23 high-priority species were identified amongst the 1285 species of Myrtaceae that occur in areas predicted to be climatically suitable for myrtle rust (Berthon et al. 2018).

Figure 3.8: Dead *Rhodomyrtus psidioides* in natural forest stand in north coastal New South Wales infected with myrtle rust

Figure 3.9: Extensive branch dieback in susceptible species of the Myrtaceae in the mid- and understorey layers of a rust-infected subtropical wet sclerophyll forest at Tallebudgera Valley, Queensland

Names of species indicate dieback of individuals of that species.

Case study 3.2: Mangrove dieback

Mangrove forests along the southern coast of the Gulf of Carpentaria experienced a sudden and extensive dieback event in 2015. An area of between 7 thousand and 10 thousand hectares along a 700-km stretch of coastline was affected, which is among the largest mass-death events ever reported for mangrove ecosystems. The two common mangrove species in the Gulf, *Rhizophora stylosa* and *Avicennia marina*, were both affected.

Because of its remoteness, reports of the dieback event only began to emerge in early 2016. Three aerial and field surveys in June, October and November 2016, combined with analysis and validation of satellite imagery, mapped affected areas and described the patterns of damage (Duke et al. 2017). Dieback occurred in 6% of the mangrove cover from Roper River estuary in the Northern Territory, east to Karumba in Queensland, but was most severe in those catchments draining into the central section of the southern coastline of the Gulf. In the worst-affected area, the Robinson River catchment, 26% of the mangrove cover was lost.

There was a strong spatial patterning of dieback. Mangroves occupying the highest points of the intertidal zone were most affected. In areas with less extensive dieback, narrow bands of dieback occurred in mangroves fringing saltmarshes along the inland edge of the intertidal zone (Figure 3.10, left-hand panel). In areas with a high level of impact, dieback affected mangroves throughout the intertidal zone (Figure 3.10, right-hand panel). Mangroves lining estuaries were less affected.

Visual symptoms were first noticed by residents of the Karumba area (at the south-eastern corner of the Gulf) at the end of the 2015 dry season, in mid to late November 2015 (Duke et al. 2017). However, analysis of satellite imagery indicated anomalous reductions in greenness of mangrove areas began appearing at the beginning of the dry season, around March 2015 (Harris et al. 2017). The 2015 dry season along the southern coast of the Gulf was characterised by a period of unusually low sea levels during an intense El Niño event, coupled with the co-occurrence of several climatic anomalies. This combination of conditions is considered to have resulted in hypersaline conditions in the mangrove ecosystem.

Similar conditions were recorded at around the same time and associated with a separate small dieback event at Mangrove Bay near Ningaloo Reef in Western Australia. Regular monitoring of the Mangrove Bay site since 2001 has shown two dieback events over the 15-year period: the 2015–2016 event and an earlier event in 2002–2003 (Lovelock et al. 2017). Both of these events coincided with periodic minima in sea levels and maxima in soil-pore salinity (Figure 3.11).

Proving the mechanism that links climate anomalies and mangrove dieback would allow consideration of how to reduce the risk of such dieback events recurring.

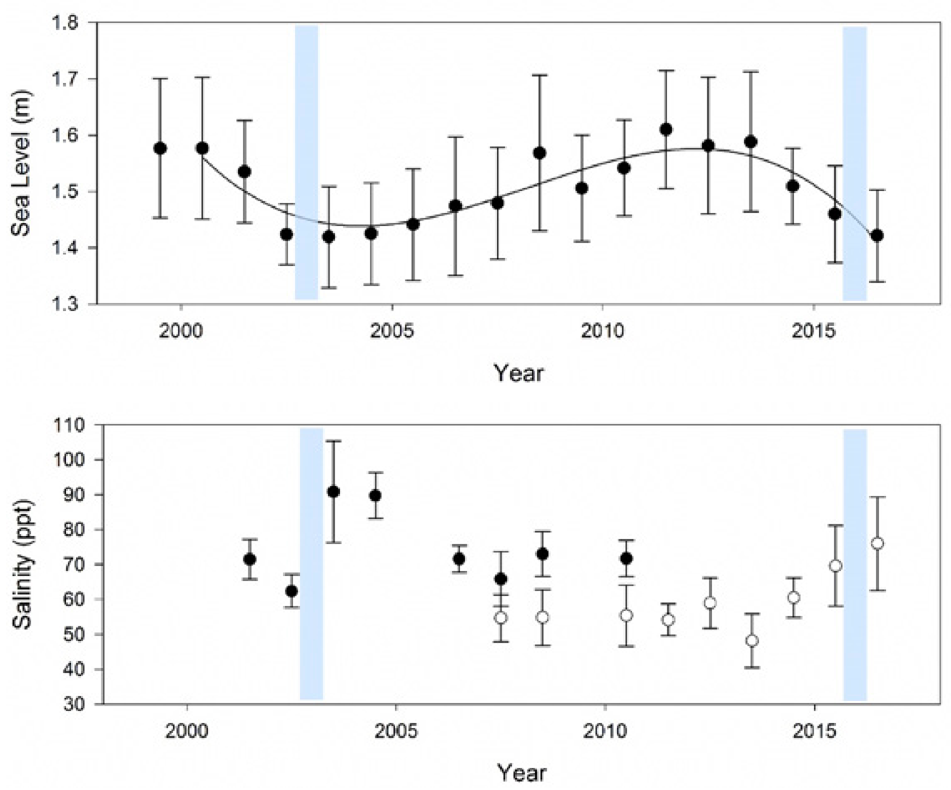
Figure 3.10: Aerial views of mangrove dieback in the Gulf of Carpentaria

Left panel, areas with dieback restricted to the inland edge of the intertidal zone; right panel, areas with a high level of dieback throughout the intertidal zone.

Continued

Continues

Figure 3.11: Sea level and mean soil-pore salinity at Mangrove Bay, Western Australia



Blue bars indicate the timing of mangrove dieback events; black and white circles represent two different monitoring campaigns; error bars are standard deviations; ppt, parts per thousand. Reproduced with permission from Lovelock et al. (2017).

Indicator 3.1b

Area of forest burnt by planned and unplanned fire

Rationale

This indicator is used to provide an understanding of the impact of fire on forests through the reporting of planned and unplanned fire. Fire is an important part of many forest ecosystems in Australia and may have either positive or negative impacts on forest health and vitality.

Key points

- The fire regime (the frequency, seasonality and intensity of burning of an area over a period of time) is a major determinant of many aspects of Australia's forest ecosystems.
  - Unplanned fires (bushfires) occur naturally in many forest ecosystems, or can be lit accidentally or deliberately.
  - Planned fire is used as a forest management tool in fire-adapted forest types for forest regeneration, to promote regeneration after harvest, to maintain forest health and ecological processes, and to reduce fuel loads and thereby increase the ability to manage bushfires and protect vulnerable communities.
- This indicator presents separately the cumulative area of fire in forest in the period 2011–12 to 2015–16, calculated as the sum of the individual forest fire areas for these five years; and the total area of forest burnt once or more over the period 2011–16, in which areas burnt multiple times, that is, in more than one year of this period, are reported only once.
- The area of fire in Australia's forests was 26.9 million hectares in 2011–12, 27.4 million hectares in 2012–13, 15.5 million hectares in 2013–14, 21.2 million hectares in 2014–15 and 14.9 million hectares in 2015–16. The cumulative area of fire in forest across this five-year period was 106 million hectares.
  - The largest cumulative areas of fire in forest over this five-year period were in Queensland (50 million hectares) and the Northern Territory (46 million hectares).
  - The cumulative area of fire in forest of 106 million hectares comprised 73 million hectares (69%) of unplanned fire and 33 million hectares (31%) of planned fire. A larger proportion of the forest area was burnt by planned fire in Western Australia than in other state or territory (other than the ACT, for which no unplanned forest fire was reported).
  - The cumulative area of fire in forest over the five-year period 2011–12 to 2015–16 includes large areas of forest, especially in northern Australia, that were burnt more than once over this period.
- When areas of forest burnt in multiple years are allowed for, the total area of forest burnt one or more times during the period 2011–12 to 2015–16 was 55 million hectares (41% of Australia's total forest area). The balance, 59% of Australia's forest area, did not experience fire in this period.
  - Tasmania (6%) and South Australia (6%) had the lowest proportions of forest area burnt one or more times during this period, while the Northern Territory (84%) had the highest proportion.
  - Of the total area of forest burnt during this five-year period, 29 million hectares were burnt multiple times, including 15 million hectares in the Northern Territory and 13 million hectares in Queensland.
- Most fires in southern Australia occurred in nature conservation reserves, whereas most fires in northern Australia occurred in leasehold or private forest.
- The area of fire in Australia's forests in each year from 2011–12 to 2015–16 was determined using spatial data provided by the states and territories, derived in turn from a combination of ground-based and remotely sensed sources. Fires were allocated as planned or unplanned by state and territory agencies, or according to state and territory agencies guidelines.
  - The new data and approaches have also allowed a more accurate view of the area of forest burnt in more than one year of the five-year reporting period.
  - However, changes in data sources, and improvements in data collection and reporting, mean that the annual forest fire areas reported in SOFR 2018 (particularly for northern Australia) cannot be compared to the areas reported in previous SOFRs.

This indicator reports on the area of forest burnt by planned or unplanned fires in the five years of the period 2011–12 to 2015–16. Monthly fire data are collated and reported annually, by financial year. The data are then reported both as the cumulative area of forest fire in the five-year period, and as the total area of forest burnt during the period.

