Criterion 1

Conservation of biological diversity

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The Eastern Spinebill (*Acanthorhynchus tenuirostris*) is a species of honeyeater found in south-eastern Australian forests.

Criterion 1 Conservation of biological diversity

This criterion addresses various aspects of the conservation of the biological diversity of forests, also known as forest biodiversity. Biodiversity refers to the full range of plants, animals and microorganisms occurring in a given area, along with the genes they contain and the ecosystems they form. Conservation of biological diversity is a key part of sustainable forest management, and its goal is the continued existence of ecosystems, species and the genetic variability within these species.

Biological diversity is usually considered at three levels: ecosystem diversity, species diversity and genetic diversity. The nine indicators in this criterion are divided into three sub-criteria that match these levels.

Native forest, Guy Fawkes River National Park, east of Armidale, New South Wales.

Ecosystem diversity

The first group of indicators in Criterion 1, Indicators 1.1a to 1.1d, provides fundamental information on Australia's forests, as reported through Australia's National Forest Inventory. This includes the geographic distribution of forests, and their type, tenure, growth stages, and degree of fragmentation. These indicators also report on the forest area in reserves of various types or protected by management prescription or through other arrangements such as covenants. Together they provide the basic area data that underpin the description in various SOFR 2018 indicators of the development of legislation and policies, the management of forest ecosystems for multiple values, the monitoring of forest condition, and the assessment of forest management outcomes. Indicator 1.1a 'Area of forest by forest type and tenure' is therefore a keystone indicator.

The reported area of Australia's forest has changed over time as available technology, and the methods used for forest assessment, have improved. SOFR 2018 continues the use of a 'Multiple Lines of Evidence' approach to determining Australia's forest area, in which data from states and territories are combined with a range of remotely sensed forest cover data to map forest communities with greater accuracy than associated with any single input dataset.

Species diversity

The second group of indicators in Criterion 1, Indicators 1.2a to 1.2c, focuses on the species found in forests. Species are treated as forest-dwelling species if they are able to use a forest habitat for all or part of their lifecycles. A subset of these are forest-dependent species, which need to use a forest habitat to complete part or all of their lifecycles.

Knowledge of the plant, animal and other species present in a forest is a pre-condition for the effective management of that forest. Information on whether populations of species are increasing or decreasing, obtained through species monitoring programs, can indicate the extent and condition of, and changes in, forest habitat, and is needed to support conservation strategies. For forest covered by Regional Forest Agreements, state governments have developed a set of criteria that include broad benchmarks for the in-situ conservation of forest biodiversity.

A number of forest-dwelling and forest-dependent species and forest ecosystems are listed as threatened on lists compiled nationally and by states and territories. Knowledge of the threats and threatening processes faced by listed species and ecosystems assists in developing management strategies for their protection.

Genetic diversity

The final group of indicators in Criterion 1, Indicators 1.3a and 1.3b, assesses conservation of forest genetic resources. This is linked both to the conservation of forest biodiversity and to the availability of forest species for commercial or environmental use.

Indicator 1.3a examines the risk of loss of the genetic diversity in forest plants and animals, and describes the conservation measures in place to minimise that risk. Native forest species and communities in Australia are conserved in protected areas such as nature conservation reserves and national parks and in other public and private forests. Conservation plantings and seed orchards (stands planted and managed for seed production) have also been established for a number of threatened species.

Indicator 1.3b assesses the genetic resources for native forest and commercial plantation species used for wood production, and provides an inventory of tree breeding and improvement programs for Australia's native forest trees and plantation species. Australia's forest genetic resources play an important role in maintaining and improving the productivity of commercial plantations grown for wood production in Australia and in other countries. They enable, for example, selection of trees that have high growth rates and superior wood quality, that are better adapted to changing climatic conditions such as lower rainfall or higher temperatures, or that are more resistant or tolerant to pests and diseases.

This icon indicates data, maps or graphics from *Australia's State of the Forests Report 2018* that are available for electronic download. Data used in figures and tables in this criterion, together with higher resolution versions of maps and other graphical elements, are available via www.doi.org/10.25814/5bda82c8d76d4 and www.doi.org/10.25814/5be3bc4321162.

Indicator 1.1a

Area of forest by forest type and tenure

Rationale

This indicator uses the area for each forest type over time as a broad measure of the extent to which forest ecosystems and their diversity are being maintained. Reporting on forest tenure aids our understanding of how different land management regimes may impact on forest biodiversity.

Key points

- Australia has 134.0 million hectares of forest, covering 17% of Australia's land area.
  - This area is determined from the spatial coverage held in Australia's National Forest Inventory as at 2016.
  - Of this total area, 131.6 million hectares (98%) are Native forests, 1.95 million hectares are Commercial plantations and 0.47 million hectares are Other forest.
  - Australia has approximately 3% of the world's forest area, and globally is the country with the seventh largest forest area.
- Native forest is the most extensive category of Australia's forest.
  - Australia's native forest is classified into forest types, and is dominated by Eucalypt forest (101 million hectares, 77% of the native forest area) and Acacia forest (11 million hectares, 8%). The area of Rainforest (3.5 million hectares, 2.7%) is relatively small.
  - By crown cover class, the majority of native forest is woodland forest (91 million hectares, 69%), which has a crown cover of 20–50%.
- Commercial plantations form the second most extensive category of Australia's forest.
  - As determined from the National Forest Inventory spatial coverage, commercial plantations total 1.95 million hectares, comprising 1.02 million hectares of softwood species (mainly pines), 0.92 million hectares of hardwood species (mainly eucalypts), and 0.01 million hectares of unknown or mixed species plantations.
- Other forest, the final category, contains 0.47 million hectares of forest not classified as Native forest or Commercial plantation.
  - Other forest comprises mostly non-commercial plantations, planted forests of various types, and non-planted forests dominated by trees of introduced species.
- The majority of Australia's native forest estate, 88 million hectares (67%), is on private and leasehold land. A further 22 million hectares of native forest (17%) is in formal nature conservation reserves, and 10 million hectares of native forest (7%) is in multiple-use public native forests.
- The National Forest Inventory forest cover dataset reported in *Australia's State of the Forests Report 2018* (SOFR 2018) has been developed by combining new or updated state, territory and national datasets with the SOFR 2013 forest cover dataset using a 'Multiple Lines of Evidence' approach, and using high-resolution imagery for validation.
  - The integration of these new or updated datasets has led to a larger forest area (134.0 million hectares) being reported in SOFR 2018 than the area (124.8 million hectares) that was reported in SOFR 2013.
  - Most of this difference in the understanding of Australia's forest extent derives from improvements in methods and datasets, not from actual on-ground changes in forest area. Most of the correction has occurred in the Northern Territory, where areas of woodland forest not reported as forest in SOFR 2013 have now been identified and mapped, and have been reported as forest in SOFR 2018.

