

# FINAL NATIONAL PRIORITISATION OF AUSTRALIAN PLANTS AFFECTED BY THE 2019-2020 BUSHFIRE SEASON



*Epicormic regeneration in Eucalyptus on the South Coast of NSW* ©Anne Kerle

Research for the Wildlife and Threatened Species Bushfire Recovery Expert Panel

Version 1.4

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The Bushfire Recovery Expert Panel and the Threatened Species Commissioner reviewed and refined the approach and delivery of this research.

## ABBREVIATIONS

ALA	Atlas of Living Australia
APNI	Australian Plant Name Index
AusTraits	The AusTraits Plant Trait Database <a href="http://traitecoevo.github.io/austraits.build/">http://traitecoevo.github.io/austraits.build/</a>
FFRD	NSW Fire Response database
NIAFED	National Indicative Aggregated Fire Extent Dataset
PAA	Preliminary Analysis Area (IBRA regions)
SPRAT	Commonwealth Species Profile and Threats Database

## APPENDICES

**Appendix 1.** Framework for prioritising impact assessments for plants following the 2019-2020 bushfires

**Appendix 2.** Final assessment by taxon. See FINAL\_ASSESSMENT\_Ver1\_2.csv

**Appendix 3.** Metadata for column names in Appendix 2

**Appendix 4.** High priority taxa for recovery actions. See FINAL\_PRIORITY\_LIST\_PLANTS\_Ver1\_2.csv

**Appendix 5.** Proposed management actions for all taxa assessed HIGH or MEDIUM risk. See FINAL\_MANAGEMENT\_ACTIONS\_BY\_TAXON\_Ver1\_1.csv

## Summary

During the 2019-2020 bushfire season, over 10 million hectares of Australia burned. In the aftermath, a continent-wide prioritisation was undertaken to identify which of Australia's 26,062 plant taxa may be most at risk of impacts and extinction. This prioritisation was based on a set of 11 criteria (A-K) developed in consultation with experts in plant and fire ecology, led by Dr Tony Auld of the NSW Department of Planning, Industry and Environment, and endorsed by the Wildlife and Threatened Species Bushfire Recovery Expert Panel.

This Final Assessment refines and extends the methods applied in the Interim Assessment Report ver. 1.4 (Gallagher 2020) by including an additional 7,058 plant taxa, new data on species traits, and revised spatial analysis for several criteria. As previously, 1,335 plant taxa listed as threatened under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) and 4,622 listed under state legislation have been assessed. Burnt area statistics are shown in Table ES1; 8% of EPBC Act taxa had more than 50% of their range burned during the 2019-2020 fire season.

Of the 26,062 plant taxa assessed, 486 were prioritised as requiring immediate action to assess impacts and support recovery. These taxa had more than 80% of their range burnt, or were listed as Endangered or Critically Endangered under the EPBC Act or state/territory listings, or were listed as HIGH risk under two or more of the criteria assessed. Of these 486 high priority species, 369 appeared in the Interim Assessment, and 117 and 102 have been gained and lost, respectively. These changes in species identified as high priority are due to the inclusion of more taxa, new trait data and refined threat information relative to the Interim Assessment.

**Table ES1.** Assessment of 26,062 Australian plant species distributions and their overlap with the National Indicative Aggregated Fire Extent Database (NIAFED) within the Preliminary Analysis Area (PAA). The range of values given reflects the use of multiple sources of distribution data for plant taxa.

Taxon group*	Count	Plant taxa with range data available	Plant taxa impacted by 2019-2020 fires (%)	Plant taxa impacted by 2019-2020 fires (count)	Plant taxa with range > 90% burnt	Plant taxa with range > 50% burnt	Plant taxa with range > 30% burnt
EPBC Act	1335	1333	44%	585	35 (3%)	90 (7%)	148 (11%)
NSW endemics	1320	1248	77 - 92%	956 - 1152	52-104 (4-8%)	306-311 (25%)	519-626 (42-50%)
WA endemics	8952	8578	32 - 68%	2754 - 5822	4-10 (<1%)	40-45 (<1%)	98-190 (1-2%)
Vic endemics	408	362	32 - 80%	113 - 278	12-13 (3-4%)	28-31 (8-9%)	43-57 (12-16%)
SA endemics	488	457	31 - 70%	160 - 319	3-6 (0-1%)	37-38 (8%)	56-58 (12-13%)
Qld endemics	3629	3436	11 - 54%	388 - 1865	1-3 (<1%)	3-11 (<1%)	19-30 (<1%)
Tas endemics	543	525	9 - 77%	49 - 402	0 (0%)	0 (0%)	1-2 (<1%)
ACT endemics	6	6	33 - 83%	2 - 5	0 (0%)	1 (17%)	1 (17%)
Listed as threatened in NSW	700	656	59 - 91%	386 - 598	32-34 (5%)	79-107 (12-16%)	139-199 (21-30%)
Listed as threatened in WA	436	434	13 - 51%	56 - 220	1-2 (<1%)	4-12 (1-3%)	24-25 (6%)
Listed as threatened in Vic	1770	1617	60 - 93%	963 - 1499	17-18 (1%)	76-95 (5-6%)	229-249 (14-15%)
Listed as threatened in SA	807	769	53 - 87%	404 - 665	3-4 (<1%)	19-21 (2-3%)	34-40 (4-5%)
Listed as threatened in Qld	935	899	15 - 43%	138 - 387	0-2 (<1%)	3-14 (<1%)	31-38 (3-4%)
Listed as threatened in Tas	460	434	59 - 79%	257 - 344	0-1 (<1%)	2 (<1%)	14-24 (3-6%)
Listed as threatened in ACT	13	13	31 - 85%	4 - 11	0-1 (0-8%)	0-1 (0-8%)	1-2 (8-15%)
All other taxa	7976	7969	40 - 65%	3203 - 5197	2-6 (<1%)	23-71 (<1%)	216-342 (3-4%)
<b>Total</b>	<b>26062</b>	<b>25052</b>	<b>36 - 69%</b>	<b>9092 - 17197</b>	<b>90-153 (&lt;1%)</b>	<b>517-593 (3%)</b>	<b>1319-1461 (5-6%)</b>

\*Note species appear in multiple taxon groups listed in this column where they are listed as threatened under multiple legislative instruments

## BACKGROUND

Over the 2019-2020 bushfire season, more than 10 million hectares of Australia burned. To effectively manage the impact of this unprecedented bushfire season, affected species and locations need to be prioritised based on objective criteria which capture inherent risk. This Final Assessment provides a national scale analysis of the impact of the 2019-2020 bushfires and other interacting threats, such as drought, disease and herbivory, on native Australian plant species. Australian plant scientists have worked collaboratively to create both the framework for prioritising impact assessments and the resources required to assess taxa presented in this report.

This Final Assessment is based on a suite of 11 criteria (A-K) which have been assessed across 26,062 plant taxa.

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## IDENTIFYING PRIORITY SPECIES

Large numbers of species were identified as at HIGH risk under one or more criteria in the Interim Assessment. To further refine a list of priority taxa for funding and recovery actions, a rule-set was developed with the Expert Panel as follows:

Priority species were either -

- (1) Listed as Critically Endangered or Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or equivalent state legislation prior to the fires,
- (2) Burnt across 80% or more of their range burnt,
- (3) Ranked as HIGH risk under two or more prioritisation criteria requiring unique management actions.

Following the revised implementation of the prioritisation criteria (as described below), 486 taxa met this rule set, which is a decrease of 9% relative to the Interim Assessment where 471 taxa were prioritised. **Of these 486 high priority species, 369 appeared in the Interim Assessment, and 117 and 102 have been gained and lost, respectively.** This decrease in priority species reflects the refinement of trait data and spatial analysis products and approaches used in this Final Assessment. Specific methods applied to each criterion are detailed below. Taxa which are no longer included as high priorities are still considered at to be impacted, but not to the degree which met the revised implementation of the prioritisation criteria.

### Key revisions relative to the Interim Assessment are:

- Addition of 7,058 plant taxa – primarily those with distributions across state borders and species with informal manuscript names in the Australian Plant Census
- Increased breadth and quality of species data for traits such as resprouting capacity, obligate seeding, and woodiness
- Incorporation of new national fire severity data (Australian Google Earth Engine Burnt Area Map – AUS GEEBAM Fire Severity; DAWE 2020)
- Incorporation of spatial products approximating exposure to disease (myrtle rust and phytophthora) and feral herbivores (pigs, goats, horses, rabbits, deer)

- Revised approach to analysis of fire return time intervals incorporating landscape productivity and state agency datasets on fire history
- Incorporation of terrain characteristics in the assessment of erosion risk

## **THE PRIORITISATION FRAMEWORK**

Framework development was led by Dr Tony Auld at NSW DPIE. The framework targets species' life-history traits that make plant species prone to population declines or local extinctions if they occur within the spatial footprint of 2019-2020 bushfires. The identification of species potentially at risk because of these fires involves three components:

1. Identifying potential mechanisms of decline.
2. Identifying where in the landscape these mechanisms are most likely to have an impact.
3. Identifying the species and most exposed to risks associated with these mechanisms.

The Framework consists of eleven criteria (A-K) which are intended to identify plant species at the greatest potential risk of population declines or local extinctions following the 2019-2020 bushfires and to prioritise such species for field impact assessments and actions.

- A. Interactive effects of fire and drought
- B. Short fire intervals (impacts of high fire frequency)
- C. Post-fire herbivore impacts
- D. Fire-disease interactions
- E. High fire severity
- F. Weed invasion
- G. Elevated winter temperatures or changed temperature regimes
- H. Fire sensitivity
- I. Post-fire erosion
- J. Cumulative exposure to high risks
- K. Other plausible threats or expert-driven nominations

The highest risk ranking obtained via any single criterion is determined to be the overall risk ranking as the risk mechanisms may operate independently or interact in complex ways, and hence the criteria are not additive. Species should be assessed against all criteria where possible. Criteria A-J have been assessed in full for this report. States and territories provided lists of high priority taxa from their own fire recovery work and these are listed under Criterion K.

Priorities for field inspections, monitoring and conservation action may be guided by a simple categorisation of impact:

**HIGH** – Very likely at risk. Require an urgent assessment of initial impacts and post-fire monitoring of recovery where impacts are significant.

**MEDIUM** – Likely to be at risk. Assessment of initial impacts and post-fire monitoring are recommended.

**LOW** – Unlikely to be at risk. Post-fire monitoring may be conducted opportunistically during sites visits or by other groups (externals, universities, citizen science).

**NONE** – Not known to be burnt in the 2019-2020 fires or not expected to be at risk.

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## **BASELINE DATA USED IN ASSESSMENT**

### ***Taxonomy***

Nomenclature follows the Australian Plant Census (accessed in June 2020 from <https://biodiversity.org.au/nsl/services/export/index>).

### ***Quantifying plant species ranges***

The distributional range of plant taxa was estimated from multiple different resources:(1) Cleaned occurrence records from the Australasian Virtual Herbarium (AVH; <https://avh.chah.org.au/>); (2) Point process models of species range built from climate and soil data; (3) ‘Range-bagging’ models built from climate and soil data; (4) Area of occupancy (AOO) in a 2km x 2km grid resolution (IUCN 2019); and, for EPBC Act listed taxa, (5) DAWE regulatory maps for Species of National Environmental Significance available from <https://www.environment.gov.au/science/erin/databases-maps/snes>. Approaches (2), (3), and (4) are collectively known as ‘modelled ranges’ hereafter.

Using a collection of approaches to quantify taxon ranges provides an estimate of the uncertainty associated with different resources. The number of taxa with data in each taxon group are shown in Table 1 (overleaf) and details for each taxon group stated below.

### ***EPBC Act listed plant taxa***

Ranges for this taxon group were quantified using range maps licensed from the *Species and Communities of National Environmental Significance Database* maintained by DAWE <https://www.environment.gov.au/science/erin/databases-maps/snes>. The full version of these data were obtained and used under licence. These range maps are used to regulate the impacts on taxa listed under the EPBC Act and were therefore considered to be the primary source of range information for these taxa. The impact of fires on EPBC Act taxa what not assessed using cleaned AVH records or modelled ranges.

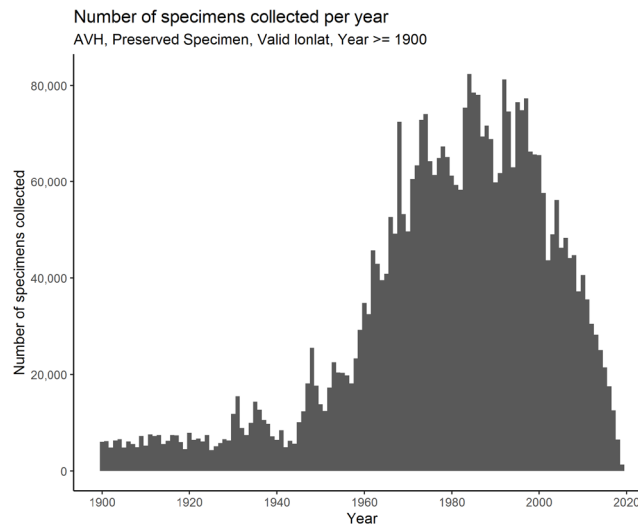
### ***State listed taxa, endemics and all other taxa***

These groups include taxa: (1) listed as threatened under state legislation; (2) endemic to a single state according to the APC; (3) all other taxa assessed. Note that species may overlap between these categories (1) and (2) and those listed on the EPBC Act. Ranges for these taxa were assessed using cleaned occurrence data from the AVH and modelled ranges. Point occurrence

**Table 1.** Number of plant taxa with range data from three different sources: DAWE, Australian Virtual Herbarium, and modelled ranges.

<b>Taxon group</b>	<b>Count</b>	<b>DAWE regulatory maps</b>	<b>Clean AVH occurrence records</b>	<b>Models of species range</b>
EPBC Act	1335	1333	1196	1194
NSW endemics	1320	230	1246	1237
WA endemics	8952	372	8574	8536
Vic endemics	408	69	361	358
SA endemics	488	65	457	457
Qld endemics	3629	209	3431	3420
Tas endemics	543	74	524	521
ACT endemics	6	2	6	6
Listed threatened in NSW	700	352	629	626
Listed threatened in WA	436	391	409	409
Listed threatened in Vic	1770	144	1610	1607
Listed threatened in SA	807	111	765	763
Listed threatened in Qld	935	268	886	883
Listed threatened in Tas	460	95	424	422
Listed threatened in ACT	13	11	12	12
All other taxa	7976	0	7900	7864
<b>Total</b>	<b>26062</b>	<b>1333</b>	<b>24843</b>	<b>24738</b>

data (latitude and longitude coordinates) were downloaded from the *Atlas of Living Australia* (ALA) application programming interface <http://api.ala.org.au/> for all taxa listed in the kingdom Plantae in December 2019. Occurrences were filtered to exclude any records of taxa with no ratified name according to the Australian Plant Census (CHAH 2010) or of non-native origin, or taxa with cultivated status, and/or flagged geographic issues in the ALA. Individual records lacking a vouchered specimen for verification and/or collected prior to 1950 were also excluded (Fig. 1).