The *cumulative area of fire in forest* in the five-year period is the sum of the annual forest fire area totals. Some areas of forest burnt in multiple years of the reporting period, and thus over a five-year period the cumulative area of fire in forest substantially exceeds the total area of forest that experienced fire. Over many years, the cumulative area of fire in forest would exceed the total area of forest in a region.

For SOFR 2018, this indicator therefore also reports the *total area of forest burnt* one or more times during the period, a metric that counts an area of burnt forest only once no matter how many times it burns in a reporting period. The total area of forest burnt can never exceed the total area of forest in a region.

Policy and coordination of fire management in Australia

The *National Bushfire Management Policy Statement for Forests and Rangelands* (FFMG 2014) outlines Australian, state and territory government objectives and policies for the management of landscape-level fire in Australia's forests and rangelands. The statement was developed by the Forest Fire Management Group, a national body within the Australian Government ministerial council structure, which has the role of providing information to governments on major forest fire-related issues, policies and practices affecting land management.

The Australasian Fire and Emergencies Authorities Council is the national peak organisation that provides advice on a range of policies and standards. Research on bushfires is performed by a number of organisations, including the Bushfire and Natural Hazards Cooperative Research Centre[162], which brings together experts from universities, fire and emergency management agencies, CSIRO, and other Australian, state and territory government organisations for long-term programs of collaborative research.

Fire in Australian forests

Fire is an intrinsic part of Australia's landscape, and bushfires have been an important factor in Australian ecosystems for millions of years. Much of Australia's native vegetation has evolved to be tolerant of fire, and many plant species require fire to regenerate, with adaptations that promote the spread of fire. The fire regime (the frequency, seasonality and intensity of burning of an area over a period of time) is a major determinant of many aspects of Australia's forest ecosystems.

Indigenous Australians have long used fire as a land-management tool. Planned fire is currently used by land managers to manage vegetation, and to protect properties from uncontrolled bushfire by reducing fuel loads.

The main factors required for propagation of fire are the presence of fuel, oxygen and an ignition source. Fires can originate from human activity and from natural causes, with lightning nearly always the natural source of fire. Fire intensity and the speed at which a fire spreads depend on fuel load and arrangement, fuel moisture, prevailing temperature, wind speed and slope angle. The most intense fires occur when temperatures are high, humidity is low, winds are strong, and the arrangement of fuel allows rapid propagation. Box 3.1 summarises the occurrence of bushfires in Australia. Detailed geographic descriptions of Australia's fire regimes have also been published (Murphy et al. 2013).

Planned and unplanned fires

Planned fires are fires lit in accordance with a fire management plan or planned burning program for fuel reduction, ecological or silvicultural purposes, or as part of bushfire control efforts; they are also called 'prescribed burns' or sometimes 'fuel reduction burns'.

Unplanned fires are fires that have started naturally (usually by lightning), accidentally or deliberately (such as by arson) but not as part of a program of prescribed burning; they are also called bushfires or wildfires.

Planned fires are scheduled for times of the year when temperature, humidity and fuel loads enable fire control, yet still allow achievement of burning targets. Planned fires can become unplanned fires if they escape containment lines and become uncontrolled.

Unplanned fires

The extent and intensity of unplanned fires, or bushfires, vary with latitude and seasonal rainfall (see Box 3.1), and the drivers of fire are substantially different across the continent:

- The incidence of fire in northern Australia is essentially limited by fuel loads, and low-intensity fires burn over large areas in each dry season.
- The incidence of fire in southern Australia is essentially limited by fuel dryness, and some areas of south-eastern and south-western Australia are prone to severe bushfires: hot, dry and windy summer conditions, especially following periods of drought, lead to fires in eucalypt forest that are often very intense and difficult to control. Such bushfires can result in the loss of human life, and destroy assets such as buildings, fences, bridges and powerlines as well as standing stocks of wood (native forest and plantations). They can also have a significant impact on ecological values, and affect water supplies.
- Bushfires are rare in the tropical rainforests of northern Australia, and are occasional in the subtropical, temperate and cool-temperate rainforests of southern Australia. However, during prolonged droughts even these forests can be damaged by fire entering from adjacent grasslands or eucalypt forests.

---

[162] www.bnhcrc.com.au/

Recovery by epicormic shoots after bushfire, Erica, Victoria.

Climate change and weather pattern variability are among the key factors that are predicted to affect the future occurrence and severity of bushfires. Projected increases in summer temperatures and declines in rainfall are predicted to exacerbate the risk of fire and increase the challenges associated with fire management.

More frequent and intense bushfires could also increase the incidence and severity of certain pests, diseases and weeds. For example, populations of bark beetles (*Ips* spp.) may increase in response to a higher availability of fire-damaged (dead, dying or stressed) trees that can be colonised. Furthermore, forests affected by pests, diseases and weeds may become more vulnerable to bushfires as a result of increases in fuel loads due to tree mortality (Singh et al. 2010). Indicator 3.1a provides more information on pests, diseases and weeds affecting forest health.

Planned burning

Planned or prescribed burning is the deliberate use of fire to achieve particular management objectives, and is an important management tool on both public and private land. Case study 3.3 on the *National Burning Project: Prescribed Burning Guidelines and Frameworks* describes how the principles underpinning planned burns were articulated and put into practice. Management objectives for planned burns can include reducing the levels of flammable fuels (fuel reduction burning), protection and enhancement of biodiversity in fire-adapted ecosystems, and promoting regeneration after wood harvesting; not all of these objectives are necessarily served equally by the same burn frequency or intensity.

Planned burning does not prevent unplanned fires. However, in some ecological communities previous planned burning can reduce the intensity of unplanned fires, aid control efforts by widening the range of weather and other conditions under which an unplanned fire may be controlled, and potentially allow firefighters to break the run of large fires (McCaw 2013). This can lead to a reduced area of unplanned fire, and a lower impact.

In the tropical savannas of northern Australia, woodland forests with a grassy understorey are part of a patchy landscape mosaic. Rapid growth occurs in the wet season, and this is converted to fuel during the dry season, with an increased risk of high-intensity fires late in the dry season. Up to 50% of some northern Australian landscapes may be burnt in a single year, and most areas burn at least once every three years. Land managers in northern savannas are increasingly employing traditional, early dry-season burning techniques, where burning occurs at low intensity and in a patchy mosaic, so as to reduce the risk of extensive, high-intensity late-season fire and consequential carbon dioxide emissions. Complete suppression of fire, on the other hand, can lead to increased tree and shrub invasion, which may adversely affect biodiversity and habitat values and reduce pastoral productivity, and can also lead to cumulative increases in fuel loads and an associated increased fire risk. Case study 5.3 in Indicator 5.1a on the Western Arnhem Land Fire Abatement project describes one such planned burning program in northern Australia.

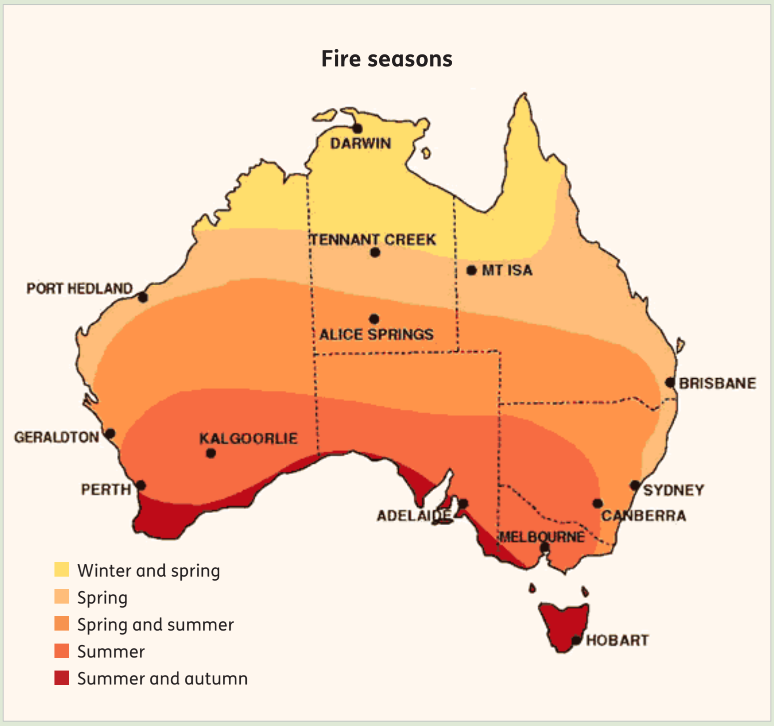
Box 3.1: Where and when do bushfires occur?

The Australian climate is generally hot, dry and prone to drought. At any time of the year, some parts of Australia are prone to bushfire, with the widely varied fire seasons reflecting the continent's different weather patterns (Figure 3.12). For most of south-eastern and south-western Australia, the fire danger period is summer and autumn. For areas in northern New South Wales and southern Queensland, peak risk usually occurs in spring and early summer. Most fires in the Northern Territory, Queensland and northern Western Australia are in the monsoonal dry season, which coincides with the southern winter and spring.

Bushfires in eucalypt forests tend to occur when fuel loads have dried out, usually following periods of low rainfall and high temperatures. In grasslands, however, and in woodlands with a grassy understorey, fires frequently occur after good periods of rainfall which result in abundant growth that dries out in subsequent hot weather.

The potential for extreme fire weather varies greatly throughout Australia, both in frequency and severity. The greatest extent of fire is in the Northern Territory and northern areas of Western Australia and Queensland, where there are large, sparsely settled areas with few roads, and where dry-season fires started by lightning or other causes burn large areas. Most loss of life and economic damage occurs in the areas around cities and regional towns in south-eastern and south-western Australia, where homes are commonly in close proximity to flammable vegetation.