Continued

Continues

Key points

- The best estimate of the actual change in Australia's total forest area over time is an increase of 3.9 million hectares from 2011 to 2016.
  - This increase is due to the net effect of forest clearing for agricultural use, regrowth of forest on areas cleared for agricultural use, expansion of forest onto areas not recently containing forest, establishment of environmental plantings, and changes in the plantation estate.
  - In each year of the period 2011–2016, the area of forest cleared or recleared was less than the area of forest regrowing from previous clearing.
  - This estimate of area change comes from annual Landsat satellite data interpreted for Australia's National Greenhouse Gas Inventory and published in annual National Inventory Reports by the Australian Government Department of the Environment and Energy[22].
  - Temporary changes in forest area or crown cover that result from a range of short-term factors, such as wildfire, wood harvesting, and regrowth or regeneration from these factors, are not included in these area change figures.

Australia's forest area

Data on Australia's forest estate are assembled in the spatial datasets of the National Forest Inventory (NFI), with spatial data for Commercial plantations incorporated from the National Plantation Inventory (NPI). These inventories are held by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Australian Government Department of Agriculture and Water Resources[23], and are used to report on Australia's forests by national forest type and national land tenure.

Forest area[24] figures presented in this indicator are national figures compiled in the National Forest Inventory (NFI), and SOFR 2018 incorporate validated data from a range of different datasets assembled using a Multiple Lines of Evidence (MLE) methodology (Mutendeudzi et al. 2013a, b). The datasets and data sources used to create the national forest coverage reported in this indicator are listed below in Tables 1.12 and 1.13.

For various reasons, these figures may not align with figures published by individual states or territories or in other Commonwealth reports. These reasons include the timing of publication of SOFR 2018 compared with the timing of other publications, use of different input datasets at different scales and with different levels of validation, and varying interpretations of forest cover and forest communities between agencies, especially in areas of low crown cover. Similar reasons explain the difference between the forest area figure for Australia derived here from the NFI, and international estimates of Australia's forest cover using other data sources (Bastin et al. 2017 provides an example for forests of low crown cover[25]).

As at 2016, Australia had 134 million hectares of forest, covering 17% of the total land area (Table 1.1). This places Australia seventh in the world for countries ranked by forest area (FAO 2015), and Australia has approximately 3% of the world's forest area. The spatial distribution of Australia's forests is shown in Figure 1.1 (on page 53).

Queensland has the largest area of forest (51.8 million hectares, 39% of Australia's forest), with the Northern Territory (23.7 million hectares, 18%), Western Australia (21.0 million hectares, 16%), and New South Wales (20.4 million hectares, 15%), making up much of the balance (Table 1.1).

The forest area reported in SOFR 2018 is larger by 9.3 million hectares than the forest area reported in SOFR 2013. Much of this difference is due not to on-ground change in forest area, but instead to methodological improvements and the incorporation of new datasets. The best available estimate of the actual change in Australia's forest area during the reporting period for SOFR 2018 is determined from annual forest area estimates from Landsat satellite imagery data interpreted for Australia's National Greenhouse Gas Inventory (NGGI) and published in National Inventory Reports (the most recent being DoEE 2018a). These NGGI data show that Australia's forest area increased by 3.9 million hectares over the period 2011 to 2016 (see section 'Change in total forest cover over time'; Figure 1.5).

Australia's forests are assigned to three broad categories, with each category divided into various forest types (Table 1.2):

- 131.6 million hectares (98%) is Native forest dominated by the Eucalypt and Acacia forest types. Queensland has the largest area of native forest (51.6 million hectares, 39% of Australia's native forest), with the Northern Territory (23.7 million hectares, 18%), Western Australia (20.5 million hectares, 16%), and New South Wales (19.9 million hectares, 15%), making up much of the balance.
- 1.95 million hectares is Commercial plantations, comprising 1.02 million hectares of softwood plantations (mainly pines), 0.92 million hectares of hardwood plantations (mainly eucalypts), and 0.01 million hectares of unknown or mixed species plantations. Commercial plantations occur in both temperate and tropical regions of Australia (Figure 1.1). The category 'Commercial plantation' refers to plantations reported through the National Plantation Inventory (ABARES 2016b); these were reported as 'Industrial plantations' in SOFR 2013.
- 0.47 million hectares is Other forest, comprising mostly non-commercial plantations, planted forests of various types, and non-planted forests dominated by trees of introduced species. The largest areas of Other forest are in Victoria (0.16 million hectares) and Western Australia (0.15 million hectares).

[22] Until July 2016, the Department of the Environment.

[23] Until September 2015, the Department of Agriculture.

[24] Forest area, cover and extent are used interchangeably in this report.

[25] See also discussion in Schepaschenko et al. (2017) *Science* 358, eaao0166; de la Cruz et al. (2017) *Science* 358, eaao0369; and Griffith et al. (2017) *Science* 358, eaao1309.

Table 1.1: Australia's forest area, by jurisdiction

	Native forest		Commercial plantation[a,b]		Other forest		Total forest		Total land[c]	
Jurisdiction	Area ('000 hectares)	Area as proportion of total Native forest (%)	Area ('000 hectares)	Area as proportion of total Commercial plantation (%)	Area ('000 hectares)	Area as proportion of total Other forest (%)	Area ('000 hectares)	Area as proportion of total forest (%)	Area ('000 hectares)	Forest area as proportion of jurisdiction's land area (%)
ACT	130	0.1	7	0.4	5	1.0	142	0.1	236	60
NSW	19,925	15	380	20	62	13	20,368	15	80,131	25
NT	23,686	18	45	2	4	1.0	23,735	18	134,837	18
Qld	51,580	39	229	12	21	4	51,830	39	173,002	30
SA	4,856	4	178	9	25	5	5,060	4	98,430	5
Tas.	3,342	3	311	16	46	10	3,699	3	6,829	54
Vic.	7,645	6	415	21	162	34	8,222	6	22,742	36
WA	20,450	16	383	20	148	31	20,981	16	252,702	8
Australia	131,615	100	1,949	100	474	100	134,037	100	768,909	17

[a] The NFI spatial coverage used to report Commercial plantation areas in Indicator 1.1a of SOFR 2018 is a rasterised version of the NPI spatial dataset used to produce the data reported for 2014–15 in *Australian plantation statistics 2016* (ABARES 2016b). Conversion of the vector format dataset used in *Australian plantation statistics 2016* to the raster format dataset used in SOFR 2018 means that the area figure for Commercial plantations reported in SOFR 2018 (1.95 million hectares) is slightly lower than the area figure (1.97 million hectares) reported in *Australian plantation statistics 2016*.