**Figure 1.** Number of vouchered specimens in the Australasian Virtual Herbarium (AVH) since 1900 with valid latitude and longitude coordinates. Note that most collections occur after 1950.

Using these cleaned occurrences, species range maps were built from the environmental conditions across the range of the taxa (climate and soils) using Poisson Point process modelling (PPPM; (Warton & Shepherd 2010; Renner & Warton 2013) or, for a limited number of taxa, range bagging (Drake 2015) or by calculating an area of occupancy (AOO). PPPMs were applied to all taxa with 10 or more unique occurrence records at a 10km x 10km grid cell resolution and were using regularized down-weighted Poisson regression based on 20,000 background (pseudo-absence) points. Predictions were limited to a spatial domain that encompassed ecoregions from Dinerstein et al. (2017) occupied by the species across its Australian range.

PPPMs and range bagging were trained on mean annual temperature (°C), mean diurnal temperature range (°C), annual precipitation (mm), precipitation seasonality (coefficient of variation), annual mean radiation (W m<sup>-2</sup>), aridity index, bedrock depth (m), soil bulk density (fine earth) in kg/m<sup>3</sup>, clay mass fraction (%), silt mass fraction (%), and pH. These climate and soil factors were chosen as they reflect major abiotic factors shaping plants growth and nutrition and have correlation coefficients of < 0.7. Variable choice optimised to individual species or clades may refine predictions (Elith *et al.* 2010). Climate data was accessed from WorldClim2 (Fick & Hijmans 2017) <http://www.worldclim.org/v2/>, except for aridity which was created by at CGIAR Consortium for Spatial Information (CGIAR-CSI) and accessed at <https://cgiarcsi.community/data/global-aridity-and-pet-database/>. Gridded soil data is described in Hengl et al. (2017) and provided by International Soil Reference and Information Centre at <https://www.isric.org/explore/soilgrids>. Soil data was averaged across the top 30cm of the soil profile and aggregated to 10km x 10km grid cell resolution.

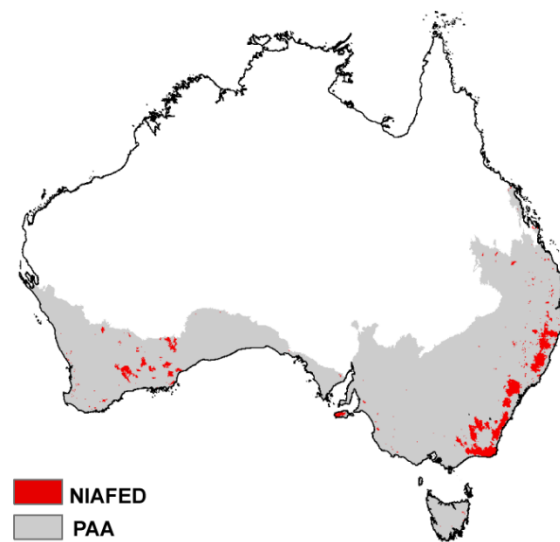
PPM models were evaluated using the area under the curve (AUC) statistic which was, on average, 0.81 (s.d. 0.16). The mean partial AUC evaluated over a range of sensitivity relevant for SDM (0.8-0.95) was 0.82 (s.d. 0.06). The mean sensitivity of binary maps used to assess range overlap (based on the 5% training threshold used to make a binary map) was 0.79 (s.d. 0.09). Small sample sizes make range bagging models difficult to meaningfully evaluate, though the mean training AUC (cross-validation not performed due to small sample size) was 0.92 (0.09 s.d.).



### *Fire extent*

The National Indicative Aggregated Fire Extent Database (NIAFED) was used to quantify the extent of the 2019-2020 bushfire season

<http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9ACDCB09-0364-4FE8-9459-2A56C792C743%7D>; Fig. 2). The NIAFED layer was only applied within the Preliminary Analysis Area (PAA; Fig. 2) as recommended by the Expert Panel.



**Figure 2.** National Indicative Aggregated Fire Extent Database (NIAFED) was used to quantify the extent of the 2019-2020 bushfire season inside the Expert Panel Preliminary Analysis Area (PAA).

The NIAFED layer has several known issues which should be considered interpretation. These include (according to the metadata record for the dataset):

- “1. The dataset draws data together from multiple different sources, including from state and territory agencies responsible for emergency and natural resource management, and from the Northern Australian Fire Information website. The variety of mapping methods means that conceptually the dataset lacks national coherency.
2. The limitations associated with the input datasets are carried through to this dataset. Users are advised to refer to the input datasets’ documentation to better understand limitations.
3. The dataset is intentionally precautionary and the rulesets for its creation elect to accept the risk of overstating the size of particular burnt areas. If and when there are overlapping polygons for an area, the internal boundaries have been dissolved.
4. The dataset shows only the outline of burnt areas and lacks information on fire severity in these areas, which may often include areas within them that are completely unburnt. For the intended purpose this may limit the usability of the data, particularly informing on local environmental impacts and response. This issue will be given priority, either for future versions of the dataset or for development of a separate, but related, fire severity product.
5. This continental dataset includes large burnt areas, particularly in northern Australia, which can be considered part of the natural landscape dynamics. For the intended purpose of

informing on fire of potential environmental impact, some interpretation and filtering may be required. There are a variety of ways to do this, including by limiting the analysis to southern Australia, as was done for recent Wildlife and Threatened Species Bushfire Recovery Expert Panel's preliminary analysis of 13 January 2020. For that preliminary analysis area, boundaries from the Interim Biogeographic Regionalisation of Australia version 7 were used by the Department to delineate an area of southern Australia encompassing the emergency bushfire areas of the southern summer. The Department will work in consultation with the expert panel and other relevant bodies in the future on alternative approaches to defining, spatially or otherwise, fire of potential environmental impact.

6. The dataset cannot be used to reliably recreate what the national burnt area extent was at a given date prior to the date of release. Reasons for this include that information on the date/time on individual fires may or may not have been provided in the input datasets, and then lost as part of the dissolve process discussed in issue 2 above.

7. Fire extents are downloaded daily and datasets are aggregated. This results in an overlap of polygon extents and raises the issue that refined extents are disregarded at this early stage.”

### ***Caveats for interpreting burnt area statistics***

Multiple types of distribution data were used to estimate burnt area for all taxa: herbarium records, range maps and - for EPBC Act listed taxa - DAWE regulatory maps. As a precaution, the largest estimate of area burnt was used to assess taxa against the prioritisation framework. All sources of data have known issues, including:

- Distributional ranges estimated from herbarium collection data may underestimate the full extent of known occurrences for a taxon due to sparse sampling across the range. This underestimation may be more pronounced for taxa with manuscript names (i.e. new taxa without databased records) or for taxa which are difficult to detect in the field. Other sources of occurrence data may be available from state agencies which may alter burnt area statistics. The likelihood of an omission error (underestimation of range) may increase as true range size decreases. The use of state agency databases of occurrence information was investigated for both NSW and WA, though was considered to duplicate resources already provided for the Interim Assessment or to have significant issues with taxonomy (J. Renwick and T. Auld pers. comm.).
- Modelled ranges are prone to two styles of potential error: (1) commission errors (overestimation of range size) as environmental conditions at known sites are extrapolated across space; and (2) omission errors resulting from occurrence data which may poorly represent the range of species where sampling is inadequate or biased.
- DAWE maps of Species of National Environmental Significance are, in some instances, precautionary in their estimation of species ranges.
- DAWE maps may also not capture the full known extent of distributions for some species. This is not unique to this source of range data, but as DAWE maps were preferred over other sources of burnt area data for EPBC Act taxa some species may have their impact underestimated. This is a known issue for some species of national significance in the Stirling Ranges National Park in Western Australia.

## **PROPOSED MANAGEMENT ACTIONS FOR EACH CRITERIA**

Management actions are provided for all criteria and are grouped into three types:

- Immediate – essential actions to undertake in the short-term
- Measured – to be undertaken before the 2020-2021 fire season, where feasible
- Universal – actions which should be applied when managing threatened or sensitive species against a background suite of potential threats

Most actions allow the gathering of specific evidence on population size and inferred or continuing threats and/or decline which is required to list species under Commonwealth, state and territory threatened species legislation using IUCN Red List criteria. It is intended that the immediate management actions scored against each taxon in Appendix 5 will guide the prioritisation of recovery actions. Management actions for each criterion are outlined in Table 2. Management actions were assigned to species based on their ranking scores and therefore do not include advice from management staff who can provide more nuanced understanding of priorities for on-ground actions.

**Table 2.** Proposed management actions for taxa listed under the prioritisation criteria. Actions are listed as immediate, measured (before the 2020-2021 fire season, where feasible) and universal.

Management Action	Criteria										Urgency of action
	A	B	C	D	E	F	G	H	I	J	
Field inspections – damage and threats			✓	✓		✓		✓	✓		Immediate
Germplasm collection			✓	✓						✓	Immediate
Field inspections - resprouting assessment	✓	✓			✓						Immediate
Field inspections - seedling emergence assessment	✓	✓			✓					✓	Immediate
Disease – field assessments and emergency germplasm collection of cuttings where resprouting is affected				✓							Immediate
Exclude forestry impacts	✓	✓			✓			✓		✓	Immediate
Alleviate herbivory		✓	✓							✓	Immediate
Field inspections - recovery assessment							✓				Medium-term
Irrigation	✓										Medium-term
Weed control						✓			✓	✓	Medium-term
Exclude prescribed fire	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Medium-term
Rapid response to wildfire	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Medium-term
Carefully-planned translocation	✓	✓	✓	✓	✓		✓	✓	✓	✓	Medium-term
Alleviate pollinator competition from feral bees and European wasp		✓	✓			✓				✓	Medium-term / Ongoing
Minimise mining impacts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Ongoing
Illegal collecting or over-collecting of germplasm or plants	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Ongoing
Habitat disturbance from human activities	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Ongoing

**Criteria are:** **A** Interactive effects of fire and drought; **B** Short fire intervals (impacts of high fire frequency); **C** Post-fire herbivore impacts; **D** Fire-disease interactions; **E** High fire severity; **F** Weed invasion; **G** Elevated winter temperatures or changed temperature regimes; **H** Fire sensitivity; **I** Post-fire erosion; **J** Cumulative exposure to high risks. Note that species listed under Criterion K will likely need some of the management actions outlined as well as actions identified by experts nominating the taxa.

**Management actions are:** **Immediate** actions are essential actions to undertake in the short-term; **Medium-term** actions are to be undertaken before the 2020-2021 fire season; **Ongoing** actions should be universally applied when managing threatened or sensitive species against a background suite of potential threats

## GENERAL RECOMMENDATIONS

- 1. Actions undertaken towards recovery should not jeopardise species.** For instance, strict hygiene protocols should be obeyed when visiting sites to avoid the spread of plant diseases or weed propagules. It is critically important to allow natural systems to recover after fire without seeding or planting interventions in the immediate to medium term. Post-fire recovery can take months or years (and even longer for some species) and will depend on certain environmental conditions. The focus in the first 12 months after the fires should be on eliminating threats to natural recovery rather than on translocation (which itself needs to be carefully planned).
- 2. Germplasm collection should be limited to species at immediate risk of local extinction.** Significant collecting of seed may jeopardise the replenishment of seedbanks and **there should be no seed collection for any species until its seed bank has been sufficiently replenished to enable population recovery in the event of a subsequent fire.** The resilience of many species to fire is dependent upon the maintenance of persistent soil or canopy seed banks. Seed banks allow post-fire seedling recruitment and the magnitude of the seed bank (along with fire-related factors such as heat and smoke) and post-fire rainfall govern the magnitude of post-fire seedling recruitment. Canopy seed banks may be exhausted by a single fire (where all plants are burnt). Soil seed banks likely provide some buffer against successive fires due to residual seeds surviving in the soil after a fire without germinating, but soil seed banks too can be exhausted in a single fire. For population persistence, seed banks need to be sufficiently replenished after a fire and before the next fire occurs. While the length of time required varies between species, an approximation is to allow three times the primary juvenile period between fires. Seed collection (e.g. for ex situ conservation or other restoration activities) prior to adequate post-fire replenishment of in situ seed banks may limit species' persistence capacity, especially as more frequent fire is predicted under a changing climate. Cases of urgent ex situ conservation may be an exception, in which case seed collection should be carried out to minimise impacts on in situ seed bank accumulation in accordance with collection guidelines for threatened plant species.
- 3. Translocation needs to be well-planned and appropriate.** Seed addition and supplementary planting (translocations) should only be considered (as a long-term option) if it is demonstrated that species fail to recover effectively at a site. Decisions to proceed with translocation should be based on rigorous post-fire site assessments of recovery and should follow appropriate national guidelines on translocation (ANPC 2019).
- 4. All taxa in high and medium categories require inspections at some time to assess active threats.** The spatial analysis and trait-based approach applied in this prioritisation will not identify all threats present across the range of a species. Appendix 5 provides a list of all HIGH and MEDIUM ranked taxa and their associated management actions.

- 5. Planned recovery actions should be made with reference to the Prioritisation Framework.** The criteria in the Prioritisation Framework reflect the need to collect data on information which is required for statutory listing of taxa, particularly under IUCN Red list criteria adopted under Commonwealth, state and territory threatened species legislation (e.g. population size, threat information, decline).

## APPLICATION OF THE PRIORITISATION FRAMEWORK

Each criterion, methods used to assess and risk categorisation across taxon cohorts (EPBC Act listed species, state listed species, state endemics and all other taxa) are detailed below. All taxon level data, including proportion of range burnt and assessment against each criterion are available in Appendix 2 (see Appendix 3 for an explanation of column names).

### Summary tables of burnt area statistics and risk categories

Table 3 details the extent of range burnt across 26,062 taxa in the 2019-2020 bushfire season. Table 4 shows which criteria are contributing to the greatest number of high risk classifications.