Figure 3.12: Distribution of bushfire seasonality across Australia



Map source: Bureau of Meteorology (www.bom.gov.au/weather-services/bushfire/about-bushfire-weather.shtml); see also Luke and MacArthur (1978)

Source: Adapted text from Geoscience Australia (www.ga.gov.au/scientific-topics/hazards/bushfire)

The EcoFire project in the Kimberley, Western Australia (Legge et al. 2011), a partnership between landholders, private conservation organisations and government agencies, is also working to use planned early dry-season fires to minimise the area of extensive, intense, uncontrolled and unplanned mid-to-late dry season fires and thereby improve habitat quality and the proportion of long-unburnt vegetation across the landscape.

Prescribed burning for fuel reduction needs to bring together contrasting expectations: the public expectation that fuel hazards will be managed to protect life and property, and concerns that inappropriate burning will affect biodiversity and other values (McCaw 2013). Prescribed burning regimes will have undue impacts if burning is more frequent, intense or uniform than the natural fire regime for a particular ecological community, or if it occurs at times of the year when natural processes are adversely affected. Area targets for fuel-reduction burning can be designed to balance community safety and asset protection with protection of ecological values and maintenance of ecological processes. Whether or not area targets are achieved depends on weather and fuel conditions: unseasonably warm, dry or windy weather can make prescribed burning too risky, and unseasonably cold or wet weather can make prescribed burning ineffective.

Case study 3.3: National Burning Project: Prescribed Burning Guidelines and Frameworks

Prescribed burning (also referred to as 'planned burning') is defined by the Australasian Fire and Emergency Service Authorities Council (AFAC) as

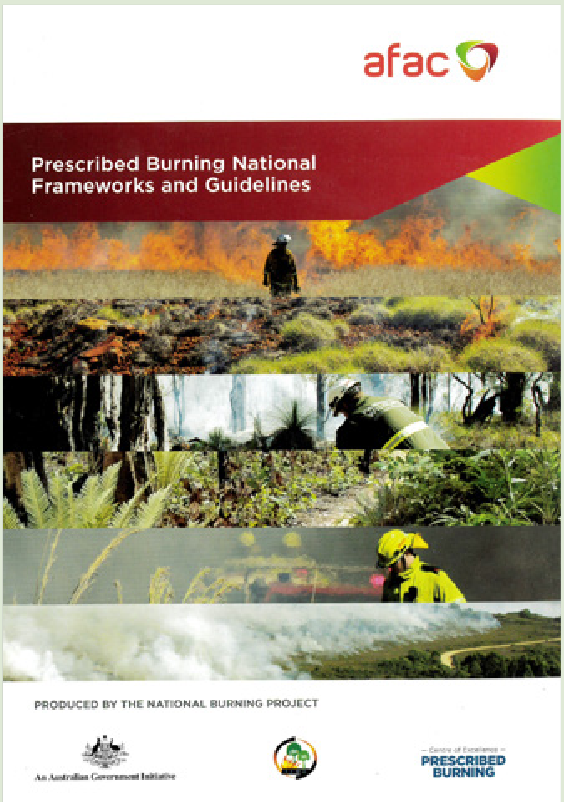
> *"The controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity and rate of spread required to attain planned resource management objectives"* (AFAC 2012).

Fire managers use prescribed burning as an effective way to manage fuel accumulation, maintain ecosystem processes and achieve silvicultural outcomes in forests and woodlands. However, some people and community organisations have concerns for the effects on flora and fauna, visual amenity, air quality and other values. The risk to people and assets from fires escaping from planned burning areas is also an issue.

For these and other reasons, many enquiries over the years (for example, House of Representatives Select Committee 2003; Ellis et al. 2004) have recommended the development of nationally agreed principles and practices for prescribed burning. AFAC and the Forest Fire Management Group (FFMG) initiated the National Burning Project to address those recommendations (Sparkes 2017). AFAC is the national council for fire and emergency services; FFMG is a committee of Australian and New Zealand land management agencies and representatives from research, education and the forest industry that provides a forum and centre of expertise on forest fire management and control. The National Burning Project was funded by AFAC members and the Commonwealth Government National Bushfire Mitigation Program.

The aim of the National Burning Project was to develop guidelines and frameworks for a more holistic and consistent approach to prescribed burning. The project started in 2011 and, by completion in 2017, had delivered a suite of policy and procedural documents that addresses all aspects of prescribed burning. These documents, all available through the Australian Disaster Resilience Knowledge Hub[163], include:

- An *Overview of Prescribed Burning in Australasia*.
- A *National Position on Prescribed Burning*: this confirms 10 principles for prescribed burning, including that prescribed burning is used to reduce the quantity, extent and connectivity of fuel hazards, and that protection of human life is the highest priority in prescribed burning operations.
- *National Guidelines for Prescribed Burning Strategic and Program Planning*: this lays down principles for strategic, program and operational planning.
- *Best Practice Principles for Prescribed Burning.*
- National risk management frameworks to address ecological, fuel management, smoke, greenhouse gas emissions and operational safety risks arising from prescribed burning.
- Training manuals for a range of prescribed burning competencies, from support roles to managing complex prescribed burns.
- A large number of case studies and reviews of science, best practice and capability.



AFAC *Prescribed Burning National Framework and Guidelines*, which presents the key documents of the National Burning Program.

163 knowledge.aidr.org.au/resources/national-prescribed-burning-guidelines-and-frameworks/

Determining the extent of fire in Australia's forests: data sources and analysis

Australia has no nationally coordinated approach to the systematic mapping and reporting of fire areas. For reporting in SOFR 2018, annual spatial coverages of fires for the period 2011–12 to 2015–16 were therefore sourced from each state and territory separately, either by direct provision by the state or territory or from the North Australia and Rangelands Fire Information (NAFI) website[164]. Most jurisdictions create their fire area dataset from multiple sources, including satellite imagery, aerial photography, aerial reconnaissance, and operational and on ground knowledge and measurement.

Meaningful datasets of fires or burnt areas in woodland forests, such as the savannas of northern Australia, can be derived from satellite-based platforms carrying Advanced Very High Resolution Radiometer (AVHRR[165]), Moderate-resolution Imaging Spectroradiometer (MODIS[166]) and Landsat ETM[167] sensors. The different satellites detect areas affected by fire in different ways (for example, through hot-spots, smoke plumes or vegetation changes), and combining the fire area data from different sensors gives a fire area statement that is larger than that from each satellite individually.

The extent and distribution of fire or burnt areas in open or closed forests, such as in the forests of southern Australia, is determined by combining satellite data with ground-based measurements and high-resolution aerial photography. Spatial data collated in this way were provided by the Australian Capital Territory, New South Wales, South Australia, Tasmania, Victoria and Western Australia. For these jurisdictions, each fire was allocated as either unplanned or planned by the jurisdiction that provided the data, as the seasonal distribution of planned and unplanned fires differs between jurisdictions.

Fire area provided by the Northern Territory and Queensland were derived solely from remote sensing. Fire area data provided by the Northern Territory were derived from the NAFI website, which combines MODIS satellite data with data from satellites carrying an AVHRR sensor, and also incorporates Landsat satellite data. Queensland agencies provided data from NAFI as well as Landsat data used in the Queensland Statewide Landcover and Trees Study program, with these two datasets being combined by ABARES.

For the Northern Territory and Queensland, the allocation of fires as unplanned or planned was based on their month of occurrence. Northern Territory fires occurring from January to July were allocated as planned fires, while those occurring from August to December were allocated as unplanned fires. Queensland fires occurring between January and June were allocated as planned fires, while those occurring between July and December were allocated as unplanned fires.

The data indicated that some areas had burnt more than once in any one financial year. In such situations, only the first fire in that year (whether planned or unplanned) was retained in the data. This approach had only a small (<2%) effect on total area figures.

The fire datasets for each jurisdiction were then intersected with the forest cover dataset (Indicator 1.1a) to produce forest fire statistics.

Large areas of northern Australia were reported as having burnt in multiple years of the five-year reporting period, (2011–12 to 2015–16). This indicator therefore reports separately the *cumulative area of fire in forest* (the sum of the five individual-year forest fire areas; this counts every time an area of forest was burnt in the five-year period) and the *total area of forest burnt* (in which a burnt area of forest is counted only once in the five-year period, even if it was burnt more than once in that period). SOFR 2008 and SOFR 2013 reported only the cumulative area of fire in forest in the five-year reporting period (the sum of the five individual-year areas).

Both the data sources and the methods used to derive area of forest fire for SOFR 2018 are different to those used for SOFR 2008 and SOFR 2013, and therefore the results cannot be directly compared between these reports. This is particularly so for Northern Territory, Queensland and northern Western Australia, where only the MODIS dataset was used for SOFR 2008 and SOFR 2013, compared to the wider range of datasets used for SOFR 2018. Furthermore, different algorithms and data resolutions were used in analysis of the fire datasets reported in SOFR 2018. Lastly, a larger and more accurate forest coverage was used for SOFR 2018, particularly in the Northern Territory (see Indicator 1.1a).

Area of forest fire

The national area of fire in forest in each year over the period 2011–12 to 2015–16, by jurisdiction, is shown in Figure 3.13, separately by planned and unplanned fire. Across the reporting period, the area of unplanned forest fire was highest for reporting years 2011–12 and 2012–13, these annual areas being more than twice the area burnt by unplanned fire in 2013–14 (Figure 3.13). In contrast, the annual area of planned forest fire remained relatively constant over the reporting period. Overall, these trends are driven by differences in fire areas between years in northern Australia.