[b] The Commercial plantation area data reported here is derived from the spatial data reported for 2014–15 in *Australian plantation statistics 2016* (ABARES 2016b). Updated tabular data for 2015–16 are available in *Australian plantation statistics 2017 update* (Downham and Gavran 2017) (area of 1.97 million hectares), and for 2016–17 in *Australian plantation statistics 2018 update* (Downham and Gavran 2018) (area of 1.96 million hectares).

[c] The land area data reported here is derived from the raster (grid) used for the NFI spatial coverage, and is slightly lower than the land area data reported in SOFR 2013 that was derived from Geosciences Australia vector data[26].

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Native forest types

The vast majority of Australia's native forest area is dominated by evergreen, broadleaf, hardwood tree species. For national reporting, the NFI classifies Australia's native forests into eight broad forest types defined by dominant species and structure (as described in the Introduction). The first seven distinctive types are Acacia, Callitris, Casuarina, Eucalypt, Mangrove, Melaleuca and Rainforest. Of these, Callitris is the only native forest type dominated by coniferous softwood tree species. The eighth type, Other native forest, comprises less common native forest types with relatively small individual areas, as well as native forests where the type is unknown (generally because of an absence of floristic information in the National Vegetation Information System (NVIS)). Commercial plantations are divided into two main types: hardwood (broadleaf) and softwood (coniferous) plantations. 'Other forest' includes mostly non-commercial plantations, planted forests of various types, and non-planted forests dominated by trees of introduced species. The areas of these forest types are presented in Table 1.2.

Native eucalypt forest in the Blue Mountains, New South Wales.

The Eucalypt forest type, comprising forests dominated by members of the genera *Eucalyptus*, *Corymbia* and *Angophora*, is dominant across most of Australia's forest area, with a total of 101 million hectares (77% of Australia's native forest area). It is generally reported as subtypes by height class, crown cover class and structural form, including mallees (stands of multi-stemmed eucalypts). The second most common forest type is Acacia, comprising forests dominated by species of the genus *Acacia*, with a total of 11 million hectares (8%). Despite the overwhelming dominance of these two forest types, Australia's forests are nonetheless very diverse. There are more than 800 species of *Eucalyptus*, *Corymbia* and *Angophora*, and almost 1,000 species of *Acacia*, as well as many other genera of trees, in a rich array of ecosystems that vary in their floristic composition, their structure and the fauna they support. Rainforest covers 3.5 million hectares (2.7% of Australia's forest area); some rainforests are particularly rich in floral and faunal biodiversity.

[26] The land area for Australia, states and territories reported in SOFR 2013, Table 1.1, was derived from the Geosciences Australia "GEODATA COAST 100K 2004" vector dataset (www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories).

Table 1.2: Australia's forest areas by category and type

Native forest type	Area ('000 hectares)	Proportion of total native forest area (%)	Proportion of total forest area (%)
Acacia	10,813	8.2	8.1
Callitris	2,011	1.5	1.5
Casuarina	1,236	0.9	0.9
Eucalypt	101,058	77	75
Mangrove	854	0.6	0.6
Melaleuca	6,382	4.8	4.8
Rainforest	3,581	2.7	2.7
Other native forest[a]	5,679	4.3	4.2
Total Native forest	**131,615**	**100**	**98**

Commercial plantation[b]	Area ('000 hectares)	Proportion of total commercial plantation area (%)	Proportion of total forest area (%)
Softwood	1,015	52	0.8
Hardwood	922	47	0.7
Unknown or mixed species[c]	11	0.6	0.01
Total Commercial plantation	**1,949**	**100**	**1.5**

Other forest[d]	Area ('000 hectares)	Proportion of total other forest area (%)	Proportion of total forest area (%)
Other forest	474	100	0.4
Total Other forest	**474**	**100**	**0.4**

Total	134,037		100

[a] Other native forest comprises a range of minor forest types, including Agonis, Atalaya, Banksia, Hakea, Grevillea, Heterodendron, Leptospermum, Lophostemon and Syncarpia (each named after its dominant genus), as well as native forests where the type is unknown.

[b] Determined from the National Forest Inventory spatial coverage. See footnote on Commercial plantation areas under Table 1.1.

[c] Plantations of mixed hardwood and softwood species, and plantations where the species type is not reported.

[d] Other forest comprises mostly non-commercial plantations, planted forests of various types, and non-planted forests dominated by trees of introduced species.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Forests are generally confined to regions where average rainfall exceeds 500 millimetres per year. Most forests are in the northern, eastern, south-eastern and south-western coastal zones of Australia, although woodland forests extend into drier areas in many parts of the country (Figure 1.1).