**Table 3.** Intersection of species ranges against National Indicative Aggregated Fire Extent Database (NIAFED) layer within the Preliminary Analysis Area (PAA). Ranges of EPBC Act taxa were quantified using the DAWE regulatory maps only. All other taxa were assessed against both cleaned AVH occurrence data and modelled ranges where available. The range of values given reflect the use of these different range size estimates. For % of taxa with range > 30, 50 or 90% burnt, this is a percentage of the total number of taxa with data available e.g. 35/1333 = 3%. Note that this table does not contain 20 species listed under Criterion K which were identified in consultation with state agencies after conclusion of the Interim Assessment.

Taxon group	Count	Plant taxa with range data available	Plant taxa impacted by 2019-2020 fires (%)	Plant taxa impacted by 2019-2020 fires (count)	Plant taxa with range > 90% burnt	Plant taxa with range > 50% burnt	Plant taxa with range > 30% burnt
EPBC Act	1335	1333	44%	585	35 (3%)	90 (7%)	148 (11%)
NSW endemics	1320	1248	77 - 92%	956 - 1152	52-104 (4-8%)	306-311 (25%)	519-626 (42-50%)
WA endemics	8952	8578	32 - 68%	2754 - 5822	4-10 (<1%)	40-45 (<1%)	98-190 (1-2%)
Vic endemics	408	362	32 - 80%	113 - 278	12-13 (3-4%)	28-31 (8-9%)	43-57 (12-16%)
SA endemics	488	457	31 - 70%	160 - 319	3-6 (0-1%)	37-38 (8%)	56-58 (12-13%)
Qld endemics	3629	3436	11 - 54%	388 - 1865	1-3 (<1%)	3-11 (<1%)	19-30 (<1%)
Tas endemics	543	525	9 - 77%	49 - 402	0 (0%)	0 (0%)	1-2 (<1%)
ACT endemics	6	6	33 - 83%	2 - 5	0 (0%)	1 (17%)	1 (17%)
Listed as threatened in NSW	700	656	59 - 91%	386 - 598	32-34 (5%)	79-107 (12-16%)	139-199 (21-30%)
Listed as threatened in WA	436	434	13 - 51%	56 - 220	1-2 (<1%)	4-12 (1-3%)	24-25 (6%)
Listed as threatened in Vic	1770	1617	60 - 93%	963 - 1499	17-18 (1%)	76-95 (5-6%)	229-249 (14-15%)
Listed as threatened in SA	807	769	53 - 87%	404 - 665	3-4 (<1%)	19-21 (2-3%)	34-40 (4-5%)
Listed as threatened in Qld	935	899	15 - 43%	138 - 387	0-2 (<1%)	3-14 (<1%)	31-38 (3-4%)
Listed as threatened in Tas	460	434	59 - 79%	257 - 344	0-1 (<1%)	2 (<1%)	14-24 (3-6%)
Listed as threatened in ACT	13	13	31 - 85%	4 - 11	0-1 (0-8%)	0-1 (0-8%)	1-2 (8-15%)
All other taxa	7976	7969	40 - 65%	3203 - 5197	2-6 (<1%)	23-71 (<1%)	216-342 (3-4%)
<b>Total</b>	<b>26062</b>	<b>25052</b>	<b>36 - 69%</b>	<b>9092 - 17197</b>	<b>90-153 (&lt;1%)</b>	<b>517-593 (3%)</b>	<b>1319-1461 (5-6%)</b>

**Table 4.** Numbers of taxa and their ranking under each of eleven criteria in the prioritisation

Criteria	A	B	C	D	E	F	G	H	I	J	K	Total
High	235	147	97	186	258	3	9	13	4	291	35	<b>831</b>
Medium	340	485	47	444	474	8	19	23	17	593	0	<b>1915</b>
Low	10375	14718	4820	3117	16080	11859	235	332	5766	1806	0	<b>16862</b>
None	14102	9498	14425	17537	8240	13182	25654	25693	19265	8543	0	<b>26062</b>
Data deficient	1010	1214	6673	4778	1010	1010	145	1	1010	14829	26027	<b>26055</b>

### CRITERION A. Interactive effects of fire and drought

Pre-fire drought can: i) reduce internally stored resources of resprouter plants that are critical in sustaining post-fire regeneration; and ii) reduce pre-fire reproductive output, impacting on the size of the seed bank available for post-fire recruitment.

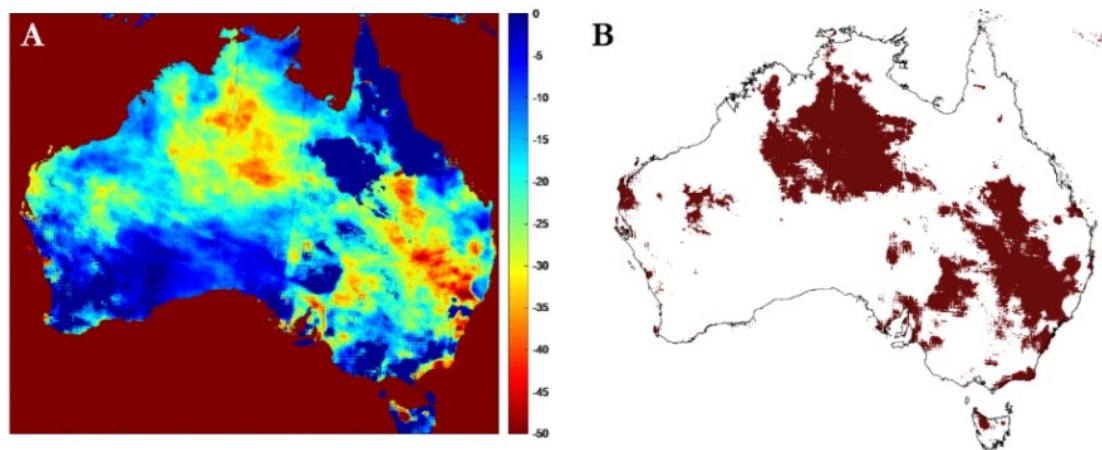
Post-fire drought can negatively impact post-fire recruitment success by reducing seed germination (due to insufficient soil moisture; possibly causing seed mortality in some dormancy types), seedling survival (through desiccation) and survival of resprouts (through xylem embolism in susceptible new shoots). Risks to mortality may be large if drought occurs in the first autumn-winter after fire or the following spring-summer.

- 1) *HIGH* – Species with  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - a) Significant pre-fire drought; OR
  - b) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 2) *MEDIUM* – Species with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - a) Significant pre-fire drought; OR
  - b) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 3) *LOW* – Species with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - a) Significant pre-fire drought; OR
  - b) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood of pre- or post-fire drought impacts in any known sites or habitat.

### Methods

Pre-fire drought was assessed by intersecting species range data with mapping of the accumulated severity of drought conditions in the 12 months prior to December 2019. The 12-month time period captures conditions during the previous growing season and was mapped as the accumulated severity of drought based on the Standardised Precipitation Index (SPI) (McKee et al. 1993). The SPI is defined as the number of standard deviations that observed cumulative precipitation deviates from the average.

Raw data values for accumulated drought severity were classified into four equal-sized bins across Australia (Figure 3). The upper quartile was assumed to adequately represent areas of significant pre-fire drought and was intersected with species range datasets.



**Figure 3.** (A) Continuous raw data values of accumulated severity of drought conditions for December 2019 according to the Standardised Precipitation Index (SPI). Lower values denote more severe drought conditions; (B) Classification of areas of significant pre-fire drought conditions used to assess against Criterion A.

### Assessment outcome

Accumulated drought severity, fire extent mapping and distributional range data were combined to assess against the criterion.

**Table 5.** Number of taxa in each risk category under Criterion A - Interactive effects of fire and drought

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	29	23	230	1051	2
State listed NSW	39	39	382	196	44
State listed WA	0	0	12	422	2
State listed Vic	41	53	1180	343	153
State listed SA	0	1	540	228	38
State listed Qld	3	5	209	682	36
State listed Tas	2	7	274	151	26
State listed ACT	0	0	5	8	0
NSW endemics	151	196	674	227	72
WA endemics	1	0	2261	6316	374
SA endemics	0	0	232	225	31
Vic endemics	16	7	113	226	46
Qld endemics	3	6	833	2594	193
Tas endemics	0	0	166	359	18
ACT endemics	0	0	2	4	0
All other taxa	25	70	4261	3613	7
<b>Total*</b>	<b>235</b>	<b>340</b>	<b>10375</b>	<b>14102</b>	<b>1010</b>

\* Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category.



## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion A (Table 5) are at specific risk from:

- Pre-fire drought affecting post-fire resprouting ability, especially where the 2019/2020 fires were of high severity.
- Post-fire drought conditions affecting seedling recruitment success and resprouting capacity.

### *Immediate actions*

**Field inspections – resprouting:** Inspections to quantify the number of plants resprouting and the survival of resprouted tissue.

**Field inspections – seedling emergence:** For obligate seeding species, field inspections to quantify seedling emergence and survival.

**Exclude forestry impacts:** Enforcement of buffers, surveys of burnt production forests to detect threatened taxa at appropriate time intervals and use of education and liaison to minimise any damage of logging activities to post-fire recovery.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

**Irrigation:** investigate the feasibility of supplementary watering during plant establishment.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires a thorough independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## CRITERION B. Short fire intervals (impacts of high fire frequency)

Exposure to short temporal intervals between successive fires can disrupt the replenishment of seed banks which are essential to post-fire recruitment and population persistence. Species most susceptible include obligate seeders (species that lack regenerative organs and rely entirely on seed germination for post-fire recovery) and resprouters (species with the capacity to generate new shoots from dormant buds post-fire) that suffer high mortality rates. The time required to replenish seed banks post-fire varies. For most species, up to 15 years between successive fires is needed to ensure that a seed bank is sufficiently replenished to maintain future post-fire populations, although some trees (for example) may require longer fire-free periods.

Short intervals between fires may also kill juveniles of resprouting plants before they become large enough to survive subsequent fires. The species that are most susceptible to these risks are resprouters that are slow to develop regenerative structures (i.e. lignotubers, thick bark, rhizomes etc.) or slow to replace mortality due to low fecundity. At least 15 years between successive fires is needed to ensure the juveniles of most plant species can develop their fire-regenerative organs, although some species such as mallee eucalypts may require at least 25 years.

Finally, some long-lived trees may suffer basal scarring where fires (or other factors related to fires such as falling trees or limbs) damage and/or kill bark tissue. This enables subsequent fires to smoulder into heartwood and weaken the structural integrity of the tree, causing mortality, collapse and structural change to the ecosystem. Trees with thin bark are most prone to this impact and replacement depends on fecundity and growth rates. Many rainforest trees and some eucalypts are susceptible and are likely to require at least 50 years between successive fires to enable partial recovery and replacement.

- 1) *HIGH* –  $\geq 25\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR
    - ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
    - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 2) *MEDIUM* –  $\geq 10\%$  to  $< 25\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR
    - ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
    - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 3) *LOW* –  $> 0\%$  to  $< 10\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR
    - ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
    - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 4) *NONE* – Either:
  - a. No known sites or habitat burnt in the 2019-2020 fires
  - b. Non-woody species with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 5 years; OR
  - c. Woody species (excluding long-lived trees prone to collapse from basal charring) with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 15 years; OR

- d. Long-lived trees prone to collapse from basal charring with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 50 years.

## Methods

### *Trait data*

Growth form data for all species was accessed from the AusTraits database <http://traitecoevo.github.io/austraits.build/> and used to characterise species as ‘woody’ or ‘non-woody’ as follows:

Growth form	Class
Herb	non-woody
Shrub	woody
Tree	woody
Climber	(case dependent)
Shrub/Tree	woody
Subshrub	woody
Graminoid	non-woody
Epiphyte	non-woody
Parasite	non-woody
Aquatic	non-woody
Palm	non-woody
Climber/Herb	non-woody
Climber/Shrub	woody
Climber/Tree	woody
Fern	non-woody
Geophyte	non-woody
Herb/Shrub	woody

Growth form data in AusTraits is largely sourced from published floras for each state and the Flora of Australia Online <http://www.anbg.gov.au/abrs/online-resources/flora/main-query-styles.html>.

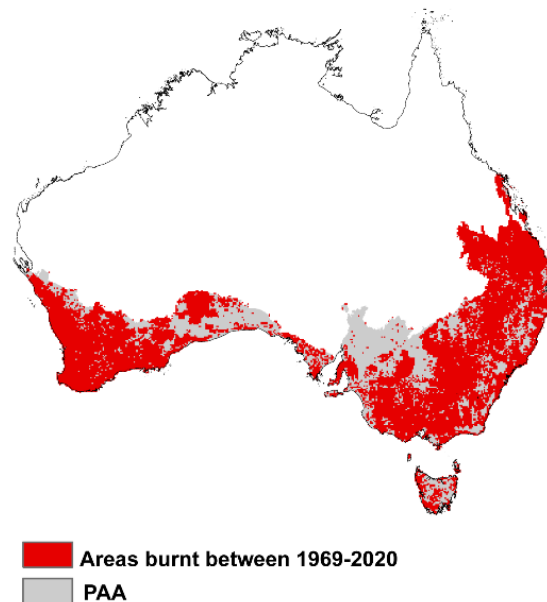
### *Fire history data*

Multiple resources were combined to produce a single fire history layer for Australia (Fig. 4). These resources are:

- (1) Mapping from the Global Fire Atlas <https://www.globalfiredata.org/fireatlas.html> for years 2003-2016. The Global Fire Atlas tracks the daily dynamics of individual fires to determine the timing and location of ignitions, fire size and duration, and daily expansion, fire line length, speed, and direction of spread. Methods are detailed in Andela et al.

(2019). These methods were also used to map data on extent in each annual fire season between 2017-2020 (Kang He, unpublished data).

- (2) NSW National Parks and Wildlife Service Fire History – Wildfire and Prescribed Burns dataset <https://data.nsw.gov.au/data/dataset/1f694774-49d5-47b8-8dd0-77ca8376eb04>. This dataset shows areas burnt since 1903 across NSW and has known limitations to its use in some parts of the state (e.g. Western Division) which fall largely outside the PAA.
- (3) Victorian Department of Environment, Land, Water and Planning Fire History dataset provided under license.
- (4) Western Australian Department of Biodiversity, Conservation and Attractions Fire History dataset (1969-2020) provided under license. In non-forested areas of WA (e.g. Great Western Woodlands, arid zone and south coast) precise dates of fire are unknown for the period 1969-70 and overall coverage of fire history mapping is likely to be less accurate on private lands (C. Gosper pers. comm.).



**Figure 4.** Areas burnt between 1969 and 2020 from multiple sources: (1) remotely sensed mapping of fire extent from the Global Fire Atlas, (2) the NPWS Fire History – Wildfire and Prescribed Burns dataset for NSW, (3) DELWP Victoria Fire History dataset, and (4) WA DBCA Fire History dataset.