The area of forest fire in each year over the period 2011–12 to 2015–16 is shown for each jurisdiction in Table 3.6, separately by planned and unplanned fire, as well as the cumulative total area of fire in forest in each jurisdiction for this five-year period. The data for Western Australia are shown separately for southern and northern Western Australia (south and north of the Tropic of Capricorn) due to differences in climate and fire management in these regions.

164 www.firenorth.org.au/nafi3/
165 noaasis.noaa.gov/NOAASIS/ml/avhrr.html
166 modis.gsfc.nasa.gov/
167 landsat.gsfc.nasa.gov/

Table 3.6: Area of forest fire, 2011–12 to 2015 16, by year and jurisdiction, separately for planned and unplanned fire ('000 hectares)

Jurisdiction	Forest fire area					Cumulative area of fire in forest, 2011–12 to 2015–16[a]	Proportion of cumulative area of fire in forest, 2011–12 to 2015–16
	2011–12	2012–13	2013–14	2014–15	2015–16		
Planned fire							
ACT	0	9	0	3	5	17	0.1%
NSW	75	221	125	122	248	791	2.4%
NT	3,810	1,969	2,475	3,059	1,853	13,166	40%
Qld	2,700	2,371	3,102	3,056	1,930	13,159	40%
SA	7	11	2	2	3	24	0.1%
Tas.	10	14	10	23	4	60	0.2%
Vic.	99	118	46	146	118	526	1.6%
WA	1,536	1,484	828	651	686	5,184	16%
southern WA[b]	96	35	80	139	155	504	1.5%
northern WA[c]	1,441	1,450	748	512	531	4,681	14%
Australia	**8,236**	**6,197**	**6,587**	**7,061**	**4,847**	**32,927**	**100%**
Unplanned fire							
ACT	0	0	0	0	0	0	0.0%
NSW	11	318	485	119	41	975	1.3%
NT	6,299	8,107	4,310	7,532	6,152	32,399	44%
Qld	11,940	12,360	3,088	6,082	3,273	36,743	50%
SA	6	28	221	8	16	279	0.4%
Tas.	3	51	7	6	80	147	0.2%
Vic.	2	136	318	28	14	498	0.7%
WA	363	153	467	398	457	1,837	2.5%
southern WA[b]	104	70	26	155	313	668	0.9%
northern WA[c]	259	83	441	243	143	1,169	1.6%
Australia	**18,623**	**21,154**	**8,896**	**14,174**	**10,032**	**72,880**	**100%**
All fire							
ACT	0	9	0	3	5	17	0.0%
NSW	85	540	610	241	289	1,766	1.7%
NT	10,109	10,076	6,784	10,591	8,004	45,565	43%
Qld	14,640	14,731	6,190	9,138	5,203	49,902	47%
SA	13	39	222	10	19	302	0.3%
Tas.	13	65	18	29	84	208	0.2%
Vic.	100	255	363	174	132	1,025	1.0%
WA	1,899	1,637	1,294	1,049	1,142	7,022	6.6%
southern WA[b]	199	104	106	294	469	1,172	1.1%
northern WA[c]	1,700	1,533	1,189	755	674	5,849	5.5%
Australia	**26,860**	**27,351**	**15,483**	**21,235**	**14,879**	**105,807**	**100%**

[a] Cumulative area of fire in forest is the sum of the five annual area totals, and therefore counts multiple times any forest areas that were burnt in two or more years of the five-year period. This metric can therefore exceed the total forest area.

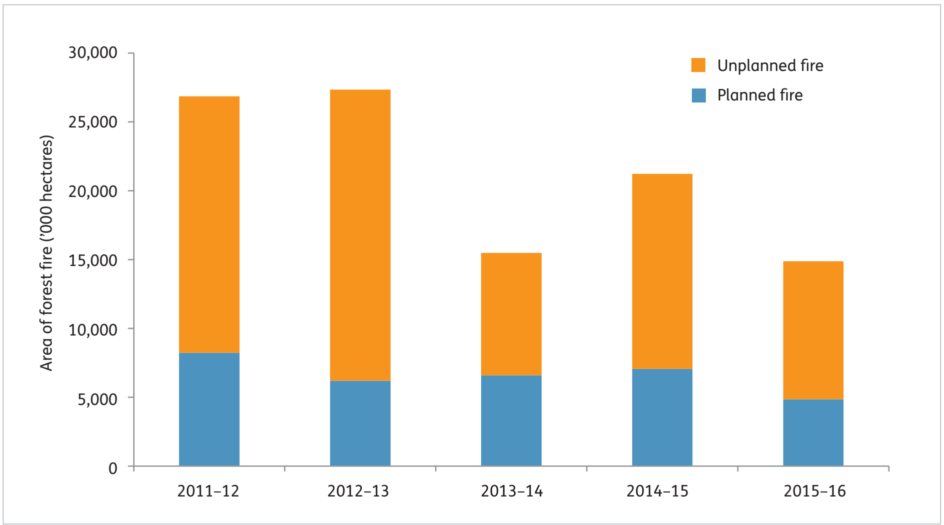
[b] Data for forest south of the Tropic of Capricorn, calculated using an interim area mask.

[c] Data for forest north of the Tropic of Capricorn, calculated using an interim area mask.

Totals may not tally due to rounding.

This table, together with other data for Indicator 3.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

Figure 3.13: Area of planned and unplanned forest fire ('000 hectares) by year



The data used to create this figure, together with other data for Indicator 3.1b, are available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

The area of forest burnt nationally in any one year from 2011–12 to 2015–16 varied from 15 million hectares to 27 million hectares (Figure 3.13). Summing these figures gives the cumulative area of fire in forest over this period as 106 million hectares (Table 3.6). Forest areas that are burnt on multiple occasions during the reporting period are counted multiple times in this total. The largest cumulative areas of fire in forest were Queensland (50 million hectares, 47% of the national total) and the Northern Territory (46 million hectares, 43% of the national total). Together, these two jurisdictions accounted for 90% (95 million hectares) of the cumulative total of all fire in forest in the period 2011–12 to 2015–16.

Nationally, over the period 2011–12 to 2015–16 the cumulative area of fire in forest of 106 million hectares comprised 73 million hectares of unplanned fire (69% of the total) and 33 million hectares of planned fire (31% of the total). The proportion of the cumulative area of forest that was burnt by planned fire varied between jurisdictions, from 8% in South Australia to 80% for the northern part of Western Australia (and 100% in the ACT, for which no unplanned forest fire was reported in the period). The cumulative area of unplanned fire in forest was greater than the cumulative area of planned fire in forest in all jurisdictions except the Australian Capital Territory, Victoria and Western Australia. Queensland and the Northern Territory had the largest cumulative areas of planned fire in forest in the period 2011–12 to 2015–16 (each 13 million hectares), as well as the largest cumulative areas of unplanned forest fire in forest (37 and 32 million hectares, respectively). There was also a substantial cumulative area of planned fire in forest (4.7 million hectares) in the northern part of Western Australia (Table 3.6).

Area of forest burnt one or more times

Spatial analysis of the fire areas in the individual years of the five-year reporting period 2011–12 to 2015–16 showed that most areas of forest burnt in southern Australia burnt only once during this period. On the other hand, large areas of forest were burnt multiple times during this reporting period, especially in northern Australia. Figure 3.14 (see page 269) shows the distribution of burnt forest in Australia by the number of times each hectare was burnt in the period 2011–12 to 2015–16.

Forest areas burnt in more than one year of the period 2011–12 to 2015–16 contribute multiple times to the cumulative area of fire in forest presented in Table 3.6, depending on the number of years in which each such area was burnt. When fire areas burnt in multiple years are allowed for, the total area of forest that was burnt once or more in the period 2011–12 to 2015–16 was determined as 55 million hectares, which is 41% of Australia's forest area (Table 3.7). This is the total area impacted by fire once or more during the reporting period, and is represented as the various colour areas labelled 1–5 on Figure 3.14.

The largest areas of forest burnt in the period 2011–12 to 2015–16 were in Queensland (28 million hectares, 55% of Queensland's total forest area, and 52% of the total national area of forest burnt) and the Northern Territory (20 million hectares, 84% of the Northern Territory's total forest area, and 37% of the total national area of forest burnt) (Table 3.7).

Of the total area of forest burnt in the period 2011–12 to 2015–16, 29 million hectares (22% of Australia's forest area) was burnt multiple times. These areas of forest were almost completely confined to northern Australia (Figure 3.14), including substantial areas of forest in the Northern Territory (15 million hectares, 62% of the Northern Territory's total forest area), Queensland (13 million hectares, 25% of Queensland's total forest area) and northern Western Australia (1.8 million hectares, 49% of the total forest area

Table 3.7: Area of forest burnt by number of times burnt, by jurisdiction, 2011–12 to 2015–16 ('000 hectares)

Jurisdiction	Total forest area	Forest area not burnt, 2011–12 to 2015–16	Forest area burnt, 2011–12 to 2015–16								
			Area burnt one times	Area burnt two times	Area burnt three times	Area burnt four times	Area burnt five times	Area burnt one or more times[a]	Proportion of total jurisdictional forest area	Area burnt two or more times[b]	Proportion of total jurisdictional forest area
ACT	142	125	17	0	0	0	0	17	12%	0	0.0%
NSW	20,368	18,637	1,696	35	0	0	0	1,731	8%	35	0.2%
NT	23,735	3,689	5,434	6,836	5,106	2,212	459	20,046	84%	14,612	62%
Qld	51,830	23,539	15,397	6,913	3,708	1,809	463	28,291	55%	12,894	25%
SA	5,060	4,759	300	1	0	0	0	301	6%	1	0.0%
Tas.	3,699	3,495	200	4	0	0	0	204	6%	4	0.1%
Vic.	8,222	7,228	964	30	0	0	0	995	12%	30	0.4%
WA	20,981	17,737	1,447	589	660	324	224	3,244	15%	1,797	9%
southern WA[c]	17,357	16,220	1,107	25	4	1	0	1,136	7%	30	0.2%
northern WA[d]	3,624	1,516	341	564	656	323	224	2,108	58%	1,768	49%
Australia	**134,037**	**79,208**	**25,456**	**14,408**	**9,474**	**4,345**	**1,146**	**54,829**	**41%**	**29,374**	**22%**
Proportion of total national forest area	100%	59%	19%	11%	7%	3.2%	0.9%	41%		22%	

[a] Sum of the areas burnt one times, two times, three times, four times and five times in the period 2011–12 to 2015–16, giving the total area of forest burnt one or more times. The forest areas burnt on multiple occasions are counted only once in these totals.