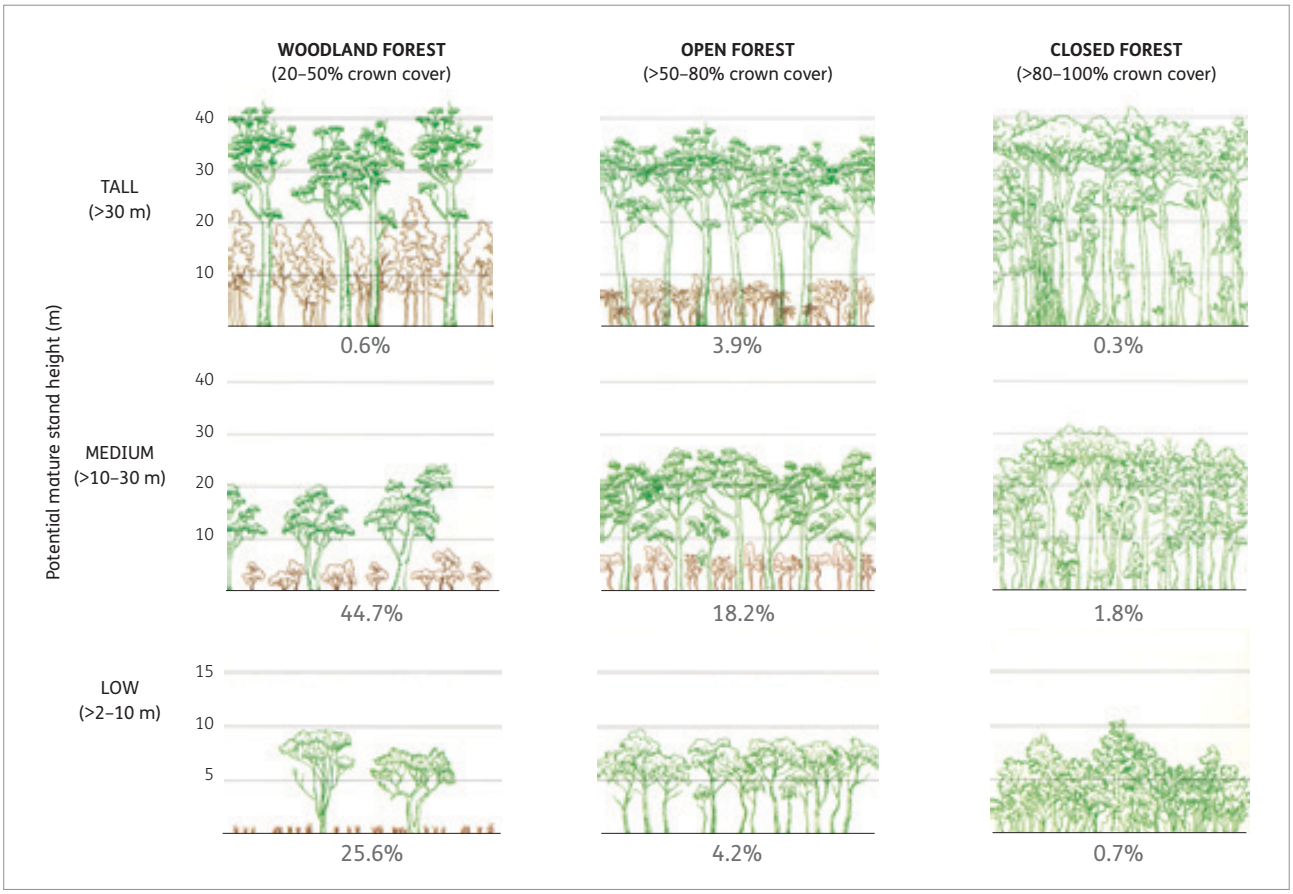
Forest classified as 'Eucalypt medium open' forest. This forest is dominated by eucalypts, and has a stand height of >10–30 metres and crown cover >50–80%. Northern New South Wales.

Crown cover, height and form

Australia's definition of forest specifies a minimum existing or potential crown cover of 20%, a minimum mature or potentially mature stand height exceeding 2 metres, and stands dominated by trees usually having a single stem. Within this definition, native forests are classified into nine structural classes, based on three crown cover classes (woodland forest, crown cover 20–50%; open forest, crown cover >50–80%; and closed forest, crown cover >80–100%) and three stand height classes (low, height >2–10 metres; medium, height >10–30 metres; and tall, height >30 metres), as shown in Figure 1.2. Australia's multi-stemmed eucalypt mallee associations are included in the definition of forest if they meet the criteria for height and crown cover.

Forest type and crown cover are reasonably well measured across Australia, but only limited forest height information is collected outside forests in which wood is harvested.

Figure 1.2: Native forest crown cover classes, height classes, and area proportions



Note: Percentages are area proportions of each height class/crown cover class combination in Australia's total native forest area, excluding 'Other native forest' for which height and cover class is unknown. In accordance with the definition of forest used for the National Forest Inventory, the crown cover values relate to existing or potential crown cover, and the height values relate to mature or potentially mature stand height.

Source: Adapted from Australian Land Information Group and JA Carnahan (1990). *Atlas of Australian Resources, Vegetation*. Australian Government Publishing Service, Canberra.

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

Land classified as non-forest comprises both land carrying other woody vegetation (defined as woody vegetation often but not necessarily containing a tree component, and with existing or potential crown cover less than 20% or with a mature or potentially mature stand height of 2 metres or less), and land not carrying other woody vegetation. 'Other woody vegetation' is sometimes referred to as 'Sparse woodland'.

A total of 91 million hectares (69%) of Australia's native forest area is classified as woodland forest of 20–50% crown cover (Table 1.3). Open forests of >50–80% crown cover comprise 34 million hectares (26%) of the native forest area. Closed forests of >80–100% crown cover comprise 3.7 million hectares (2.8%) of the native forest area. Eucalypt forest types are the largest component of both woodland forest (73 million hectares) and open forest (28 million hectares), while Rainforest is the largest component of closed forest (2.6 million hectares) (Table 1.3).

The distribution of Australia's native forest types, subtypes and crown cover classes varies across the continent, depending on climate, geology and soil type, and fire history. This distribution is closely related to soil moisture regimes and water availability, as well as past and present land management practices. Figure 1.3 shows the mapped distribution of native forest by crown cover class. Data from various sources including NPI 2016, NVIS 5.0, SOFR 2013 and new forest cover datasets provided by state and territory agencies were used to allocate NFI forest types to the SOFR 2018 forest extent (see Table 1.13). Tables 1.4 and 1.5 provide a breakdown of the areas of the various forest types and height and crown cover classes, by jurisdiction, and Figure 1.2 shows the area proportions of nine structural classes (three crown cover classes by three height classes) across Australia's native forests.

Woodland forest is the largest crown cover class of forest in all jurisdictions except Victoria and the Australian Capital Territory (Table 1.4). In South Australia, woodland forest represents 93% of the native forest area, in Western Australia 89%, and in Queensland 77%; there are 40 million hectares of woodland forest in Queensland alone. Open forests dominate in the Australian Capital Territory (71% of the native forest area in that jurisdiction) and Victoria (61%). Woodland and open forests occur in similar proportions in Tasmania and New South Wales, while Tasmania has the highest proportion of closed forests (0.67 million hectares, 20% of that state's native forest area).