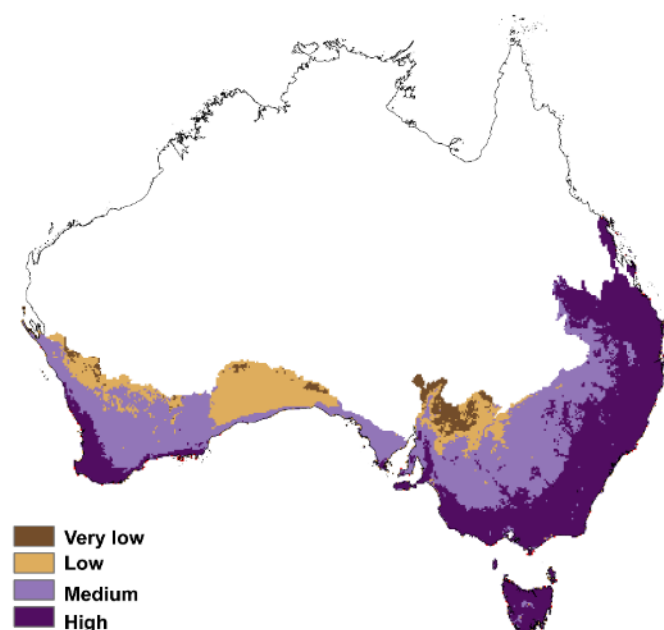
### ***Short fire interval assessment***

Data on traits and fire history were combined with information on the productivity of Australian vegetation to produce an estimate of appropriate fire return times across the PAA. Specifically, a spatial layer of the estimated Gross Primary Productivity (GPP, g C m<sup>-2</sup> year<sup>-1</sup>) of vegetation calculated using a Vegetation Photosynthesis Model (VPM) at spatial resolution (0.05 degree) was accessed from Zhang et al. (2017) (Fig. 5). Raw values of GPP were classified into four categories based on quartiles (extremely low, low, medium, high) and fire return times were estimated for each category based on a review of the literature as follows:

GPP category	Woody species	Non-woody species
Extremely low	25 years	12 years
Low	20 years	10 years
Medium	15 years	8 years
High	10 years	5 years

Return times required for regeneration of some woody taxa in high GPP areas may be longer than 10 years, particularly for fire sensitive eucalypts and slow growing taxa.

All areas classified as the Major Vegetation Grouping 'Rainforest' in the National Vegetation Inventory System were excluded from this analysis and assumed to have inappropriate fire regimes if burnt at any time since 1969.



**Figure 5.** Four categories of vegetation productivity across the PAA based on quartiles of Gross Primary Productivity (GPP). Raw data on GPP sourced from Zhang et al. (2017).

Fire return times based on GPP were combined with fire history data to create a spatial layer of all locations where the interval between the 2019-2020 fires and the previous recorded fire was too short to accommodate plant regeneration. Separate layers were generated for woody or non-woody return times. Species range data was then intersected with the spatial layers of fire intervals to assess the proportion of the range which is exposed to inappropriately short fire return times.

### Assessment outcome

Data on fire history, 2019-2020 fire extent, traits and distributional range were combined to assess against the criterion.

**Table 6.** Number of taxa in each risk category under Criterion B - high fire frequency

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	25	42	338	928	2
State listed NSW	30	59	398	167	46
State listed WA	0	2	111	321	2
State listed Vic	11	54	1300	249	156
State listed SA	1	1	541	224	40
State listed Qld	5	23	261	609	37
State listed Tas	0	2	277	153	28
State listed ACT	0	0	5	8	0
NSW endemics	107	261	674	203	75
WA endemics	6	31	5183	3349	383
Vic endemics	9	11	199	141	48
SA endemics	1	0	184	272	31
Qld endemics	5	15	1684	1716	209
Tas endemics	0	0	17	505	21
ACT endemics	0	0	1	5	0
All other taxa	12	96	4856	2838	174
<b>Total*</b>	<b>147</b>	<b>485</b>	<b>14718</b>	<b>9498</b>	<b>1214</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category.

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion B (Table 6) are at specific risk from:

- Short fire return cycles which eliminate regenerating plants. Many of the populations of obligate seeding species must mature and replenish seedbanks before further fires lead to local declines and possibly local extinctions. Short intervals between fires may also kill juveniles of resprouting plants before they become large enough to survive subsequent fires.

### *Immediate actions*

**Field inspections to assess resprouting:** Inspections to quantify the number of plants resprouting and the survival of resprouted tissue.

**Field inspections to assess seedling emergence:** For obligate seeding species, inspections to quantify seedling emergence and survival.

**Exclude forestry impacts:** Enforcement of buffers, surveys of burnt production forests to detect threatened taxa at appropriate time intervals and use of education and liaison to minimise any damage of logging activities to post-fire recovery.

**Alleviate herbivory:** exclusion or removal of feral grazers, stock and excessive native herbivores by fencing and feral animal control.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires a thorough independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION C. Post-fire herbivore impacts**

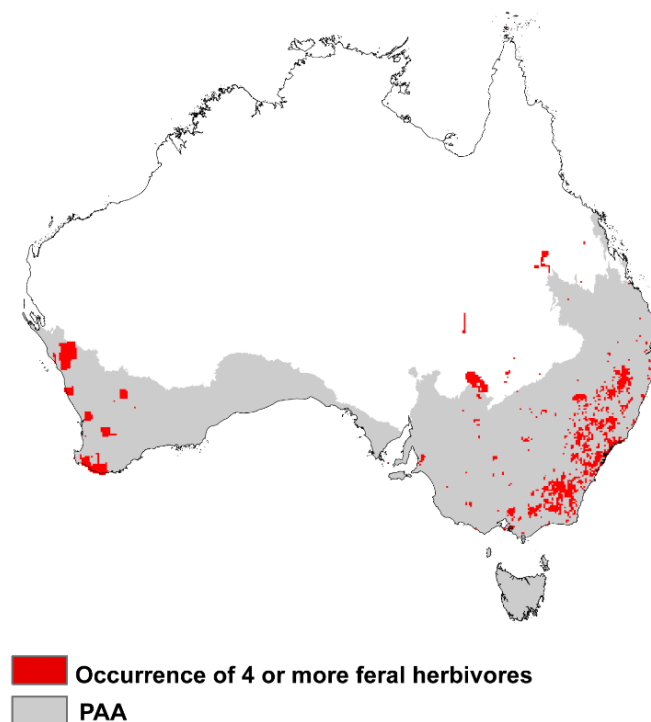
Plants are often at their most palatable and least resilient to herbivore activity (e.g. leaf and shoot removal, trampling and substrate degradation) in the post-fire environment where herbivores have enhanced foraging efficiency and converge on regenerating burnt areas to exploit fresh growth. Concentrations of herbivores may therefore increase mortality of both seedlings and resprouters of palatable plants. In some cases, elevated mortality may lead to local extinction. Effects may be exacerbated when burnt patches are small or have high perimeter to area ratios which promote herbivore incursions in high densities.

- 1) *HIGH* – Evidence or likelihood of significant post-fire grazing impacts AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Evidence or likelihood of significant post-fire grazing impacts AND obligate seeder with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Evidence or likelihood of significant post-fire grazing impacts AND either:
  - a) Obligate seeder with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires; OR
  - b) Resprouter with  $> 0$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood of significant post-fire grazing impacts in any known sites or habitat.

## Methods

This criterion was assessed using spatial data on the likely distribution of five non-native mammal species which are known to cause significant impacts to plant species across their range: horse (*Equus caballus*), pig (*Sus scrofa*), goat (*Capra hircus*), deer (various species) and rabbit (*Oryctolagus cuniculus*). National mapping of the distributional range of all herbivores was accessed from <https://pestsmart.org.au/national-mapping-pest-animals-abundance-part1/> and sourced by DAWE. Range maps were combined to create a single spatial layer detailing the number of feral herbivore species (0-5) presumed present in each 10km x 10km grid cell across the PAA (Fig. 6). Taxa with >50% of their range burnt and four or more feral herbivores mapped as likely to be present across these burnt areas were classified as HIGH risk. MEDIUM and LOW risk taxa had 30-50% and 10-30% of range burnt plus four feral herbivores likely present in these areas, respectively.

Spatial data on occurrence can provide a broad perspective on the potential exposure of herbivores, however expert knowledge of on-ground impacts should also be considered when designing post-fire management actions. This may consider the palatability of species and likely requires field assessment to verify.



**Figure 6.** Areas where  $\geq 4$  feral herbivores (horse, pig, goat, deer or rabbit) are present based on mapping of potential distributions. Raw data accessed from: <https://pestsmart.org.au/national-mapping-pest-animals-abundance-part1/>



## Assessment outcome

Data on feral herbivore distributions, 2019-2020 fire extent, and distributional range were combined to assess against the criterion.

**Table 7.** Number of taxa in each risk category under Criterion C - Post-fire herbivore impacts

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	17	14	105	1066	133
State listed NSW	27	16	171	224	262
State listed WA	0	0	3	404	29
State listed Vic	22	18	901	408	421
State listed SA	0	0	323	302	182
State listed Qld	1	4	48	763	119
State listed Tas	0	0	208	156	96
State listed ACT	0	0	3	6	4
NSW endemics	54	18	427	257	564
WA endemics	1	0	740	5366	2845
Vic endemics	7	1	129	181	90
SA endemics	0	0	56	358	74
Qld endemics	1	0	73	3040	515
Tas endemics	0	0	11	505	27
ACT endemics	1	0	1	3	1
All other taxa	10	7	2178	4034	1747
<b>Total*</b>	<b>97</b>	<b>47</b>	<b>4820</b>	<b>14425</b>	<b>6673</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category.

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion C (Table 7) are at specific risk from:

- Browsing or grazing of regenerating tissues by herbivores which reduces the likelihood of successful recovery
- Trampling of emerging seedlings and associated habitat damage

### *Immediate actions*

**Field inspections – damage and threats:** to quantify the damage to standing or recovering plants from the fires or from other threats (e.g. *herbivory*, disease, weed invasion, erosion).

**Alleviating herbivory:** exclusion or removal of feral grazers, stock and excessive native herbivores by fencing and feral animal control.

**Germplasm collection:** during field inspections, germplasm collection of seeds and/or cuttings for species at immediate risk of local extinction should be conducted to preserve the species in ex-situ cultivation and allow for reintroduction.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires a thorough independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION D. Fire-disease interactions**

Plant species from particular genera and families are susceptible to diseases such as *Phytophthora* spp., *Armillaria* spp., Myrtle Rust, Canker fungi and other pathogens. Tissue death caused by these diseases reduces the capacity of plants to acquire resources through their roots and/or leaves. Plants are more sensitive to resource deprivation in the post-fire period and reduced post-fire survival rates have been observed in areas infected by disease, such that fire accelerates disease-related population decline. Resprouting individuals in certain families appear most susceptible to this threat. Disease effects may be exacerbated by drought.

- 1) *HIGH* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood of pathogen/disease susceptibility

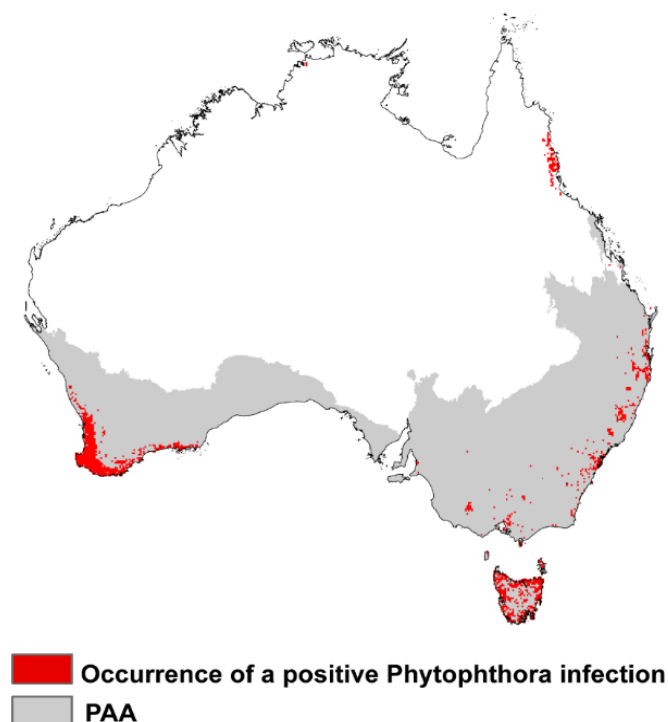
## Methods

Two major plant pathogens affecting native species in Australia were targeted for this analysis: *Phytophthora cinnamomi* (phytophthora) and *Austropuccinia psidii* (myrtle rust). The risk associated with each pathogen was assessed separately and then combined to give an overall disease risk rank due to the different cohorts of species which are susceptible.

### *Phytophthora*

Taxa known to be susceptible to *Phytophthora cinnamomi* were collated from multiple expert-advised resources (Threat Abatement Plan for Phytophthora (Commonwealth Government 2018; McDougall & Liew, unpublished data; WA DBCA). These 214 taxa were classified as HIGH risk if >30% of their range was burnt, or MEDIUM risk if <30% burnt.

All other taxa were assessed for risk of phytophthora exposure through spatial analysis of the overlap between their burnt range and areas of known phytophthora infection derived from national datasets. A basic phytophthora risk map was created from point occurrence data of known sites of infection accessed from Burgess et al. (2016) and, for Western Australia, under license from the DBCA Plant Diseases Program (Fig. 7). All 10km x 10km grid cells across the PAA with documented infections were classified as known areas of infection risk and mapped. Taxa from genera with species known to be susceptible ( $n = 7,752$  species) with >50% of their range burnt and phytophthora risk present in these burnt areas were also classified HIGH risk. Taxa in susceptible genera were ranked MEDIUM risk of post-fire phytophthora impacts if <30% of the range was burnt, and LOW risk if >0% and <30% of their range was burnt.