[b] Sum of the areas burnt two times, three times, four times and five times in the period 2011–12 to 2015–16, giving the total area of forest burnt multiple times.

[c] Data for forest south of the Tropic of Capricorn, calculated using an interim area mask.

[d] Data for forest north of the Tropic of Capricorn, calculated using an interim area mask.

Note: Multiplying each area of forest burnt by the number of years in which it was burnt in the period 2011-12 to 2015-16, and summing the results, gives the cumulative area of forest fire over the reporting period (Table 3.6).

This table, together with other data for Indicator 3.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

of northern Western Australia). A small area of forest was burnt in all five years of the reporting period (Table 3.7). Only very small areas of forest in southern Australia were burnt more than once between 2011–12 and 2015–16. Figure 3.15 (see page 270) shows the distribution of burnt forest in Australia coloured according to whether the area was burnt by planned fire, by unplanned fire, or by both planned and unplanned fires, in the period 2011–12 to 2015–16.

Nationally, 79 million hectares of forest (59% of Australia's forest area) were not burnt at all in the period 2011–12 to 2015–16 (Table 3.7, Figure 3.15). The jurisdictions with the highest proportions of forest area not burnt during this period were Tasmania (94%) and South Australia (94%).

The high fire frequency in northern Australia is driven by the characteristics of vegetation and climate. In open tropical forests with a grassy understorey, periods of prolific annual growth in the wet season are followed by rapid drying in the dry season, and lightning associated with storm events leads to frequent and extensive unplanned fires, especially late in the dry season. Case study 5.3 in Indicator 5.1a describes how planned burns early in the dry season, implemented by traditional owners and land managers, are being used to reduce the extent and impact of unplanned fires late in the dryseason.

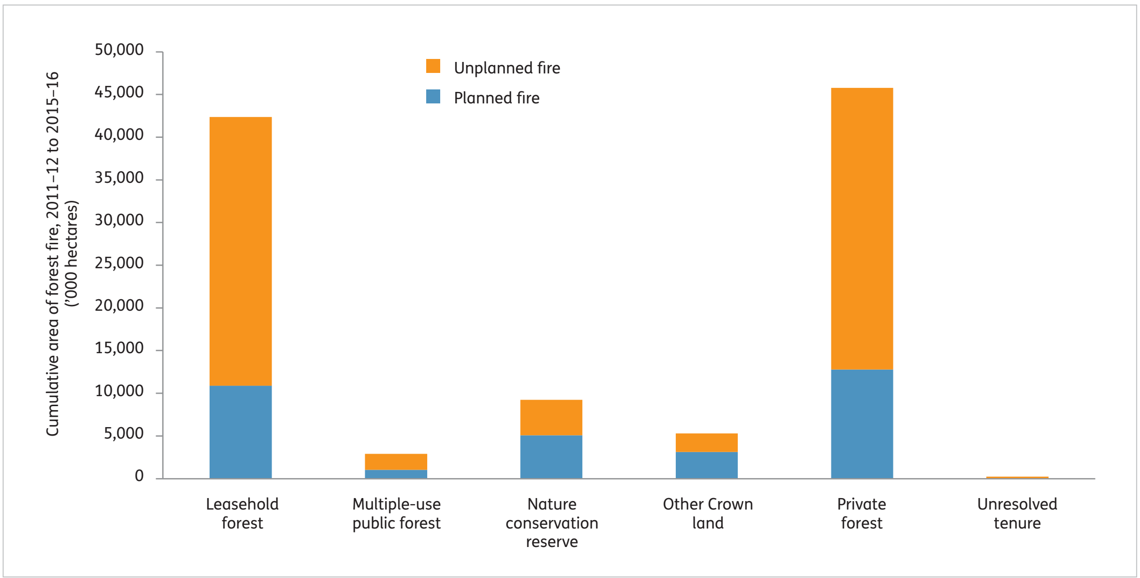
Tenure of forest areas burnt by planned and unplanned fire

The cumulative area of fire in forest over the period 2011–12 to 2015–16 in different forest tenures is shown in Table 3.8, separately by planned and unplanned fire, and by jurisdiction. Of the cumulative area of fire in forest of 106 million hectares over this period, the largest areas nationally were in leasehold forest (42 million hectares) and private forest (46 million hectares) (Figure 3.16). The large areas of fire in leasehold and private tenure forests derive from the large areas of forests in these tenures across northern Australia where the majority of forest fire occurs, rather than from the nature of land management across tenures.

The ratio of planned fire to unplanned fire in this period varied by tenure (Figure 3.16) and jurisdiction (Table 3.8). In nature conservation reserves, 55% of the cumulative forest fire area for 2011–12 to 2015–16 was planned fire, whereas in leasehold and private forests 26% and 24% respectively of the cumulative forest fire area for 2011–12 to 2015–16 was planned fire. The area proportions of fire that was planned in multiple-use public forest in Victoria and in southern Western Australia were substantially higher than the national average for that tenure, at 64% and 69% respectively. All fire in the ACT in this period was planned fire.

Analysis of the area of forest burnt in the period 2011–12 to 2015–16 in different tenures (Table 3.9), by jurisdiction, shows a similar pattern. Of the total forest area of 55 million hectares burnt in this period, the largest areas nationally were in leasehold forest (24 million hectares, which is 51% of the total national area of forest on that tenure) and private forest (20 million hectares, which is 47% of the total national area of forest on that tenure). Forest burnt on these two tenures comprises 88% of the total area of forest burnt in Australia in this period.

Figure 3.16: Cumulative area of planned and unplanned forest fire by tenure, 2011–12 to 2015–16



The data used to create this figure, together with other data for Indicator 3.1b, are available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

Table 3.8: Cumulative area of fire in forest, 2011–12 to 2015–16, by tenure and jurisdiction, separately for planned and unplanned fire

	Forest fire area ('000 hectares)						
Jurisdiction	**Leasehold forest**	**Multiple-use public forest**	**Nature conservation reserve**	**Other Crown land**	**Private forest**	**Unresolved tenure**	**Total**
Planned fire							
ACT	0	1	16	0	0	0	17
NSW	5	83	622	20	61	1	791
NT	4,132	0	5	1,294	7,728	8	13,166
Qld	6,527	412	1,114	536	4,524	46	13,159
SA	1	1	21	0	1	0	24
Tas.	0	23	22	12	4	0	60
Vic.	0	279	223	18	6	0	526
WA	210	240	3,045	1,241	449	0	5,184
southern WA[a]	3	240	228	22	11	0	504
northern WA[b]	207	0	2,817	1,218	438	0	4,681
Australia	**10,874**	**1,039**	**5,067**	**3,121**	**12,773**	**54**	**32,927**
Unplanned fire							
ACT	0	0	0	0	0	0	0
NSW	18	131	479	28	320	0	975
NT	9,722	0	18	747	21,899	14	32,399
Qld	21,562	1,409	2,250	855	10,511	156	36,743
SA	47	10	181	2	38	0	279
Tas.	0	48	34	28	37	0	147
Vic.	0	159	303	3	33	0	498
WA	140	107	910	510	170	0	1,837
southern WA[a]	29	107	349	127	56	0	668
northern WA[b]	110	0	561	384	114	0	1,169
Australia	**31,488**	**1,864**	**4,175**	**2,174**	**33,008**	**170**	**72,880**
All fire							
ACT	0	1	16	0	0	0	17
NSW	22	214	1,100	48	380	1	1,766
NT	13,853	0	22	2,041	29,627	22	45,565
Qld	28,090	1,820	3,364	1,391	15,035	202	49,902
SA	48	11	202	2	39	0	302
Tas.	0	71	56	41	40	0	208
Vic.	0	438	526	21	39	0	1,025
WA	349	347	3,955	1,751	619	0	7,022
southern WA[a]	32	347	576	149	67	0	1,172
northern WA[b]	317	0	3,379	1,602	552	0	5,850
Australia	**42,362**	**2,903**	**9,242**	**5,295**	**46,229**	**225**	**105,807**

[a] Data for forest south of the Tropic of Capricorn, calculated using an interim area mask.

[b] Data for forest north of the Tropic of Capricorn, calculated using an interim area mask.

This table, together with other data for Indicator 3.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

CRITERION 3

3.1b

The largest area of forest burnt by fire in southern Australia in this period was in nature conservation reserves (a total of 2.4 million hectares); this was also the case in each jurisdiction in southern Australia except for Tasmania, where the largest forest area burnt was in multiple-use public forests (Table 3.9). In the Northern Territory, the largest area of forest burnt by fire was on private land (12 million hectares) followed by leasehold land (7.1 million hectares), whereas in Queensland the largest area of forest burnt by fire was on leasehold land (17 million hectares) followed by private land (7.1 million hectares).