Table 1.3: Australia's native forest area, by forest type and crown cover class

Native forest type	Area ('000 hectares) Woodland	Open	Closed	Unknown	Total	Proportion of total native forest area (%)
Acacia	8,536	2,233	44	0	**10,813**	8.2
Callitris	951	1,060	0	0	**2,011**	1.5
Casuarina	1,070	150	16	0	**1,236**	0.9
Eucalypt	72,829	27,776	454	0	**101,058**	77
Eucalypt mallee	12,530	842	0	0	**13,372**	10
Eucalypt low	8,227	2,205	58	0	**10,490**	8.0
Eucalypt medium	51,326	19,783	256	0	**71,365**	54
Eucalypt tall	746	4,945	140	0	**5,830**	4.4
Mangrove	63	370	420	0	**854**	0.6
Melaleuca	5,416	938	28	0	**6,382**	4.9
Rainforest	0	1,006	2,574	0	**3,581**	2.7
Other native forest[a]	2,590	429	85	2,576	**5,679**	4.3
Total Native forest	**91,455**	**33,962**	**3,622**	**2,576**	**131,615**	**100**
Proportion of total native forest area (%)	**69**	**26**	**2.8**	**2.0**	**100**	

[a] Other native forest comprises a range of minor forest types, including Agonis, Atalaya, Banksia, Hakea, Grevillea, Heterodendron, Leptospermum, Lophostemon and Syncarpia (each named after its dominant genus), as well as native forests where the type is unknown.

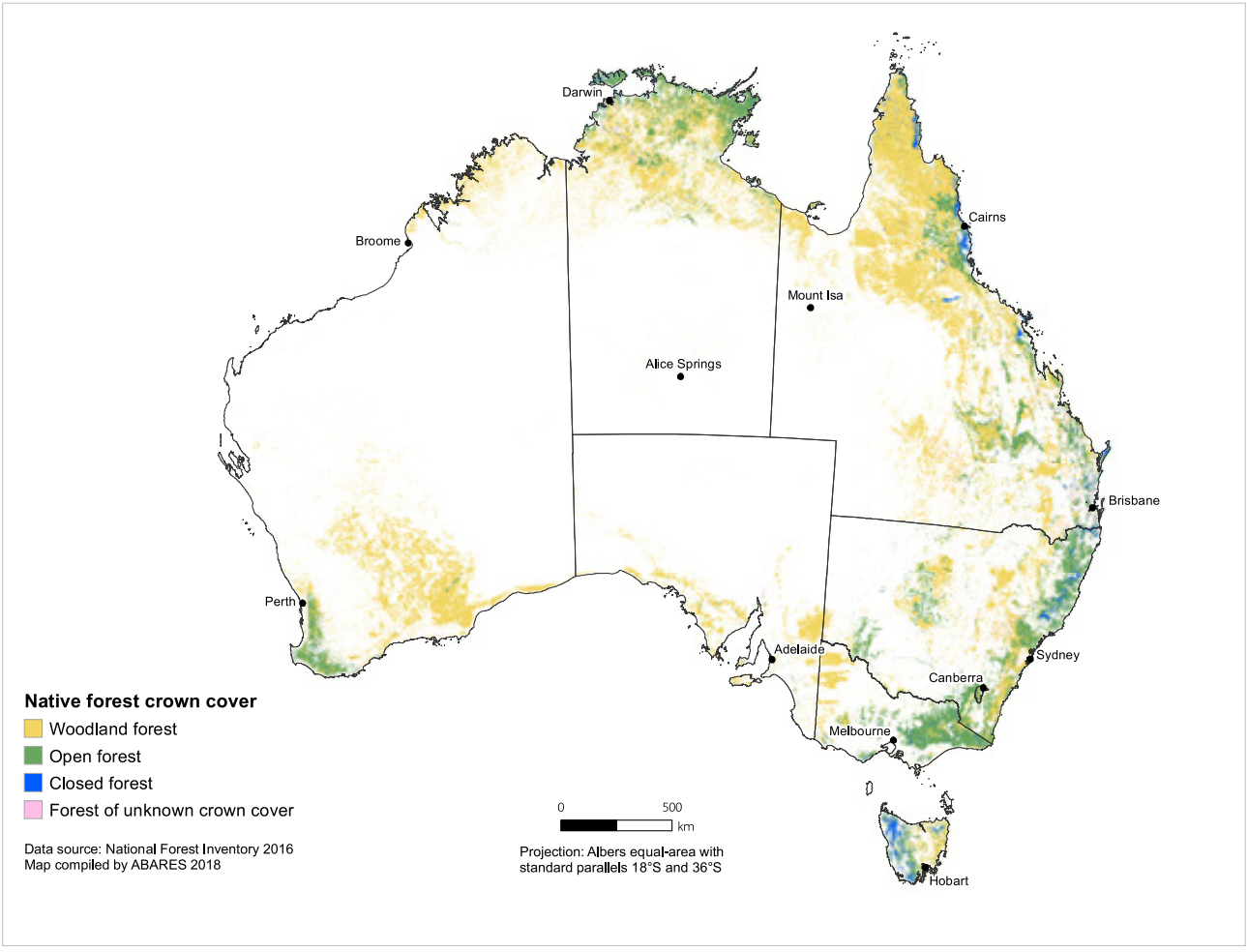
Notes: Totals may not tally due to rounding.

The area for 'Rainforest – Open' was originally published as 1,026 thousand hectares. The correct figure, as shown above, is 1,006 thousand hectares.