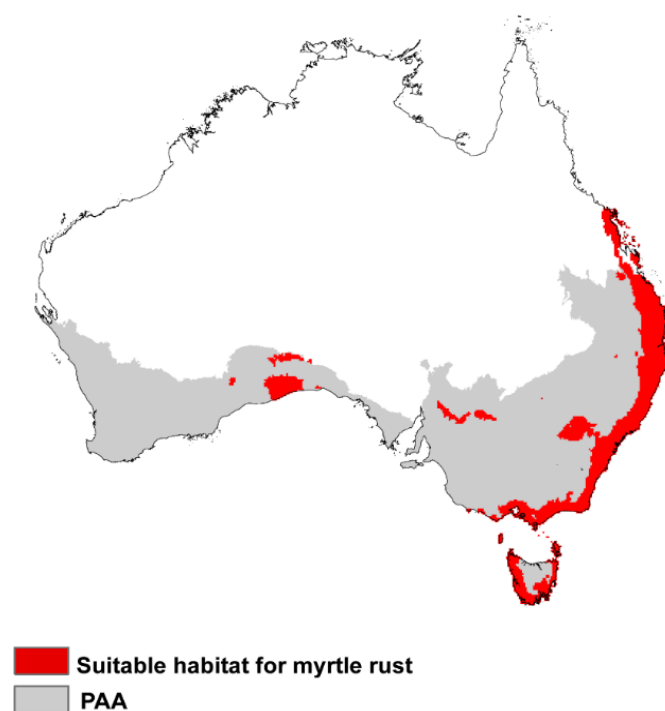


**Figure 7.** Known areas of infection risk for *Phytophthora cinnamomi* at a 10km x 10km scale across the PAA. Raw data accessed from Burgess et al. (2016) and WA DBCA Plant Diseases Program under license.

### *Myrtle rust*

Taxa known to be susceptible to myrtle rust were accessed from the national review of the impacts of the pathogen on Australian plants (Makinson 2018). Additional susceptible species not listed in Makinson (2018) were also provided (B. Makinson pers. comm.). Taxa with a susceptibility ranking of ‘relatively tolerant’ in Makinson (2018) were excluded from this analysis. Taxa with >30% of their range burnt and susceptibility to myrtle rust according to Makinson (2018) were classified as HIGH risk. Taxa with >0% and <30% of their range burnt and susceptibility to myrtle rust were classified as MEDIUM risk.

All other taxa in the family Myrtaceae lacked data on susceptibility to myrtle rust but may still be affected by the fungus. These species were assessed by intersecting burnt areas of their range with national mapping of suitable habitat for myrtle rust from Berthon et al. (2018) (Fig. 8). Taxa with >50% of their range burnt and suitable habitat for myrtle rust present in these burnt areas were classified as MEDIUM risk. Taxa with >0% and <50% of their range burnt and suitable habitat for myrtle rust present in these burnt areas were classified as LOW risk.



**Figure 8.** Suitable habitat for *Austropuccinia psidii* (myrtle rust) across the PAA based on distribution modelling. Raw data accessed from Berthon et al. (2018).

### Assessment outcome

Data on phytophthora and myrtle rust susceptibility and risk of exposure, 2019-2020 fire extent, and distributional range were combined to assess against the criterion.

**Table 8.** Number of taxa in each risk category under Criterion D - Fire-disease interactions

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	33	57	70	1088	87
State listed NSW	18	32	95	343	212
State listed WA	24	30	24	356	2
State listed Vic	7	17	206	875	665
State listed SA	0	14	56	460	277
State listed Qld	9	18	26	749	133
State listed Tas	1	11	38	183	227
State listed ACT	0	0	1	11	1
NSW endemics	39	72	430	501	278
WA endemics	103	122	1495	6839	393
Vic endemics	0	7	30	315	56
SA endemics	0	4	10	437	37
Qld endemics	8	42	161	2991	427
Tas endemics	2	21	45	382	93
ACT endemics	0	0	1	5	0
All other taxa	19	136	659	4885	2277
<b>Total*</b>	<b>186</b>	<b>444</b>	<b>3117</b>	<b>17537</b>	<b>4778</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category.

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion D (Table 8) are at specific risk from:

- Infection by Myrtle Rust (*Austropuccinia psidii*) and *Phytophthora cinnamomi* and infection is known to particularly effect young, regenerating tissues.

### *Immediate actions*

**Field inspections – damage and threats:** to quantify the damage to standing or recovering plants from the fires or from other threats (e.g. herbivory, *disease*, weed invasion, erosion).

**Disease:** Treatment of soil or plants to enhance their ability to cope with diseases. Maintenance of strict phytosanitary measures during site visits to minimise risk of disease transfer and introduction.

**Germplasm collection:** during field inspections, germplasm collection of seeds and/or cuttings for species at immediate risk of local extinction should be conducted to preserve the species in ex-situ cultivation and allow for reintroduction.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires a thorough independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION E. High fire severity**

In some plant species, survival of established individuals and/or seed banks may be sensitive to fire severity due to limitations in the insulating capacity of protective tissues (thickness of bark or walls of serotinous fruits). Species that rely on persistence of long-lived standing plants (due to low fecundity) or post-fire regeneration from small serotinous fruits are most susceptible to this mechanism of decline. For long-lived trees, these effects may be cumulative through successive fires (high fire frequency – see B above) that undermine their structural integrity. In such cases, fire severity impacts may be influenced by prolonged basal and internal smouldering rather than canopy consumption (as commonly reflected in fire severity maps). Effects may be exacerbated by drought reducing water content within insulating tissues prior to fires.

- 1) *HIGH* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires at high severity (i.e. fire likely to cause death or serious damage and recovery is not certain).
- 2) *MEDIUM* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in 2019-2020 fires at high severity.
- 3) *LOW* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires at high severity.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt at high severity in the 2019-2020 fires; OR
  - b) Survival of standing plants and/or seed bank is largely unaffected by fire severity.

## Methods

Spatial data on fire severity was accessed from the Australian Google Earth Engine Burnt Area Map (AUS GEEBAM) under license. The metadata record for this dataset provides a list of known issues and can be accessed here:

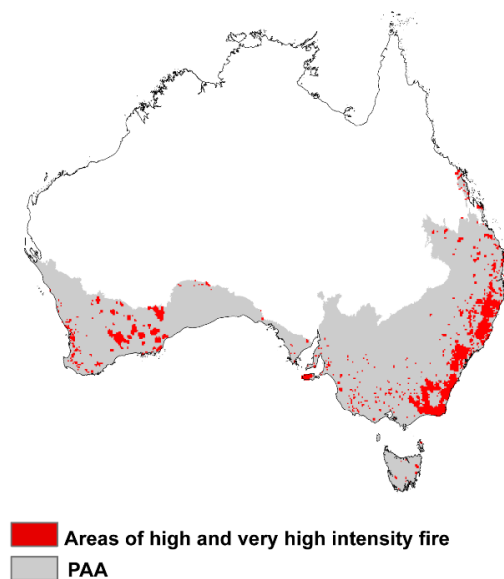
<http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B8CE7D6BE-4A82-40D7-80BC-647CB1FE5C08%7D>

and notes the following:

“AUS GEEBAM Fire Severity uses Sentinel 2A satellite imagery from before and after fire to estimate the severity of burn within each 40m grid cell. Fire severity is defined as a metric of the loss or change in organic matter caused by fire. The extent of the 2019/2020 fires was derived from the National Indicative Aggregated Fire Extent Dataset (NIAFED). NIAFED was sourced from the national Emergency Management Spatial Information Network Australia (EMSINA) data service, which is the official fire extent currently used by the Commonwealth and adds supplementary data from other sources to form a cumulative national view of fire extent. AUS GEEBAM relies on a vegetation index (Relativised Normalized Burnt Ratio, RNBR) that is calculated for burnt areas and adjacent unburnt areas, before and after the fire season. The result is a map of four fire severity classes that represent how severely vegetation was burnt during the 2019/2020 fires.

To determine a reference unburnt condition, the NIAFED extent was buffered by 2km. For each NVIS broad vegetation type, in each IBRA bioregion a reference unburnt RNBR class was determined. That value was available to calculate a standardised offset or a reference unburnt value. Each IBRA bioregion was systematically assessed to correct for obvious errors. For example, the Very High severity class could be adjusted down by one RNBR Value for a fire where its extent extended into an area of lower severity. Conversely, there were areas of shrublands that had clearly burnt at Very High severity where all of the biomass is likely to have been consumed but low pre-fire biomass had given it a lower RNBR Value. Each pixel of AUS GEEBAM contains the raw RNBR Value, the RNBR Class and the GEEBAM Value. This allows an end user to observe which values have been adjusted during the calibration away from the default global RNBR Value and allows for some transparency in the process.”

Data for the two highest severity classes in AUS GEEBAM (High and Very High) were reclassified to create a single spatial layer of ‘high’ severity fire (Fig. 9). Each species distribution was then intersected with the severity dataset to calculate the proportion of the range burnt at high severity. Species with 50% of their range burnt at high severity were considered HIGH risk, 30-50% at MEDIUM risk and <30% at LOW risk.



**Figure 9.** Areas classified as high or very high severity fire in the Australian Google Earth Engine Burnt Area Map (AUS GEEBAM).

### Assessment outcome

Data for fire severity, 2019-2020 fire extent, and distributional range were combined to assess against the criterion.

**Table 9.** Number of taxa in each risk category under Criterion E - High fire severity

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	29	56	446	802	2
State listed NSW	34	58	442	122	44
State listed WA	7	10	124	293	2
State listed Vic	42	70	1341	164	153
State listed SA	10	18	601	140	38
State listed Qld	3	13	327	556	36
State listed Tas	1	4	321	108	26
State listed ACT	0	0	8	5	0
NSW endemics	116	208	782	142	72
WA endemics	38	70	5546	2924	374
Vic endemics	23	10	211	118	46
SA endemics	24	26	251	156	31
Qld endemics	7	11	1788	1630	193
Tas endemics	0	0	379	146	18
ACT endemics	0	0	3	3	0
All other taxa	14	65	5125	2765	7
<b>Total*</b>	<b>258</b>	<b>474</b>	<b>16080</b>	<b>8240</b>	<b>1010</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category



## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion E (Table 9) are at specific risk from:

- High fire temperatures that scorch the soil seedbank and limit recovery via seedling emergence, particularly for obligate seeding species.
- Damage to regenerative organs in resprouting species (e.g. lignotubers, epicormic buds)
- Loss of the canopy-held seedbank

### *Immediate actions*

**Field inspections to assess resprouting:** Inspections to quantify the number of plants resprouting and the survival of resprouted tissue.

**Field inspections to assess seedling emergence:** For obligate seeding species, inspections to quantify seedling emergence and survival.

**Exclude forestry impacts:** Enforcement of buffers, surveys of burnt production forests to detect threatened taxa at appropriate time intervals and use of education and liaison to minimise any damage of logging activities to post-fire recovery.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires a thorough independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

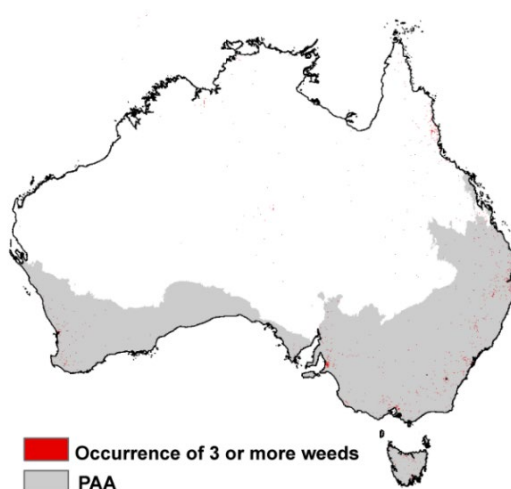
## CRITERION F. Weed invasion

Some sites are predisposed to invasion by transformer exotic plants. Fire may provide opportunities for growth of existing exotics or entry of these species into the vegetation (especially where weed sources are within or proximal to burnt areas) and subsequent elimination of native species through competition. Native species that occur mainly in areas where bushland has been fragmented, disturbed by logging or clearing, or affected by runoff from nutrient sources (e.g. urban infrastructure, improved pasture, wastewater or stormwater disposal etc.) are most susceptible to this mechanism, and these factors should be considered in assessing the likelihood of weed impacts below.

- 1) *HIGH* – Evidence or likelihood of significant weed impacts post-fire AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Evidence or likelihood of significant weed impacts post-fire AND  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Evidence or likelihood of significant weed impacts post-fire AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires OR
  - b) No evidence or likelihood of significant weed impacts post-fire in any known sites or habitat.

## Methods

A list of 732 taxa from national and international invasive plant species lists was compiled and occurrence records accessed from the Australasian Virtual Herbarium. These 732 taxa include species on the Weeds of National Significance list (and shortlist), previously declared noxious weeds in NSW, national sleeper weeds and alert lists, and the 100 of the World's Worst Invasive Alien Species list [http://www.iucngisd.org/gisd/100\\_worst.php](http://www.iucngisd.org/gisd/100_worst.php). Occurrence records for each taxon were limited to the time period 1990-present and were buffered by 2km and stacked using the *raster* package in R. Weed species richness in each 2km grid cell was then mapped and areas with  $\geq 3$  weed species were identified (Fig. 10). Weed species may be highly locally abundant and this analysis will not capture these areas of infestation. For instance, in NSW where data on local weed abundance is available or can be inferred weed invasion was considered an important driver of post-fire impacts (Auld *et al.* 2020). Species listed as threatened where weed impacts have been identified as a key threat should also be considered as potentially at risk.



**Figure 10.** Weed occurrence mapping based on records of 723 known weed species in Australia. Occurrence records were accessed from the Australasian Virtual Herbarium for the period 1990-present in March 2020.

## Assessment outcome

Data on weed occurrence, 2019-2020 fire extent, and distributional range were combined to assess against the criterion.

**Table 10.** Number of taxa in each risk category under Criterion F – Weed invasion

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	0	0	220	1113	2
State listed NSW	0	2	340	314	44
State listed WA	0	0	38	396	2
State listed Vic	0	0	1142	475	153
State listed SA	0	0	487	282	38
State listed Qld	0	0	216	683	36
State listed Tas	0	0	278	156	26
State listed ACT	0	0	7	6	0
NSW endemics	2	6	796	444	72
WA endemics	0	0	3302	5276	374
Vic endemics	0	0	125	237	46
SA endemics	0	0	169	288	31
Qld endemics	0	1	1405	2030	193
Tas endemics	0	0	18	507	18
ACT endemics	0	0	2	4	0
All other taxa	1	1	4262	3705	7
<b>Total*</b>	<b>3</b>	<b>8</b>	<b>11859</b>	<b>13182</b>	<b>1010</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion F (Table 10) are at specific risk from:

- Competition from over-abundant species, in particular ‘transformer’ weed species which can rapidly change habitat upon spread, leading to failure of seedling regeneration.

### *Immediate actions*

**Field inspections – damage and threats:** to quantify the damage to standing or recovering plants from the fires or from other threats (e.g. herbivory, disease, *weed invasion*, erosion).