Burnt snowgums (*Eucalyptus pauciflora*) above the Guthega River, New South Wales.

Table 3.9: Area of forest burnt, by jurisdiction and tenure, 2011–12 to 2015–16

	Forest area burnt, 2011–12 to 2015–16 ('000 hectares)							
Jurisdiction	**Leasehold forest**	**Multiple-use public forest**	**Nature conservation reserve**	**Other Crown land**	**Private forest**	**Unresolved tenure**	**Total**	**Proportion of total area burnt**
ACT	0	1	16	0	0	0	17	0.0%
NSW	22	207	1,076	48	377	1	1,731	3.2%
NT	7,098	0	8	811	12,115	13	20,046	37%
Qld	16,524	1,528	2,121	801	7,165	153	28,291	52%
SA	48	11	201	2	39	0	301	0.5%
Tas.	0	70	54	40	40	0	204	0.4%
Vic.	0	424	510	21	39	0	995	1.8%
WA	202	334	1,642	740	326	0	3,244	5.9%
southern WA[a]	29	334	563	146	65	0	1,136	2.1%
northern WA[b]	173	0	1,079	594	262	0	2,108	3.8%
Australia	**23,894**	**2,574**	**5,629**	**2,464**	**20,101**	**167**	**54,830**	**100%**
Forest area burnt as a proportion of total forest area of that tenure[c]	51%	24%	26%	22%	47%	21%	100%	

[a] Data for forest south of the Tropic of Capricorn, calculated using an interim area mask.

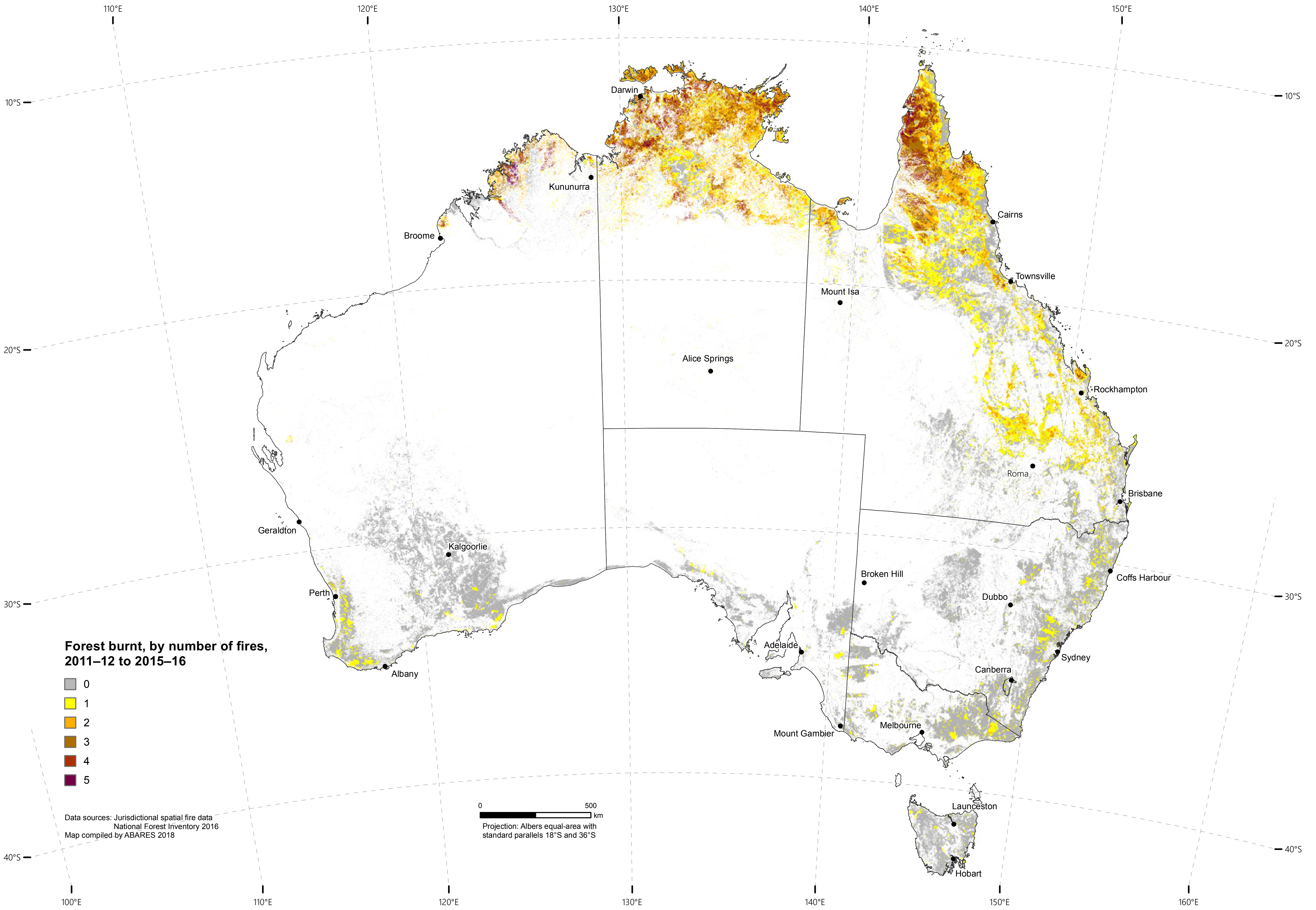
[b] Data for forest north of the Tropic of Capricorn, calculated using an interim area mask.

[c] Table 1.7, Indicator 1.1a, shows forest area totals by tenure.

Includes both planned and unplanned fire. Forest areas burnt on multiple occasions are counted only once in these figures.

This table, together with other data for Indicator 3.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda8e8ad76d6

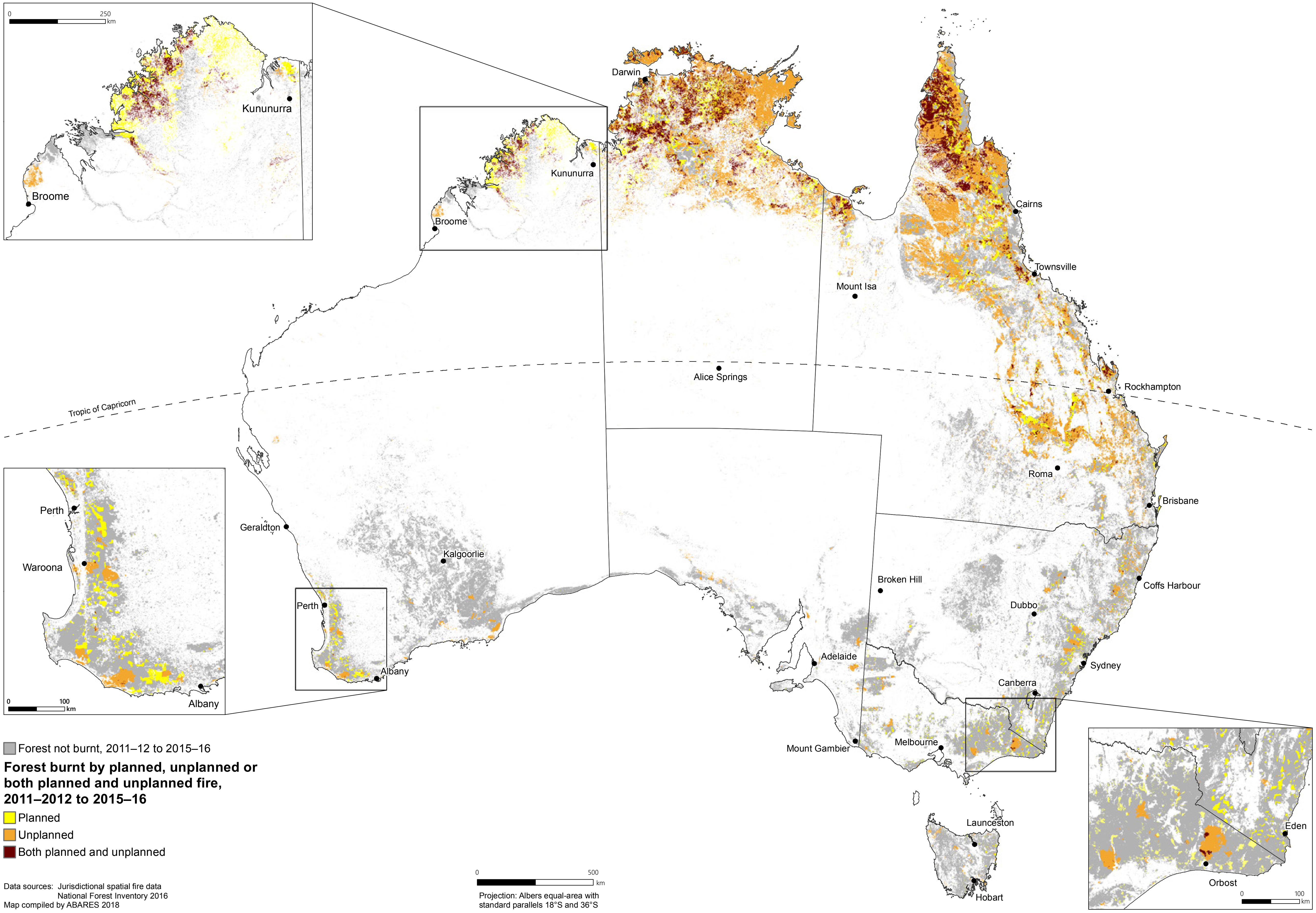
Figure 3.14: Forest burnt, by number of fires, 2011–12 to 2015–16



Note: Fire frequency is the number of years in the five-year reporting period in which a forest area was reported as being burnt. Occasionally, an area was reported as having burnt more than once in a year; in such situations, only the first fire in that year was retained in the data.