Source: ABARES, National Forest Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.3: Native forest, by crown cover class



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

Table 1.4: Area of native forest, by crown cover class and jurisdiction

	Woodland forest		Open forest		Closed forest		Unknown		Total native forest	
Jurisdiction	Area ('000 hectares), and proportion of jurisdiction's native forest area (%)									
ACT	38	29	92	71	0	0	0.1	0.1	130	100
NSW	9,479	48	9,233	46	507	3	707	4	19,925	100
NT	15,482	65	7,485	32	483	2	236	1	23,686	100
Qld	39,663	77	8,720	17	1,673	3	1,524	3	51,580	100
SA	4,534	93	261	5	1	0.02	61	1	4,856	100
Tas.	1,373	41	1,299	39	666	20	4	0.1	3,342	100
Vic.	2,771	36	4,641	61	233	3	0	0	7,645	100
WA	18,116	89	2,231	11	60	0.3	44	0.2	20,450	100
Australia	**91,455**	**69**	**33,962**	**26**	**3,622**	**3**	**2,576**	**2**	**131,615**	**100**

Note: Totals may not tally due to rounding.
Source: ABARES, National Forest Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

More than half (27 million hectares, 53%) of Queensland's native forests are classified as Eucalypt medium woodland (Table 1.5). Queensland also has the largest area of Acacia forest (5.1 million hectares, 47% of Australia's total) and Melaleuca forest (5.1 million hectares, 81% of Australia's total), which are both mostly woodland forests, as well as the largest area of Rainforest (2.0 million hectares, 55% of Australia's total).

Eucalypt forests dominate the Northern Territory (20 million hectares, 83% of the territory's native forest area). The largest components are Eucalypt low and medium woodland and medium open forests, together with significant amounts of Acacia and Melaleuca forests. There are no tall Eucalypt forests in the Northern Territory.

Western Australia's native forests are dominated by Eucalypt forests (16.6 million hectares, 79% of the state's native forest area) and Acacia forests (3.2 million hectares, 15%). Over half of Australia's Eucalypt mallee woodland is in Western Australia.

Over three-quarters of New South Wales native forests (15.5 million hectares) are Eucalypt forest types, with approximately equal areas of Eucalypt woodland forests and Eucalypt open forests.

Victoria's native forests are also dominated by Eucalypt forests (7.2 million hectares, 94% of the state's native forest area). Over 40% of Victoria's native forests are Eucalypt medium open forests (3.1 million hectares), with over 1 million hectares each of Eucalypt mallee woodland, Eucalypt medium woodland and Eucalypt tall open forests.

South Australia's native forests are dominated by Eucalypt mallee forests (78% of the state's native forest area). There are no tall Eucalypt forests or Rainforest in South Australia.

Although Tasmania and the Australian Capital Territory have the smallest areas of native forest of all the states and territories, they have the highest proportion of forest area (Table 1.1). Native forests in the Australian Capital Territory are almost completely Eucalypt forests (0.13 million hectares, 91% of the territory's native forest area), with the balance comprising Commercial plantations and Other forests (Table 1.5). Tasmania has the highest proportional area of Rainforest (20% of the state's native forest area, covering 0.7 million hectares), with most of the balance represented by Eucalypt forests (2.5 million hectares, 67%).

Australia has a total of 0.85 million hectares of Mangrove forests (Table 1.2). About 84% of these are in Queensland and the Northern Territory (Table 1.5).

Native forest managed for wood production occurs predominantly in the tall open and medium open Eucalypt forest types on public and private land in the 10 Regional Forest Agreement (RFA) regions and south-eastern Queensland (see Introduction and below). Across Australia, low and medium open forests and woodland forests, typically on leasehold and private land, are generally used for livestock grazing, with only occasional low-intensity wood production.

Eucalypt low woodland forest, Kalgoorlie, Western Australia.

Table 1.5: Forest area, by forest type and jurisdiction

	Area ('000 hectares)								
Forest type	**ACT**	**NSW**	**NT**	**Qld**	**SA**	**Tas.**	**Vic.**	**WA**	**Australia**
Acacia	0	730	1,522	5,121	104	77	37	3,222	10,813
Callitris[a]	0	1,394	0	527	66	1	23	0.1	2,011
Casuarina	1	512	38	272	252	10	48	103	1,236
Eucalypt	129	15,460	19,764	35,184	4,283	2,461	7,175	16,602	101,058
Eucalypt mallee open	0	617	0	0	208	0	11	6	842
Eucalypt mallee woodland	0	1,147	44	1	3,721	0.1	1,280	6,338	12,530
Eucalypt low closed	0	0	16	10	0	12	14	5	58
Eucalypt low open	0	76	624	1,295	8	52	69	83	2,205
Eucalypt low woodland	0	472	4,224	1,949	134	59	20	1,369	8,227
Eucalypt medium closed	0	17	72	42	0	0	97	28	256
Eucalypt medium open	1	4,669	5,673	4,434	17	197	3,092	1,700	19,783
Eucalypt medium woodland	8	6,015	9,111	27,052	195	1,050	1,037	6,859	51,326
Eucalypt tall closed	0	17	0	0	0	0	117	6	140
Eucalypt tall open	91	2,308	0	154	0	831	1,367	194	4,945
Eucalypt tall woodland	30	123	0	247	0	259	73	14	746
Mangrove	0	6	334	384	13	0	1	116	854
Melaleuca	0	67	1,038	5,141	34	25	19	58	6,382
Rainforest	0	594	287	1,981	0	699	20	0.2	3,581
Other native forest	0.2	1,162	702	2,970	104	69	322	350	5,679
Total Native forest	**130**	**19,925**	**23,686**	**51,580**	**4,856**	**3,342**	**7,645**	**20,450**	**131,615**
Softwood	7	294	1	196	127	76	216	98	1,015
Hardwood	0	86	44	34	51	233	198	276	922
Unknown or mixed species[b]	0	0.1	0	0	0.2	2	1	9	11
Total Commercial plantation[c]	**7**	**380**	**45**	**229[d]**	**178**	**311**	**415**	**383**	**1,949**
Other forest[d]	**5**	**62**	**4**	**21**	**25**	**46**	**162**	**148**	**474**
Total forest	**142**	**20,368**	**23,735**	**51,830**	**5,060**	**3,699**	**8,222**	**20,981**	**134,037**

[a] Stands of Callitris not sufficiently large to map at a 1 hectare scale are present in the ACT, NT and WA

[b] Plantations of mixed hardwood and softwood species, and plantations where the species type is not reported.

[c] Determined from the National Forest Inventory spatial coverage. See footnote on Commercial plantation areas under Table 1.1.