### *Medium-term actions*

**Weed control:** removal and control of weeds that may outcompete plants and impede post-fire recovery.

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Exclude mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION G. Elevated winter temperatures or changed temperature regimes**

Seed germination of some plants in alpine and subalpine (or frost-hollow) habitats is reliant on cold stratification during winter. Alpine plant phenology is also affected by temperature. If the 2020 winter is warm, seedling regeneration may be reduced with flow-on effects on seed bank replenishment. Species with short-lived standing plants and/or short-lived seed banks are likely to be most susceptible. Enhanced insolation of fire-blackened soils may exacerbate climatic warming effects. For other species diurnal temperature cycles cue germination and changes to these cycles may delay or reduce germination.

- 1) *HIGH* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND with  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND obligate seeder with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND either:
  - a) Obligate seeder with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires; OR
  - b) Resprouter with  $> 0$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence that cold stratification is needed for successful seedling recruitment post-fire.

## **Methods**

A list of 415 taxa which occur in subalpine regions known to have been impacted by the 2019-2020 fires (K. McDougall pers. comm.) was collated from Doherty et al. (2015). As a precautionary measure, all taxa in this group were considered to potentially require cold stratification for germination. Data on regeneration capacity (e.g. resprouting, obligate seeding) were collated from AusTraits.

## Assessment outcome

Lists of subalpine taxa, 2019-2020 fire extent, and distributional range were combined to assess against the criterion.

**Table 11.** Number of taxa in each risk category under Criterion G - Elevated winter temperatures or changed temperature regimes

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	2	0	5	1325	3
State listed NSW	2	0	8	686	4
State listed WA	0	0	0	436	0
State listed Vic	1	11	81	1646	31
State listed SA	0	0	23	772	12
State listed Qld	0	0	1	933	1
State listed Tas	0	2	26	426	6
State listed ACT	0	0	0	12	1
NSW endemics	5	1	5	1301	8
WA endemics	0	0	0	8952	0
Vic endemics	0	1	1	406	0
SA endemics	0	0	0	488	0
Qld endemics	0	0	0	3629	0
Tas endemics	0	0	0	543	0
ACT endemics	0	0	0	6	0
All other taxa	3	7	122	7751	93
<b>Total*</b>	<b>9</b>	<b>19</b>	<b>235</b>	<b>25654</b>	<b>145</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion G (Table 11) are at specific risk from:

- Warmer than average winter temperatures in the 2020 winter which may influence cold stratification requirements of alpine/subalpine/frost hollow taxa, growth and phenology.

### *Immediate actions*

None. Actions required following winter 2020.

### *Medium-term actions*

**Field inspections for recovery assessment:** to quantify factors such population size and demography.

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Ensure rapid response to wildfire:** any future wildfires that threaten to burn over recovering sites should be rapidly extinguished.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Exclude mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION H. Fire sensitivity**

Some plant species have no means of *in situ* persistence through fire events because their standing plants lack protected regenerative organs and there is no seed bank. A single fire may eliminate such species or damage a significant proportion of individuals in the population, which must then rely entirely on dispersal from unburnt populations for re-establishment in the area.

- 1) *HIGH* –  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 2) *MEDIUM* –  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 3) *LOW* –  $> 0$  to  $< 30\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) Species is not a long-lived tree prone to collapse from basal charring AND either:
    - i) Can resprout; OR
    - ii) Has a seed bank.

## **Methods**

A list of 463 rainforest tree taxa greater than 30m in maximum height was accessed from the AusTraits database. These taxa are considered long-lived and prone to collapse from basal charring. A list of taxa known to resprout or have a soil seedbank was also compiled from AusTraits which includes the NSW Fire Response Register (DPIE) and fire response datasets from state agency staff (M. White, S. Sinclair pers. comm.).

## Assessment outcome

Lists of long-lived taxa, regeneration traits, 2019-2020 fire extent, and distributional range data were combined to assess against the criterion.

**Table 12.** Number of taxa in each risk category under Criterion H - Fire sensitivity

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	2	1	20	1312	0
State listed NSW	2	2	31	664	1
State listed WA	0	0	0	436	0
State listed Vic	4	0	4	1762	0
State listed SA	0	0	1	806	0
State listed Qld	1	1	22	911	0
State listed Tas	0	0	0	460	0
State listed ACT	0	0	0	13	0
NSW endemics	8	7	7	1298	0
WA endemics	0	0	0	8952	0
Vic endemics	0	0	0	408	0
SA endemics	0	0	0	488	0
Qld endemics	0	2	148	3479	0
Tas endemics	0	0	3	540	0
ACT endemics	0	0	0	6	0
All other taxa	0	12	140	7824	0
<b>Total*</b>	<b>13</b>	<b>23</b>	<b>332</b>	<b>25693</b>	<b>1</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion H (Table 12) are at specific risk from:

- Loss of mature plants, particularly where seeds are held in the canopy with no or limited soil seedbank and no capacity to resprout.

### *Immediate actions*

**Field inspections – damage and threats:** to quantify the damage to standing or recovering plants from the fires or from other threats (e.g. herbivory, disease, weed invasion, erosion). Damage inspections are particularly important for rainforest taxa that are long-lived trees prone to collapse from basal charring to assess the scale of tree loss or damage.

**Exclude forestry impacts:** Enforcement of buffers, surveys of burnt production forests to detect threatened taxa at appropriate time intervals and use of education and liaison to minimise any damage of logging activities to post-fire recovery.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Rapid response to wildfire:** ensure that any future wildfires that threaten to burn over recovering sites are rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires an independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION I. Post-fire erosion**

Intense rainfall events after fires may lead to extensive localised erosion that either covers recovering plants in soil and ash or depletes soil seed banks. In steep terrain, post-fire erosion may dislodge rocks and trees or cause larger scale landslides with associated plant mortality. Effects are likely to be localised and evident in the first few months after a fire. Steep habitats, riparian habitats, peaty habitats and unconsolidated floodplains or sandplains would seem to be potentially vulnerable to erosion.

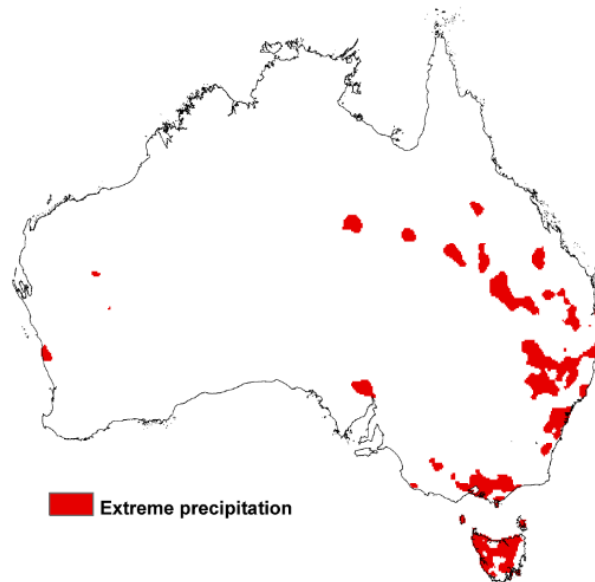
- 1) *HIGH* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $> 0$  to  $< 30\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood that species has been impacted by severe post-fire soil erosion.



## Methods

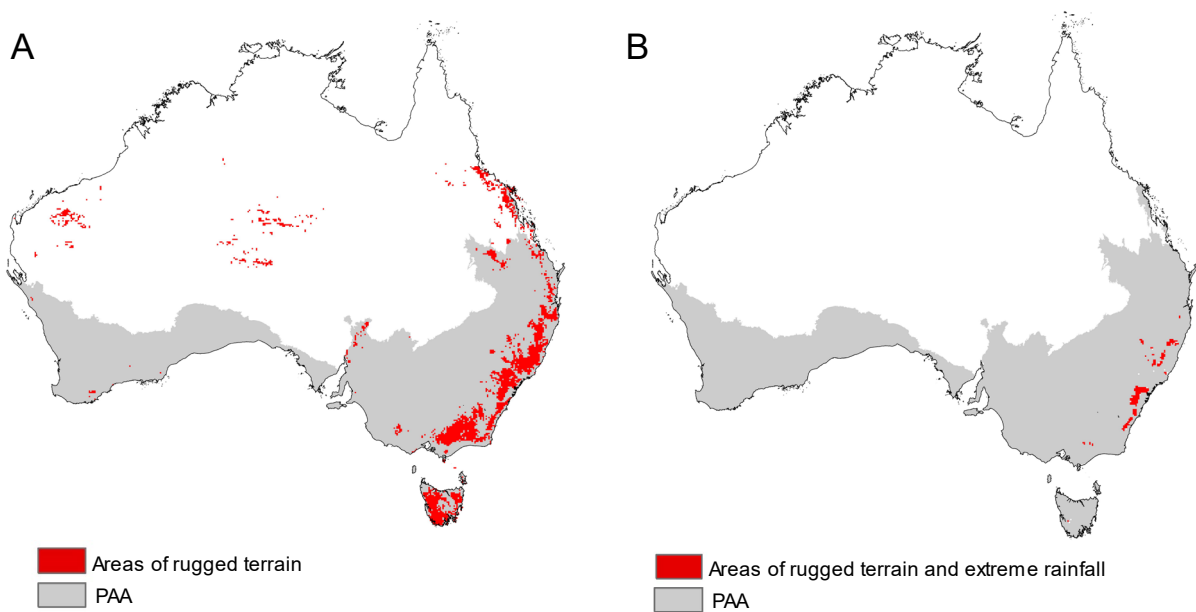
A combination of spatial data on extreme precipitation across the fire grounds and terrain characteristics were used to approximate erosion potential. Erosion is influenced by extreme rainfall events, erodibility of soils (especially after vegetation cover has been removed), and the ruggedness of terrain. This is especially acute in the Alps, or on slopes where wind and frost are also agents of erosion, particularly at high altitude.

A spatial layer of extreme rainfall between January 15 2020 and March 15 2020 was created using daily rainfall data from the Australian Water Availability Project (AWAP) via <http://www.bom.gov.au/jsp/awap/>. Methods used to derive the AWAP are described in Jones et al. (2009). Grid cell size was aggregated from 0.05 x 0.05 to 0.1 x 0.1 degrees of latitude using the *raster* package in R. Daily rainfall data was summed for the period between the 15th January to the 15th of March for the years 2000 to 2020. For this period, the mean and standard deviation of rainfall was calculated across 2000-2019 (20 years) and 2020 rainfall compared to the mean by calculating how many standard deviations this year was from average. Locations which were 2 standard deviations away from the average rainfall over the previous 20-year period were classified as areas of extreme rainfall (Fig. 11).



**Figure 11.** Areas of extreme precipitation in the period January 15<sup>th</sup> 2020-March 15<sup>th</sup> 2020, relative to average rainfall in this time period between 2000 and 2019. Red areas are two standard deviations from the mean 2000-2019 conditions.

This spatial layer of extreme rainfall over the fire grounds was intersected with a Topographic Ruggedness Index (TRI) derived from a digital elevation model (DEM) at 250m resolution accessed from <https://www2.jpl.nasa.gov/srtm/>. TRI was calculated using the spatialEco package in R, which conducts a moving window analysis of the slope in adjacent cells in a DEM. The window for analysis was 3 x 3 pixels, equating to 0.0075 x 0.0075 degrees which is approximately 750m x 750m. Values of TRI range from 0-1700, and were classified into multiple categories as recommended by the spatialEco package authors: 0-80 = level terrain, 81-116 = nearly level, 117-161 = slightly rugged, 162-239 = intermediately rugged, 240-497 = moderately rugged, 498-958 = highly rugged, 959-above = extremely rugged. All values classified as moderately rugged and above were combined into a single layer of rugged terrain across the PAA (Fig. 12).



**Figure 12.** (A) Areas of rugged terrain derived from a Topographic Ruggedness Index (TRI) calculated from a digital elevation model at 250m resolution. Raw data accessed from <https://www2.jpl.nasa.gov/srtm/> and (B) Areas of rugged terrain intersected with areas of extreme precipitation (from Fig. 11).

Taxa with >50% of their range burnt which was also in rugged terrain subject to extreme rainfall were categorised as HIGH risk. MEDIUM and LOW risk taxa were those with 30-50% and 10-30% of their range burnt which was also in rugged terrain subject to extreme rainfall.

### Assessment outcome

Extreme rainfall layers, terrain ruggedness, fire extent mapping and distributional range data were combined to assess against the criterion. See Table 13 overleaf.

**Table 13.** Number of taxa in each risk category under Criterion I - Post-fire erosion

Taxon group	HIGH	MEDIUM	LOW	NONE	Data deficient
EPBC Act	0	2	105	1226	2
State listed NSW	0	4	282	370	44
State listed WA	0	0	0	434	2
State listed Vic	0	0	848	769	153
State listed SA	0	0	293	476	38
State listed Qld	0	0	90	809	36
State listed Tas	0	0	220	214	26
State listed ACT	0	0	2	11	0
NSW endemics	3	17	838	390	72
WA endemics	0	0	18	8560	374
Vic endemics	0	0	80	282	46
SA endemics	0	0	9	448	31
Qld endemics	0	0	261	3175	193
Tas endemics	0	0	256	269	18
ACT endemics	0	0	1	5	0
All other taxa	1	0	2990	4978	7
<b>Total*</b>	<b>4</b>	<b>17</b>	<b>5766</b>	<b>19265</b>	<b>1010</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category

## PROPOSED MANAGEMENT ACTIONS

Species assessed HIGH or MEDIUM risk under Criterion I (Table 13) are at specific risk from:

- Loss of the seed bank and standing plants to landslide and erosion of river banks and floodplains, which is related to the topographic position of the populations in the landscape

### *Immediate actions*

**Field inspections – damage and threats:** to quantify the damage to standing or recovering plants from the fires or from other threats (e.g. herbivory, disease, weed invasion, *erosion*).

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Rapid response to wildfire:** ensure that any future wildfires that threaten to burn over recovering sites are rapidly extinguished.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires an independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## **CRITERION J. Cumulative exposure to high risks**

Loss of all mature plants in a species exposes it to risks associated with recruiting new plants to replace those lost. Where fire causes such losses in obligate seeding species, risks include stochastic events, failure or limited successful recruitment of new plants (e.g. through grazing, weed, pathogen and drought impacts). This criterion addresses where the current 2019-2020 fires have exposed obligate seeding species to having significant proportions of their entire known populations as immature plants, as cumulatively the current fires have added to previous fires in other locations that have eliminated all mature plants. Species with canopy seed banks are most at risk as these can be completely exhausted after a single fire event. Species with soil seed banks may have more resilience but there may still be little to no seed bank remaining after a fire in some cases.