A higher resolution version of this map is available via www.doi.org/10.25814/5be3bc4321162

Figure 3.15: Forest burnt, 2011–12 to 2015–16, by planned, unplanned, or planned and unplanned fire



A higher resolution version of this map, together with other data and maps for Indicator 3.1b, is available via www.doi.org/10.25814/5be3bc4321162

Case study 3.4: The Waroona bushfire, south-west Western Australia

The Waroona bushfire was ignited by lightning in the Murray River valley south-east of Dwellingup, Western Australia, and was detected by satellite hotspot imagery early on the morning of 06 January 2016. Burning under prevailing east to north-east winds, the fire made a series of major runs to the west, eventually burning to the Indian Ocean near Lake Preston, some 50 kilometres from the point of ignition. Around sunset on 07 January, the fire burned through the town of Yarloop, resulting in the loss of two lives, destruction of more than 100 homes, and severe damage to other buildings and infrastructure.

The fire burnt a total area of 69,165 hectares, making it the second largest individual fire in the south-west since the Dwellingup fires of January 1961. The Waroona fire was notable for the scale, complexity and duration of suppression operations, and for its significant social and economic impacts on the south-west community. The loss of homes, businesses and infrastructure in the town of Yarloop was so severe that the future viability of the community was questioned (Michael 2016).

A total of around 35,000 hectares of native forest were burned, including many thousands of hectares burnt by high-intensity fire causing complete crown scorch and canopy defoliation (Figure 3.17). Widespread mortality of the above-ground parts of even mature trees occurred in severely burnt forest, and it will be many decades before the regrowth of basal sprouts leads to re-establishment of a forest of comparable structure. In the meantime, standing dead stags will pose an ongoing safety issue for forest users, and will make fire management more difficult. Further, as these dead stags collapse and fall, it is likely that there will be a temporary shortage of large hollows which are used by large birds, including owls and black cockatoos. Changes in forest structure resulting from the impacts of severe bushfire will thus have long-term impacts on biodiversity, ecosystem health and vitality, as well as productive capacity and water values.

During the evening of 06 January 2016, the fire burnt through forest subject to bauxite mining operations, and large areas of young forest on rehabilitated mine sites were severely burnt (Figure 3.18).

The fire also burnt 3,300 hectares of commercial *Pinus pinaster* plantations on the Swan coastal plain, ranging in age from 3 to 40 years (Figure 3.19). Older plantations were subject to salvage harvesting operations to recover commercial wood products, but this was not possible in younger plantations because the trees were too small to produce saleable products. An estimated 500 thousand cubic metres of logs were lost, equivalent to about seven months of supply to processing industries (FPC 2016). In addition to the direct costs associated with re-establishing burnt plantations, the fire will affect the supply of logs to wood processing industries for several years.

The exceptionally high intensity and rate of spread of this fire is attributable to a number of factors (Government of Western Australia 2016).

- Firstly, rainfall in the region in the previous year was in the lowest 10% of records, and this was also a notably warm year; Dwellingup, for example, experienced its warmest year in 75 years of records. Forest fuels were consequently significantly drier than average for the time of year.
- Secondly, fire weather conditions at the time of the fire were sufficiently extreme to enable pyrocumulonimbus events to develop (Figure 3.20). These resulted in turbulence in the upper atmosphere that carried many large burning embers large distances and induced lightning strikes, substantially increasing the rate of spread of the fire (Peace et al. 2017).

Figure 3.17: Widespread mortality of the above-ground parts of mature *Eucalyptus megacarpa* and *E. patens* in severely burnt forest near Willowdale

Figure 3.18: Immediate impact of severe fire in young forest rehabilitated following bauxite mining near Mt William, Western Australia

CRITERION 3

3.1b

Continued

- Lastly, heavy fuel loads in forests and farmland and inaccessible terrain played a major role in the extreme fire intensity, rate of spread and difficulty of suppression and containment. For example, there were substantial areas of long-unburnt forest within the fire area, including the rehabilitated mine sites from which fuel reduction burning was excluded to protect the regenerating vegetation.

The Waroona bushfire therefore highlighted the importance of effective fuel management in bushland close to settlements, as well as across the broader landscape.

Source: Department of Biodiversity, Conservation and Attractions, Western Australia.

Figure 3.19: Plantation of *Pinus pinaster* burnt by high intensity crown fire

Figure 3.20: Pyrocumulonimbus cloud above the Waroona fire

Criterion 3 References

AFAC (Australasian Fire and Emergency Service Authorities Council) (2012). *Bushfire Glossary*. AFAC, Melbourne. www.afac.com.au/initiative/burning

Battaglia M, Bruce J, Brack C and Baker T (2009). *Climate Change and Australia's plantation estate: Analysis of vulnerability and preliminary investigation of adaptation options*. Project No: PNC068-0708. Forest and Wood Products Australia, Melbourne, Australia, pp.125.

Beenken L (2017). *Austropuccinia*: a new genus name for the myrtle rust *Puccinia psidii* placed within the redefined family Sphaerophragmiaceae (Pucciniales). *Phytotaxa* 297:53–61.

Berthon K, Carnegie A, Esperon-Rodriguez M, Beaumont L and Leishman M (2018). Assessment and prioritisation of plant species at risk from myrtle rust (*Austropuccinia psidii*) under current and future climates in Australia. *Biological Conservation* 218:154–162.

Bowman DMJS, Williamson GJ, Keenan RJ and Prior LD (2014). A warmer world will reduce tree growth in evergreen broadleaf forests: evidence from Australian temperate and subtropical eucalypt forests. *Global Ecology and Biogeography* 23:925–934.

Bureau of Meteorology (2014). *Annual Climate Report 2013*. Bureau of Meteorology, Melbourne, 36 pp.

Carnegie AJ (2015). First Report of *Puccinia psidii* (Myrtle Rust) in *Eucalyptus* Plantations in Australia. *Plant Disease* 99:161.

Carnegie AJ and Lidbetter JR (2012). Rapidly expanding host range for *Puccinia psidii* sensu lato in Australia. *Australasian Plant Pathology* 41:13–29.

Carnegie AJ, Kathuria A, Pegg GS, Entwistle P, Nagel M and Giblin FR (2016). Impact of the invasive rust *Puccinia psidii* (myrtle rust) on native Myrtaceae in natural ecosystems in Australia. *Biological Invasions* 18:127–144.

Carnegie AJ, Lidbetter JR, Walker J, Horwood MA, Tesoriero L, Glen M and Priest MJ (2010). *Uredo rangelii*, a taxon in the guava rust complex, newly recorded on Myrtaceae in Australia. *Australasian Plant Pathology* 39:463–466.

Commonwealth of Australia (2012). *Threat abatement plan to reduce the impacts on northern Australia's biodiversity by the five listed grasses*. Department of Sustainability, Environment, Water, Populations and Communities. Australian Government, Canberra, 17 pp.

CSIRO and Bureau of Meteorology (2015). *Climate Change in Australia*. Projections for NRM Regions. Technical Report. CSIRO, 222 pp.

DEC (Department of Environment and Conservation) (2009b). *Phytophthora dieback – detecting the pathogen*. Science Division Information Sheet 8/2009. DEC, Western Australia.

Duke NC, Kovacs JM, Griffiths AD, Preece L, Hill DJE, van Oosterzee P, Mackenzie J, Morning HS and Burrows D (2017). Large-scale dieback of mangroves in Australia. *Marine and Freshwater Research* 68:1816–1829.

Ellis S, Kanowski P and Whelan R (2004). *National Inquiry on Bushfire Mitigation and Management*. Commonwealth of Australia, Canberra. www.dfes.wa.gov.au/publications/GeneralReports/FESA_Report-NationalInquiryonBushfireMitigationandManagement.pdf

FCNSW (Forestry Corporation of New South Wales) (2016d). *Sustainability Snapshot 2015–16*. FCNSW, Pennant Hills. www.forestrycorporation.com.au/__data/assets/pdf_file/0017/692000/SustainabilitySnapshot2015-16.pdf

FFMG (Forest Fire Management Group) (2014). *National Bushfire Management Policy Statement for Forests and Rangelands*. Prepared by the Forest Fire Management Group for The Council of Australian Governments. www.sfmc.tas.gov.au/sites/sfmc.tas.gov.au/files/NationalBushfireManagementPolicy_2014.pdf and www.environment.nsw.gov.au/research-and-publications/publications-search/national-bushfire-management-policy-statement-for-forests-and-rangelands

FPC (Forest Products Commission) (2016). *Forest Products Commission Annual report 2015–16*. FPC, Perth. www.fpc.wa.gov.au/file/2314/download

Government of Western Australia (2016). *Reframing rural fire management: report of the special inquiry into the January 2016 Waroona fire*. Public Sector Commission, Perth. publicsector.wa.gov.au/sites/default/files/documents/waroona_fires_2016_-_volume_1_-_report_final.pdf

Granados GM, McTaggart AR, Barnes I, Rodas CA, Roux J and Wingfield MJ (2017). The pandemic biotype of *Austropuccinia psidii* discovered in South America. *Australasian Plant Pathology* 46:267–275.