[d] Area figures for Queensland plantations reported here differ slightly from the figures reported by Queensland in 2016[27]. Area figures for 'Commercial plantations' reported in SOFR 2018 exclude plantations assessed as non-commercial plantations for the National Plantation Inventory, and which are reported in SOFR 2018 in the 'Other forest' category.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Tenure

Land tenure is an important attribute of forests, and one determinant of forest management. Different types of ownership are linked to who has the right to use and occupy land, the right to use forest resources, and the conditions that may be attached to these rights. Tenure of forest land cannot always be used to determine ownership of trees.

In the National Forest Inventory, forest ownership is reported in six national tenure classes that bring together the wide range of land tenures used by each jurisdiction across Australia (see Introduction for descriptions of tenure classes).

The dataset used in SOFR 2018 for forest tenure analysis is a combination of datasets from state and territory land titles registries and spatial data agencies, with national land tenure data from PSMA Australia Limited[28] and the Australian Government Department of Defence.

Table 1.6 shows the areas of forest in each tenure class by jurisdiction, Table 1.7 the areas of native forest in each tenure class by jurisdiction, and Table 1.8 the areas of forest by forest category, crown cover class and tenure. The distribution of forest by tenure type is mapped in Figure 1.4.

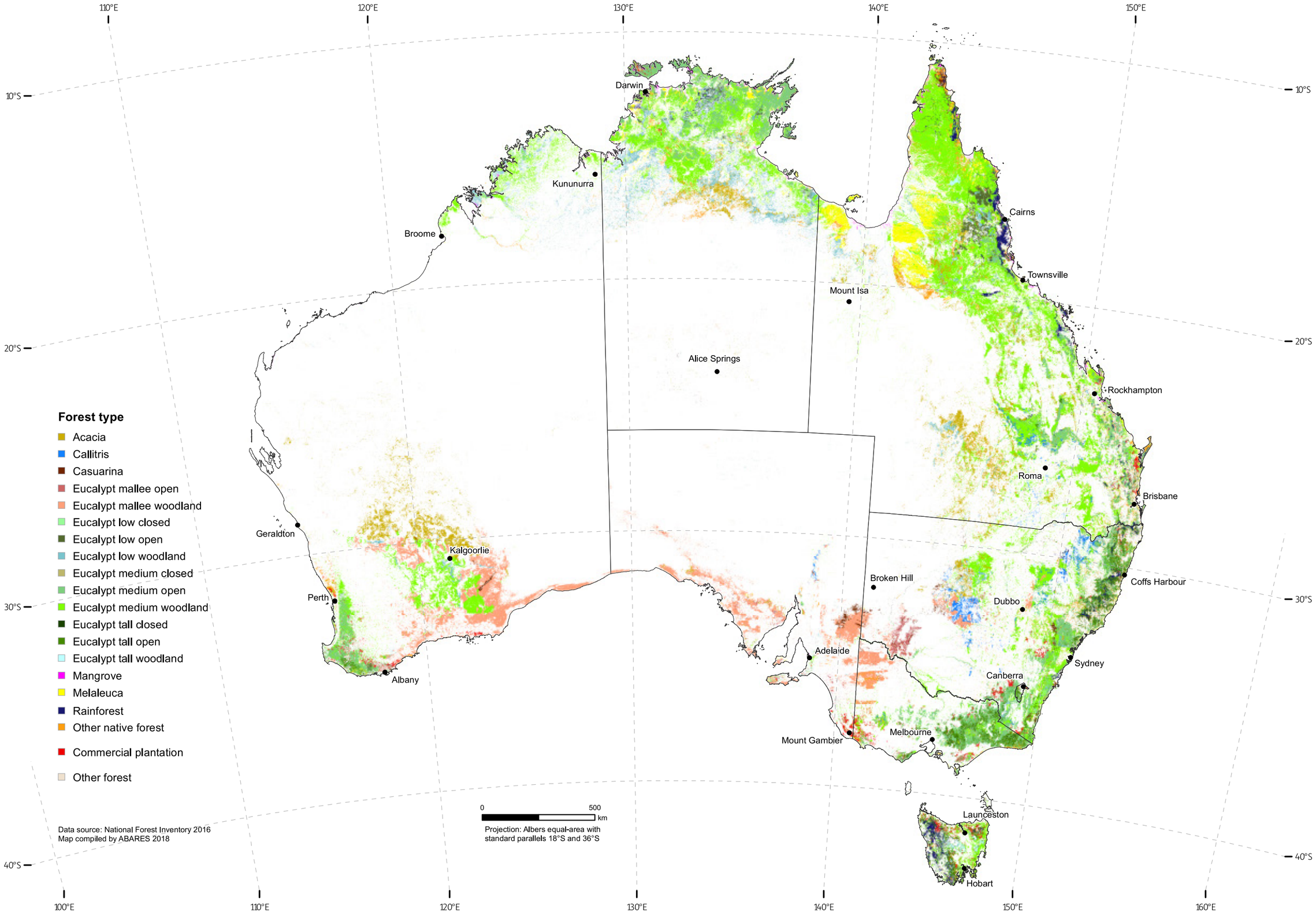
Of the 134 million hectares of forest in Australia, 47 million hectares (35%) are forest on leasehold land, and 42 million hectares (32%) are forest on land held under private freehold title (Table 1.6).

Of the 132 million hectares of native forest in Australia, 47 million hectares (36%) are native forest on leasehold land, and 41 million hectares (31%) are native forest on land held