- 1) *HIGH* – Obligate seeder with > 0% known sites or habitat burnt in the 2019-2020 fires AND with  $\geq$  50% of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature AND b) known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Obligate seeder with > 0% known sites or habitat burnt in the 2019-2020 fires AND  $\geq$  30 to < 50% of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature; AND b) known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Obligate seeder with > 0% known sites or habitat burnt in the 2019-2020 fires AND with > 0 to < 30% of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature; AND b) known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) Obligate seeders with no known sites or habitat burnt in the 2019-2020 fires; OR

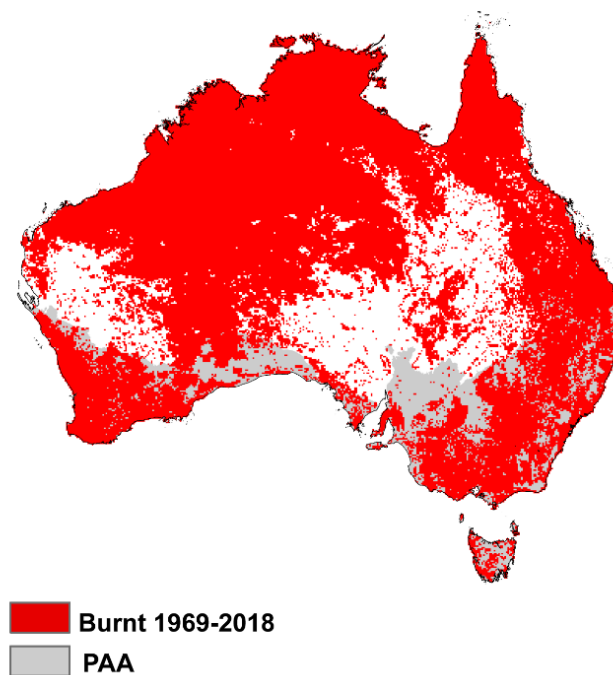
Obligate seeders with no known sites or habitat comprising immature plants as a result of fires prior to the 2019-2020 fires.

## Methods

### *Fire history data*

Multiple resources were combined to produce a single fire history layer for Australia between 1969-2018 (i.e. excluding the 2019-2020 fire season) (Fig. 13). These resources are described in detail for Criterion B and briefly are:

- (1) Mapping from the Global Fire Atlas <https://www.globalfiredata.org/fireatlas.html> for years 2003-2018.
- (2) NSW National Parks and Wildlife Service Fire History – Wildfire and Prescribed Burns dataset
- (3) Victorian Department of Environment, Land, Water and Planning Fire History dataset
- (4) Western Australian Department of Biodiversity, Conservation and Attractions Fire History dataset (1969-2020)



**Figure 13.** Areas burnt between 1969 and 2020 across all of Australia from multiple sources: (1) remotely sensed mapping of fire extent from the Global Fire Atlas, (2) the NPWS Fire History – Wildfire and Prescribed Burns dataset for NSW, (3) DELWP Victoria Fire History dataset, and (4) WA DBCA Fire History dataset.

### *Short fire interval assessment*

Data on traits and fire history were combined with information on the gross primary productivity (GPP) of Australian vegetation to produce an estimate of appropriate fire return times across the PAA as described for Criterion B.

These fire return intervals based on GPP were combined with fire history data to create a spatial layer of all locations where the interval between the 2019-2020 fires and the previous recorded

fire was too short to accommodate plant regeneration across all of Australia. Separate layers were generated for woody or non-woody return times. Species range data was then intersected with the spatial layers of fire intervals to assess the proportion of the range which is exposed to inappropriately short fire return times.

### ***Trait data***

Data on obligate seeding species was sourced from the AusTraits database. For obligate seeding species which were burnt in the PAA in 2019-2020, the % of the entire range burnt in the previous years was calculated. This % was added to the % burnt in the PAA in 2019-2020 to assign species into risk categories.

### **Assessment outcome**

**Table 14.** Number of taxa in each risk categories under Criterion J - Cumulative exposure to high risks

<b>Taxon group</b>	<b>HIGH</b>	<b>MEDIUM</b>	<b>LOW</b>	<b>NONE</b>	<b>Data deficient</b>
EPBC Act	38	15	50	1230	2
State listed NSW	43	26	66	299	266
State listed WA	0	2	3	418	13
State listed Vic	70	122	378	210	990
State listed SA	3	13	117	181	493
State listed Qld	10	5	22	635	263
State listed Tas	2	11	78	122	247
State listed ACT	0	0	0	11	2
NSW endemics	103	72	85	277	783
WA endemics	16	89	359	2949	5539
Vic endemics	21	27	39	126	195
SA endemics	0	3	39	190	256
Qld endemics	1	17	24	1664	1923
Tas endemics	0	0	65	153	325
ACT endemics	1	1	0	3	1
All other taxa	84	256	717	2737	4182
<b>Total*</b>	<b>291</b>	<b>593</b>	<b>1806</b>	<b>8543</b>	<b>14829</b>

\*Taxa may be shared between taxon groups and the total is the number of unique species across taxon groups which are listed under each risk category

### **PROPOSED MANAGEMENT ACTIONS**

Species assessed HIGH or MEDIUM risk under Criterion J (Table 14) are at specific risk from:

- Future exposure to fires that kill recovering individuals of obligate seeding taxa from previous fires. Specifically, plants will be considered immature if they were burnt in 2019-2020 or anywhere across the range before regeneration could occur after the previous fire, based on vegetation productivity and woodiness.
- The cumulative risk of fire across the range and through time.

### *Immediate actions*

**Field inspections to assess seedling emergence:** For obligate seeding species, inspections to quantify seedling emergence and survival.

**Germplasm collection:** during field inspections, germplasm collection of seeds and/or cuttings for species at immediate risk of local extinction should be conducted to preserve the species in ex-situ cultivation and allow for reintroduction.

**Exclude forestry impacts:** Enforcement of buffers, surveys of burnt production forests to detect threatened taxa at appropriate time intervals and use of education and liaison to minimise any damage of logging activities to post-fire recovery.

**Alleviate herbivory:** exclusion or removal of feral grazers, stock and excessive native herbivores by fencing and feral animal control.

### *Medium-term actions*

**Exclude prescribed fire:** prescribed burning should be excluded from sites burnt in the last 5 years for non-woody taxa; the last 15 years for woody taxa; or the last 50 years for species which are killed by fire or are long-lived and prone to basal charring.

**Rapid response to wildfire:** ensure that any future wildfires that threaten to burn over recovering sites are rapidly extinguished.

**Weed control:** Removal and control of weeds that may outcompete natives and impede post-fire recovery.

**Carefully planned translocation:** addition of seed or individual plants propagated ex-situ to populations where recovery is absent or inadequate to allow for species to avoid long-term decline. Requires an independent assessment of feasibility and likelihood of success.

### *Ongoing actions*

**Prevent illegal collecting or over-collecting of germplasm or plants:** minimise illegal losses via quarantine, other access management, education, fencing, surveillance and enforcement.

**Habitat disturbance from human activities:** Exclusion of vehicles, bikes and other human disturbance via signage, fencing and negotiations with local users. Prevention of further disturbance via fencing, liaison with relevant utility owners and land managers, and education activities.

**Minimise mining impacts:** consideration of bushfire recovery in planning, assessment and enforcement.

## CRITERION K. Other plausible threats or expert-driven nomination

Other plausible threats not addressed by A-J above may arise and this criterion is designed to capture their effects on species impacted by the 2019-2020 fires. Taxa identified as having had approximately 50% or more of their range burned and other known threats by state agencies have been included under this criterion.

- 1) *HIGH* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 2) *MEDIUM* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 3) *LOW* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND  $> 0$  to  $< 30\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 4) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood that species has been impacted by any plausible threats not addressed by A-J above.

## Assessment outcome

Seventy-nine taxa from across Australia have been listed under Criteria K due to documented fire impacts from field inspections or local knowledge of state agencies. All taxa are assessed to be HIGH risk.

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## APPENDICES

### Appendix 1. Framework for prioritising impact assessments for plants following the 2019-2020 bushfires

Tony D Auld, David A Keith, Berin DE Mackenzie, Mark KJ Ooi, Tom Le Breton, Rachael V Gallagher  
Version 2.1, 20<sup>th</sup> March 2020

#### Intended application

The purpose of this framework is to identify plant species at the greatest potential risk of population declines or local extinctions following the 2019-2020 bushfires and to prioritise such species for field impact assessments and actions. Data obtained during field assessments on the extent of any impacts can then be used to determine what, if any, further actions or interventions are required to recover particular species and whether their risk prioritisation should change.

It is intended that the criteria can be applied to all plant species affected by the 2019-2020 fires, including threatened plants, rare or restricted species, state or territory endemics that are listed in a particular jurisdiction but are not listed nationally. Application should initially be at a national scale to capture the relative impacts of the fires on the species.

#### Conceptual basis

This framework targets species' life-history traits that make plant species prone to population declines or local extinctions if they occur within the spatial footprint of 2019-2020 bushfires. The identification of species potentially at risk as a result of these fires involves three components:

1. Identifying potential mechanisms of decline, i.e. factors (A-J) below and their interactions;
2. Identifying where in the landscape these mechanisms are most likely to have an impact; and
3. Identifying the species and ecological communities most exposed to risks associated with these mechanisms.

#### Risk groups

Priorities for field inspections, monitoring and conservation action may be guided by a simple categorisation of impact:

- *HIGH* – Very likely at risk. Require an urgent assessment of initial impacts and post-fire monitoring of recovery where impacts are significant.
- *MEDIUM* – Likely to be at risk. Assessment of initial impacts and post-fire monitoring are recommended.
- *LOW* – Unlikely to be at risk. Post-fire monitoring may be conducted opportunistically during sites visits or by other groups (externals, universities, citizen science)
- *NONE* – Not burnt in the 2019-2020 fires or not expected to be at risk.

Possible: could add VERY HIGH at  $\geq 70\%$  throughout

## **Risk categorisation framework**

Species can be assessed against the following set of criteria which are structured around the most significant mechanisms likely to drive plant population decline and extinction in relation to fire. These mechanisms include:

- A. Interactive effects of fire and drought
- B. Short fire intervals (impacts of high fire frequency)
- C. Post-fire herbivore impacts
- D. Fire-disease interactions
- E. High fire severity
- F. Weed invasion
- G. Elevated winter temperatures or changed temperature regimes
- H. Fire sensitivity
- I. Post-fire erosion
- J. Cumulative exposure to high risks

The highest risk ranking obtained via any single criterion is determined to be the overall risk ranking as the risk mechanisms may operate independently or interact in complex ways, and hence the criteria are not additive. Species should be assessed against all criteria where possible.

## **Mechanisms of impact and assessment criteria**

### **A. Interactive effects of fire and drought**

Pre-fire drought can: i) reduce internally stored resources of resprouter plants that are critical in sustaining post-fire regeneration; and ii) reduce pre-fire reproductive output, impacting on the size of the seed bank available for post-fire recruitment.

Post-fire drought can negatively impact post-fire recruitment success by reducing seed germination (due to insufficient soil moisture; possibly causing seed mortality in some dormancy types), seedling survival (through desiccation) and survival of resprouts (through xylem embolism in susceptible new shoots). Risks to mortality may be large if drought occurs in the first autumn-winter after fire or the following spring-summer.

- 5) *HIGH* – Species with  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - c) Significant pre-fire drought; OR
  - d) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 6) *MEDIUM* – Species with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - c) Significant pre-fire drought; OR
  - d) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 7) *LOW* – Species with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires AND evidence or likelihood of either:
  - c) Significant pre-fire drought; OR
  - d) Incidence of post-fire drought within 18 months of the 2019-2020 fires.
- 8) *NONE* – Either:

- c) No known sites or habitat burnt in the 2019-2020 fires; OR
- d) No evidence or likelihood of pre- or post-fire drought impacts in any known sites or habitat.

## **B. Short fire intervals (impacts of high fire frequency)**

Exposure to short temporal intervals between successive fires can disrupt the replenishment of seed banks which are essential to post-fire recruitment and population persistence. Species most susceptible include obligate seeders (species that lack regenerative organs and rely entirely on seed germination for post-fire recovery) and resprouters (species with the capacity to generate new shoots from dormant buds post-fire) that suffer high mortality rates. The time required to replenish seed banks post-fire varies. For most species, up to 15 years between successive fires is needed to ensure that a seed bank is sufficiently replenished to maintain future post-fire populations, although some trees (for example) may require longer fire-free periods.

Short intervals between fires may also kill juveniles of resprouting plants before they become large enough to survive subsequent fires. The species that are most susceptible to these risks are resprouters that are slow to develop regenerative structures (i.e. lignotubers, thick bark, rhizomes etc.) or slow to replace mortality due to low fecundity. At least 15 years between successive fires is needed to ensure the juveniles of most plant species can develop their fire-regenerative organs, although some species such as mallee eucalypts may require at least 25 years.

Finally, some long-lived trees may suffer basal scarring where fires (or other factors related to fires such as falling trees or limbs) damage and/or kill bark tissue. This enables subsequent fires to smoulder into heartwood and weaken the structural integrity of the tree, causing mortality, collapse and structural change to the ecosystem. Trees with thin bark are most prone to this impact and replacement depends on fecundity and growth rates. Many rainforest trees and some eucalypts are susceptible and are likely to require at least 50 years between successive fires to enable partial recovery and replacement.

- 1) *HIGH* –  $\geq 25\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR
    - ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
    - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 2) *MEDIUM* –  $\geq 10\%$  to  $< 25\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR
    - ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
    - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 3) *LOW* –  $> 0\%$  to  $< 10\%$  known sites or habitat both:
  - a) burnt in 2019-2020 AND
  - b) experienced  $\geq 1$  fire(s) within either:
    - i) the past 5 years for non-woody species; OR

- ii) the past 15 years for woody species (excluding long-lived trees prone to collapse from basal charring); OR
  - iii) the past 50 years for long-lived trees prone to collapse from basal charring.
- 4) *NONE* – Either:
  - e. No known sites or habitat burnt in the 2019-2020 fires
  - f. Non-woody species with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 5 years; OR
  - g. Woody species (excluding long-lived trees prone to collapse from basal charring) with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 15 years; OR
  - h. Long-lived trees prone to collapse from basal charring with none of the known sites or habitat burnt in the 2019-2020 fires also burnt by one or more previous fires in the past 50 years.

### C. Post-fire herbivore impacts

Plants are often at their most palatable and least resilient to herbivore activity (e.g. leaf and shoot removal, trampling and substrate degradation) in the post-fire environment where herbivores have enhanced foraging efficiency and converge on regenerating burnt areas to exploit fresh growth. Concentrations of herbivores may therefore increase mortality of both seedlings and resprouters of palatable plants. In some cases, elevated mortality may lead to local extinction. Effects may be exacerbated when burnt patches are small or have high perimeter to area ratios which promote herbivore incursions in high densities.