Harris T, Hope P, Oliver E, Smalley R, Arblaster J, Holbrook N, Duke N, Pearce K, Braganza K and Bindoff N (2017). *Climate drivers of the 2015 Gulf of Carpentaria mangrove dieback*. Earth Systems and Climate Change Hub Technical Report No. 2, NESP Earth Systems and Climate Change Hub Australia, 32 pp.

Harrison PA, Vaillancourt RE, Harris RMB and Potts BM (2017). Integrating climate change and habitat fragmentation to identify candidate seed sources for ecological restoration. *Restoration Ecology* 25:524–531.

Holloway I (2013). *Effects of cyclone Yasi on vegetation communities in the Tully/Mission Beach area*. Queensland Parks and Wildlife Service, 39 pp. www.wettropics.gov.au/cyclone-research.html

House of Representatives Select Committee (2003). *A Nation Charred: Report on the inquiry into bushfires*. House of Representatives Select Committee into the recent Australian bushfires, 23 October 2003, Commonwealth of Australia, Canberra. www.aph.gov.au/Parliamentary_Business/Committees/House_of_Representatives_Committees?url=bushfires/inquiry/report.htm

James B, Blood K and Raleigh R (2016). Buffel grass (*Cenchrus ciliaris* L.), an early invader in Victoria. 20th Australasian Weeds Conference (Randall R, Lloyd S and Borger C., eds), pp.337–338. Perth, Western Australia.

Jeffrey M and Brooks S (2016). *Eradication in the tropics: constantly changing and adapting*. In: Proceedings of the 20th Australasian Weeds Conference (Randall R, Lloyd S and Borger C, eds), Perth, Western Australia, pp.23–27.

Keenan RJ and Nitschke C (2016). Forest management options for adaptation to climate change: a case study of tall, wet eucalypt forests in Victoria's Central Highlands region. *Australian Forestry* 79:96–107.

Legge S, Murphy S, Kingswood R, Maher B and Swan D (2011). EcoFire: restoring the biodiversity values of the Kimberley region by managing fire. *Ecological Management & Restoration* 12:84–92. doi.org/10.1111/j.1442-8903.2011.00595.x

Lovelock CE, Feller IC, Reef R, Hickey S and Ball MC (2017). Mangrove dieback during fluctuating sea levels. *Scientific Reports* 7:1680.

Luke RH and McArthur AG (1978). *Bushfires in Australia*. Australian Government Publishing Service, Canberra, 350 pp.

Machado PdaS, Alfenas AC, Alfenas RF, Mohammed CL and Glen M (2015). Microsatellite analysis indicates that *Puccinia psidii* in Australia is mutating but not recombining. *Australasian Plant Pathology* 44:455–462.

Matusick G, Ruthrof KX, Fontaine JB and Hardy GES-J (2016). *Eucalyptus* forest shows low structural resistance and resilience to climate change-type drought. *Journal of Vegetation Science* 27:493–503.

McCaw WL (2013). Managing forest fuels using prescribed fire – A perspective from southern Australia. *Forest Ecology and Management* 294:217–224.

Michael K (2016). *Waroona fire complex January 2016*. Report of the State Recovery Controller. Government of Western Australia.

Morin L, Aveyard R, Lidbetter JR and Wilson PG (2012). Investigating the host-range of the rust fungus *Puccinia psidii* sensu lato across tribes of the family Myrtaceae present in Australia. *PLoS One* 7:e35434.

Murphy BP, Bradstock RA, Boer MM, Carter J, Cary GJ, Cochrane MA, Fensham RJ, Russell-Smith J, Williamson GJ and Bowman DMJS (2013). Fire regimes of Australia: a pyrogeographic model system. *Journal of Biogeography* 40: 1048–1058. doi.org/10.1111/jbi.12065

Paap T, Burgess TI, Calver M, McComb JA, Shearer BL, Hardy GES-J and Klopfenstein NB (2017). A thirteen-year study on the impact of a severe canker disease of *Corymbia calophylla*, a keystone tree in Mediterranean-type forests. *Forest Pathology* 47:e12292.

Packham JM, Elliott HJ and Bashford R (2008). Rate of spread of myrtle wilt disease in undisturbed Tasmanian rainforests. *Australian Forestry* 73:64–69.

Peace M, McCaw L, Santos B, Kepert JD, Burrows N and Fawcett JB (2017). Meteorological drivers of extreme fire behaviour during the Waroona bushfire, Western Australia, January 2016. *Journal of Southern Hemisphere Earth Systems Science* 67:79–106. www.bom.gov.au/jshess/docs/2017/Peace.pdf

Pegg G, Taylor T, Entwistle P, Guymer GP, Giblin F and Carnegie A (2017). Impact of *Austropuccinia psidii* (myrtle rust) on Myrtaceae rich wet sclerophyll forests in south-east Queensland. *PLoS One* 12:e0188058.

Potts BM, Sandhu KS, Wardlaw T, Freeman J, Li H, Tilyard P and Park RF (2016). Evolutionary history shapes the susceptibility of an island tree flora to an exotic pathogen. *Forest Ecology and Management* 368:183–193.

Prober SM, Byrne M, McLean EH, Steane DA, Potts BM, Vaillancourt RE and Stock WD (2015a). Climate-adjusted provenancing: a strategy for climate-resilient ecological restoration. *Frontiers in Ecology and Evolution* 3:65. doi.org/10.3389/fevo.2015.00065

Prober SM, Williams KJ, Harwood CD, Doerr VAJ, Jeanneret T, Manion G and Ferrier S (2015b). *Helping Biodiversity Adapt: Supporting climate adaptation planning using a community-level modelling approach*. CSIRO Land and Water Flagship, Canberra, ACT, pp.59. adaptnrm.csiro.au

Prober SM, Potts BM, Bailey T, Byrne M, Dillon S, Harrison PA, Hoffmann AA, Jordan R, McLean EH, Steane DA, Stock WD and Vaillancourt RE (2016). Climate adaptation and ecological restoration in eucalypts. *Proceedings of the Royal Society of Victoria* 128:40–53.

Ross C and Brack C (2015). *Eucalyptus viminalis* dieback in the Monaro region, NSW. *Australian Forestry* 78:243–253.

Ruthrof K, Matusick G and Hardy G (2015). Early differential responses of co-dominant canopy species to sudden and severe drought in a Mediterranean-climate type forest. *Forests* 6:2082–2091.

Sandhu KS, Karaoglu H, Zhang P and Park RF (2016). Simple sequence repeat markers support the presence of a single genotype of *Puccinia psidii* in Australia. *Plant Pathology* 65:1084–1094.

Seaton S, Matusick G, Ruthrof K and Hardy G (2015). Outbreak of *Phoracantha semipunctata* in response to severe drought in a Mediterranean eucalyptus forest. *Forests* 6:3868–3881.

Silver MJ and Carnegie AJ (2017). *An independent review of bell miner associated dieback*. Final report June 2017. Report prepared for the Project Steering Committee: Systematic Review of bell miner associated dieback (BMAD). Office of Environment and Heritage, Sydney, NSW, 125 pp.

Singh S, Davey S and Cole M (2010). Implications of climate change for forests, vegetation and carbon in Australia. *New Zealand Journal of Forestry Science* 40:141–152.

Singh S, Senarath U and Read S (2016). *Climatic suitability of Australia's production forests for myrtle rust*. Research Report 16.7, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, 72 pp.

Sparkes D (2017). *The National Burning Project*. NPA ACT Symposium 2017: Bushfire Management – Balancing the Risks. National Parks Association of the ACT Inc., Canberra. www.npaact.org.au/res/File/2017/Deb%20Sparkes%20National%20Burning.pdf

Van Gorsel E, Wolf S, Cleverly J, Isaac P, Haverd V, Ewenz C, Arndt S, Beringer J, Resco de Dios V, Evans BJ, Griebel A, Hutley LB, Keenan T, Kljun N, Macfarlane C, Meyer WS, McHugh I, Pendall E, Prober SM and Silberstein R (2016). Carbon uptake and water use in woodlands and forests in southern Australia during an extreme heat wave event in the "Angry Summer" of 2012/2013. *Biogeosciences* 13:5947–5964.

West PW (2011). *National mapping of the abundance of established, new and emerging pest animals to improve decision-making and the assessment of government investment programs. Stage 1: Pest animals*. Final report to the Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture, Fisheries and Forestry. NSW Department of Primary Industries, Sydney, 63 pp.

Whisson DA, Dixon V, Taylor ML and Melzer A (2016). Failure to respond to food resource decline has catastrophic consequences for koalas in a high-density population in southern Australia. *PLoS One* 11:e0144348.

Williams KJ, Prober SM, Harwood CD, Doerr VAJ, Jeanneret T, Manion G and Ferrier S (2015). *Implications of Climate Change for Biodiversity: A community-level modelling approach*. CSIRO Land and Water Flagship, Canberra, 87 pp. adaptnrm.csiro.au/biodiversity-impacts/

Wills A and Farr J (2016). Gumleaf skeletoniser *Uraba lugens* (Lepidoptera: Nolidae) larval outbreaks occur in high rainfall Western Australian jarrah (Eucalyptus *marginata*) forest after drought. *Austral Entomology* 56:424–432.

Wishart J and Cox T (2016). *Rollout of RHDV1 K5 in Australia: information guide*. In: PestSmart Toolkit publication, second edition. Invasive Animals Cooperative Research Centre, Canberra, 52 pp.

Zeeman BJ, Lunt ID and Morgan JW (2014). Can severe drought reverse woody plant encroachment in a temperate Australian woodland? *Journal of Vegetation Science* 25:928–936.