- 4) *HIGH* – Evidence or likelihood of significant post-fire grazing impacts AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 5) *MEDIUM* – Evidence or likelihood of significant post-fire grazing impacts AND obligate seeder with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 6) *LOW* – Evidence or likelihood of significant post-fire grazing impacts AND either:
  - c) Obligate seeder with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires; OR
  - d) Resprouter with  $> 0$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 5) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires; OR
  - d) No evidence or likelihood of significant post-fire grazing impacts in any known sites or habitat.

### D. Fire-disease interactions

Plant species from particular genera and families are susceptible to diseases such as *Phytophthora* spp., *Armillaria* spp., Myrtle Rust, Canker fungi and other pathogens. Tissue death caused by these diseases reduces the capacity of plants to acquire resources through their roots and/or leaves. Plants are more sensitive to resource deprivation in the post-fire period and reduced post-fire survival rates have been observed in areas infected by disease, such that fire accelerates

disease-related population decline. Resprouting individuals in certain families appear most susceptible to this threat. Disease effects may be exacerbated by drought.

- 5) *HIGH* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 6) *MEDIUM* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 7) *LOW* – Evidence or likelihood of significant pathogen/disease susceptibility AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires.
- 8) *NONE* – Either:
  - a) No known sites or habitat burnt in the 2019-2020 fires; OR
  - b) No evidence or likelihood of pathogen/disease susceptibility

### **E. High fire severity**

In some plant species, survival of established individuals and/or seed banks may be sensitive to fire severity due to limitations in the insulating capacity of protective tissues (thickness of bark or walls of serotinous fruits). Species that rely on persistence of long-lived standing plants (due to low fecundity) or post-fire regeneration from small serotinous fruits are most susceptible to this mechanism of decline. For long-lived trees, these effects may be cumulative through successive fires (high fire frequency – see B above) that undermine their structural integrity. In such cases, fire severity impacts may be influenced by prolonged basal and internal smouldering rather than canopy consumption (as commonly reflected in fire severity maps). Effects may be exacerbated by drought reducing water content within insulating tissues prior to fires.

- 5) *HIGH* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires at high severity (i.e. fire likely to cause death or serious damage and recovery is not certain).
- 6) *MEDIUM* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in 2019-2020 fires at high severity.
- 7) *LOW* – Survival of standing plants and/or seed bank is known or suspected to be sensitive to high fire severity AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires at high severity.
- 8) *NONE* – Either:
  - a) No known sites or habitat burnt at high severity in the 2019-2020 fires; OR
  - b) Survival of standing plants and/or seed bank is largely unaffected by fire severity.

### **F. Weed invasion**

Some sites are predisposed to invasion by transformer exotic plants. Fire may provide opportunities for growth of existing exotics or entry of these species into the vegetation (especially where weed sources are within or proximal to burnt areas) and subsequent elimination of native species through competition. Native species that occur mainly in areas where bushland

has been fragmented, disturbed by logging or clearing, or affected by runoff from nutrient sources (e.g. urban infrastructure, improved pasture, wastewater or stormwater disposal etc.) are most susceptible to this mechanism, and these factors should be considered in assessing the likelihood of weed impacts below.

- 5) *HIGH* – Evidence or likelihood of significant weed impacts post-fire AND  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 6) *MEDIUM* – Evidence or likelihood of significant weed impacts post-fire AND  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 7) *LOW* – Evidence or likelihood of significant weed impacts post-fire AND  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires.
- 8) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires OR
  - d) No evidence or likelihood of significant weed impacts post-fire in any known sites or habitat.

## G. Elevated winter temperatures or changed temperature regimes

Seed germination of some plants in alpine and subalpine (or frost-hollow) habitats is reliant on cold stratification during winter. Alpine plant phenology is also affected by temperature. If the 2020 winter is warm, seedling regeneration may be reduced with flow-on effects on seed bank replenishment. Species with short-lived standing plants and/or short-lived seed banks are likely to be most susceptible. Enhanced insolation of fire-blackened soils may exacerbate climatic warming effects. For other species diurnal temperature cycles cue germination and changes to these cycles may delay or reduce germination.

- 5) *HIGH* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND with  $\geq 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 6) *MEDIUM* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND obligate seeder with  $\geq 30$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 7) *LOW* – Cold stratification known or suspected to be needed for successful seedling recruitment post-fire AND either:
  - c) Obligate seeder with  $> 0$  to  $< 30\%$  known sites or habitat burnt in the 2019-2020 fires; OR
  - d) Resprouter with  $> 0$  to  $< 50\%$  known sites or habitat burnt in the 2019-2020 fires.
- 8) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires; OR
  - d) No evidence that cold stratification is needed for successful seedling recruitment post-fire.

## H. Fire sensitivity

Some plant species have no means of *in situ* persistence through fire events because their standing plants lack protected regenerative organs and there is no seed bank. A single fire may

eliminate such species or damage a significant proportion of individuals in the population, which must then rely entirely on dispersal from unburnt populations for re-establishment in the area.

- 5) *HIGH* –  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 6) *MEDIUM* –  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 7) *LOW* –  $> 0$  to  $< 30\%$  of known sites or habitat burnt in the 2019-2020 fires AND species is either:
  - a) A long-lived tree prone to collapse from basal charring; OR
  - b) Not a long-lived tree prone to collapse from basal charring AND cannot resprout AND has no seed bank
- 8) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires; OR
  - d) Species is not a long-lived tree prone to collapse from basal charring AND either:
    - iii) Can resprout; OR
    - iv) Has a seed bank.

## I. Post-fire erosion

Intense rainfall events after fires may lead to extensive localised erosion that either covers recovering plants in soil and ash or depletes soil seed banks. In steep terrain, post-fire erosion may dislodge rocks and trees or cause larger scale landslides with associated plant mortality. Effects are likely to be localised and evident in the first few months after a fire. Steep habitats, riparian habitats, peaty habitats and unconsolidated floodplains or sandplains would seem to be potentially vulnerable to erosion.

- 5) *HIGH* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 6) *MEDIUM* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 7) *LOW* – Evidence or likelihood that species has been impacted by severe post-fire soil erosion leading to mortality of individuals or depletion of soil seed banks AND  $> 0$  to  $< 30\%$  of known sites or habitat burnt in the 2019-2020 fires.
- 8) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires; OR
  - d) No evidence or likelihood that species has been impacted by severe post-fire soil erosion.



## J. Cumulative exposure to high risks

Loss of all mature plants in a species exposes it to risks associated with recruiting new plants to replace those lost. Where fire causes such losses in obligate seeding species, risks include stochastic events, failure or limited successful recruitment of new plants (e.g. through grazing, weed, pathogen and drought impacts). This criterion addresses where the current 2019-2020 fires have exposed obligate seeding species to having significant proportions of their entire known populations as immature plants, as cumulatively the current fires have added to previous fires in other locations that have eliminated all mature plants. Species with canopy seed banks are most at risk as these can be completely exhausted after a single fire event. Species with soil seed banks may have more resilience but there may still be little to no seed bank remaining after a fire in some cases.

- 5) *HIGH* – Obligate seeder with  $> 0\%$  known sites or habitat burnt in the 2019-2020 fires AND with  $\geq 50\%$  of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature AND b) known sites or habitat burnt in the 2019-2020 fires.
- 6) *MEDIUM* – Obligate seeder with  $> 0\%$  known sites or habitat burnt in the 2019-2020 fires AND  $\geq 30$  to  $< 50\%$  of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature; AND b) known sites or habitat burnt in the 2019-2020 fires.
- 7) *LOW* – Obligate seeder with  $> 0\%$  known sites or habitat burnt in the 2019-2020 fires AND with  $> 0$  to  $< 30\%$  of known sites or habitat comprising immature plants, based on the sum of: a) known sites or habitat that have experienced fires prior to the 2019-2020 fires where recruiting plants are not yet mature; AND b) known sites or habitat burnt in the 2019-2020 fires.
- 8) *NONE* – Either:
  - b) Obligate seeders with no known sites or habitat burnt in the 2019-2020 fires;  
OR
  - c) Obligate seeders with no known sites or habitat comprising immature plants as a result of fires prior to the 2019-2020 fires.

## K. Other plausible threats or expert-driven nomination

Other plausible threats not addressed by A-J above may arise and this criterion is designed to capture their effects on species impacted by the 2019-2020 fires. Taxa identified as having had approximately 50% or more of their range burned and other known threats by state agencies have been included under this criterion.

*HIGH* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND  $\geq 50\%$  of known sites or habitat burnt in the 2019-2020 fires.

- 5) *MEDIUM* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND  $\geq 30$  to  $< 50\%$  of known sites or habitat burnt in the 2019-2020 fires.

- 6) *LOW* – Evidence or likelihood that species has been significantly impacted by one or more plausible threats not addressed by A-J above AND > 0 to < 30% of known sites or habitat burnt in the 2019-2020 fires.
- 7) *NONE* – Either:
  - c) No known sites or habitat burnt in the 2019-2020 fires; OR
  - d) No evidence or likelihood that species has been impacted by any plausible threats not addressed by A-J above.

## Appendix 2. FINAL\_ASSESSMENT\_Ver1\_2.csv

## Appendix 3. Column names and explanations for Appendix 2

<b>Genus</b>	Genus of assessed taxon
<b>Taxon</b>	Taxon name according to the Australian Plant Name Index
<b>EPBC Act</b>	Taxa listed on the EPBC Act. 0 = no, 1 = yes
<b>EPBC status</b>	Extinction risk category
<b>NSW listed</b>	Taxa listed on the <i>NSW Biodiversity Conservation Act 2016</i> . 0 = no, 1 = yes
<b>WA listed</b>	Taxa listed on the <i>WA Biodiversity Conservation Act 2016</i> . 0 = no, 1 = yes
<b>Vic listed</b>	Threat status on <i>Vic Flora and Fauna Guarantee Act 1988</i> . 0 = no, 1 = yes
<b>SA listed</b>	Taxa listed on the <i>SA National Parks and Wildlife Act 1972</i> 0 = no, 1 = yes
<b>Qld listed</b>	Taxa listed on the QLD Act 0 = no, 1 = yes
<b>Tas listed</b>	Taxa listed on the <i>Tas Threatened Species Protection Act 1995</i> 0 = no, 1 = yes
<b>ACT listed</b>	Taxa listed on the <i>ACT Nature Conservation Act 2014</i> 0 = no, 1 = yes
<b>Endemic NSW</b>	Endemic to NSW according to Australian Plant Census. 0 = no, 1 = yes
<b>Endemic SA</b>	Endemic to South Australia according to Australian Plant Census. 0 = no, 1 = yes
<b>Endemic WA</b>	Endemic to Western Australia according to Australian Plant Census. 0 = no, 1 = yes
<b>Endemic Vic</b>	Endemic to Victoria according to Australian Plant Census. 0 = no, 1 = yes
<b>Endemic Qld</b>	Endemic to Tasmania according to Australian Plant Census. 0 = no, 1 = yes

<b>Endemic Tas</b>	Endemic to Queensland according to Australian Plant Census. 0 = no, 1 = yes
<b>Endemic ACT</b>	Endemic to ACT according to Australian Plant Census. 0 = no, 1 = yes
<b>All other taxa</b>	Taxa not listed and not endemic in any state
<b>NSW status</b>	Threat status on the NSW <i>Biodiversity Conservation Act 2016</i> as of March 2020
<b>SA status</b>	Threat status on the SA <i>National Parks and Wildlife Act 1972</i> as of March 2020
<b>Vic status</b>	Threat status on the Vic <i>Flora and Fauna Guarantee Act 1988</i> as of March 2020 (note that Victoria lists as 'threatened' and the advisory list status has been included)
<b>WA status</b>	Threat status on the WA <i>Biodiversity Conservation Act 2016</i> as of March 2020
<b>Qld status</b>	Threat status on the <i>Nature Conservation Act 1992</i> as of March 2020
<b>Tas status</b>	Threat status on the Tas <i>Threatened Species Protection Act 1995</i> as of March 2020
<b>ACT status</b>	Threat status on the ACT <i>Nature Conservation Act 2014</i> as of March 2020
<b>A ranking</b>	Risk ranking under criterion A
<b>B ranking</b>	Risk ranking under criterion B
<b>C ranking</b>	Risk ranking under criterion C
<b>D ranking</b>	Risk ranking under criterion D
<b>E ranking</b>	Risk ranking under criterion E
<b>F ranking</b>	Risk ranking under criterion F
<b>G ranking</b>	Risk ranking under criterion G
<b>H ranking</b>	Risk ranking under criterion H
<b>I ranking</b>	Risk ranking under criterion I
<b>J ranking</b>	Risk ranking under criterion J
<b>K ranking</b>	Risk ranking under criterion K

#### **In PAA according to AVH occurrences**

Flag for presence in PAA using clean AVH occurrence

#### **In PAA according to modelled range**

Flag for presence in PAA using modelled range data (either PPPM, range bagging or AOO)

**In PAA according to DAWE range maps**

Flag for presence in PAA using DAWE regulatory maps

**Number of occurrences AVH**

Number of clean AVH occurrence records for the taxon

**Number of AVH occurrences burnt**

Area of range burnt according to intersection with AVH occurrences and NIAFED fire extent data

**Proportion of AVH occurrences burnt**

Proportion of range burnt according to intersection with AVH occurrences and NIAFED fire extent data

**Modelled range area**

Size of the range according to models

**Modelled range area burnt**

Area of range burnt according to intersection with modelled range and NIAFED fire extent data

**Modelled proportion of range area burnt**

Proportion of range burnt according to intersection with modelled range and NIAFED fire extent data

**DAWE range area**    Size of the range according to models

**DAWE proportion range burnt**

Proportion of range area burnt according to an intersection with DAWE range maps and NIAFED fire extent data

**DAWE range in PAA**

Area of range inside the PAA

**DAWE range in NIAFED and PAA**

Area burnt according to an intersection with DAWE range maps and NIAFED fire extent data

**Appendix 4.** High priority taxa for recovery actions. See  
FINAL\_PRIORITY\_LIST\_PLANTS\_V1\_3.csv

**Appendix 5.** Proposed management actions for all taxa assessed HIGH or MEDIUM risk. See  
FINAL\_MANAGEMENT\_ACTIONS\_BY\_TAXON\_Ver1\_1.csv



*Epicormic regeneration in Eucalyptus on the South Coast of NSW* ©Anne Kerle