[27] www.daf.qld.gov.au/business-priorities/forestry/plantation/plantation-area

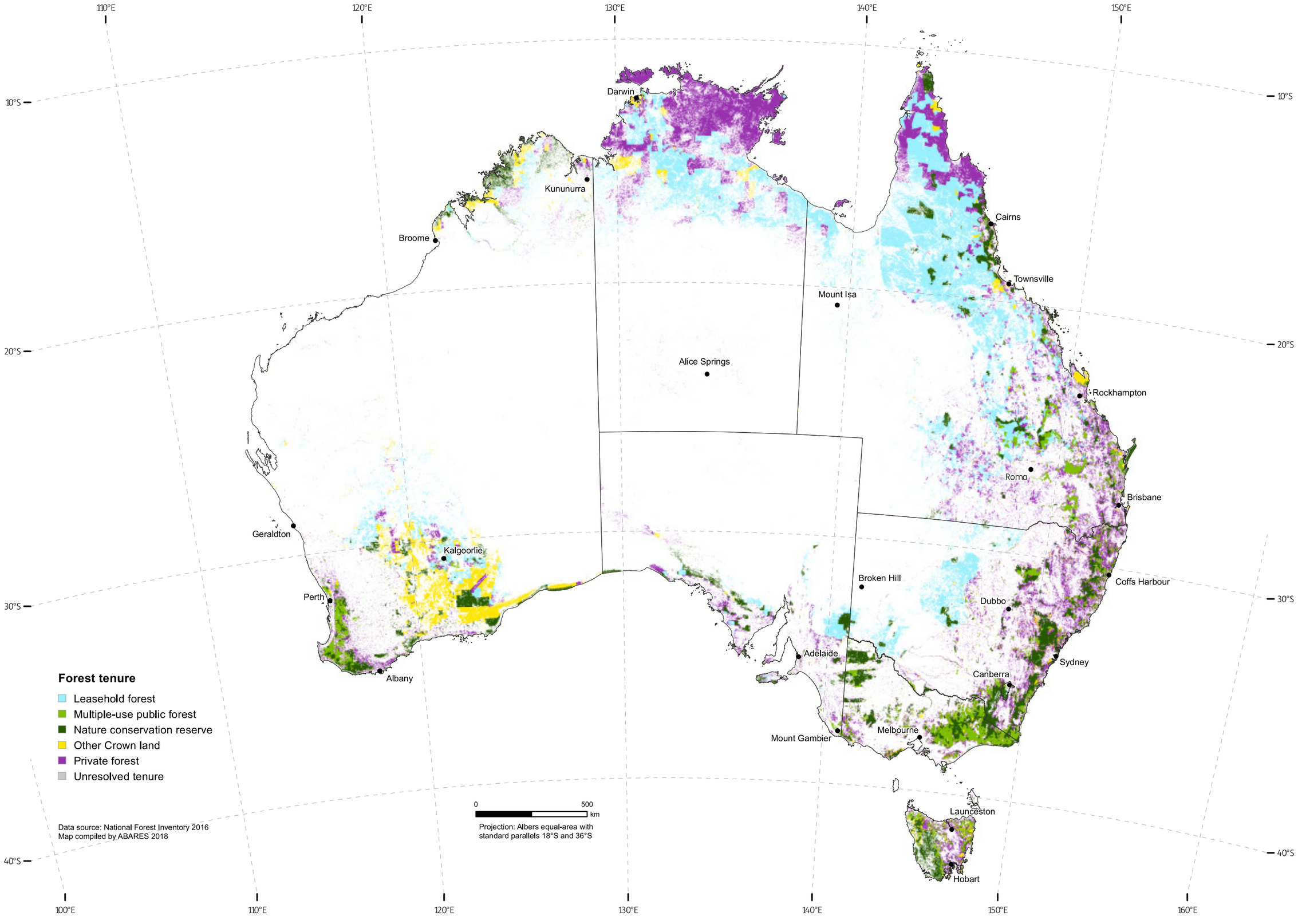
[28] www.psma.com.au/products/land-tenure. Data were purchased from OMNILINK Pty Limited (www.omnilink.com.au).

Figure 1.1: Australia's forests, by forest type



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

Figure 1.4: Australia's forests, by tenure



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

under private freehold title (Table 1.7). A total of 88 million hectares (67%) of native forest are thus under either private or leasehold tenure. The Northern Territory (96% of native forest area), Queensland (82%) and New South Wales (59%) have the highest proportions of their native forest area under private or leasehold tenure, while Western Australia (33%), Victoria (13%) and Australian Capital Territory (6%) have the lowest proportions.

Queensland has the largest area of leasehold native forest (28 million hectares, 55% of Australia's total area of leasehold native forest)[29]. Other substantial areas of leasehold native forest are in the Northern Territory, New South Wales and Western Australia. Together, Queensland, New South Wales and the Northern Territory contain 85% of Australia's native forests under private or leasehold tenure, including large areas that are Indigenous owned and managed or Indigenous managed (see Indicators 6.4a and 6.4c).

The Australian Capital Territory (86%), Tasmania (46%) and Victoria (44%) have the highest proportions of their native forest area as nature conservation reserves. The Northern Territory (0.1%) and Queensland (8%) have the lowest proportions, noting that Kakadu National Park and some other national parks in these jurisdictions are classified as private tenure.

A total of 22 million hectares of forest (17% of Australia's native forest, and 16% of Australia's total forest), is in nature conservation reserve tenure (Tables 1.6 and 1.7). Additional forest areas in different formal land tenure categories have their legislated management intent as conservation, including Indigenous owned and managed or Indigenous managed lands classified as private, leasehold or other Crown land. Kakadu National Park in the Northern Territory, classified as private tenure, is an example of such an area managed for conservation (see Indicators 1.1c, 6.4a and 6.4c).

The area of native forests in formal nature conservation reserves in SOFR 2018 is 0.24 million hectares larger than the figure reported in SOFR 2013. However, the proportion of native forest that is in nature conservation reserves is 1.0% lower than the proportion reported in SOFR 2013. This reflects the increase in the reported area of total native forest in SOFR 2018, with much of this increase occurring in the Northern Territory, where

Table 1.6: Area of forest, by tenure and jurisdiction

	Area ('000 hectares)									Proportion of total forest area (%)
Tenure class	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia	
Leasehold forest	9	4,249	9,318	28,135	1,462	0	0	4,095	47,268	35
Multiple-use public forest	15	2,138	0	3,074	117	733	3,190	1,405	10,673	8.0
Nature conservation reserve	113	5,570	15	4,379	1,698	1,545	3,377	5,056	21,752	16
Other Crown land	7	757	889	1,308	91	381	252	7,419	11,102	8.3
Private forest	0	7,572	13,476	14,269	1,671	1,040	1,402	3,006	42,436	32
Unresolved tenure	0	82	38	666	20	0	0.2	0	806	0.6
Total forest	**142**	**20,368**	**23,735**	**51,830**	**5,060**	**3,699**	**8,222**	**20,981**	**134,037**	**100**

Note: Totals may not tally due to rounding.
Source: ABARES, National Forest Inventory, PSMA Australia Ltd.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.7: Area of native forest, by tenure and jurisdiction

	Area ('000 hectares)									Proportion of total native forest area (%)
Tenure class	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia	
Leasehold forest	8	4,249	9,318	28,135	1,447	0	0	4,089	47,246	36
Multiple-use public forest	5	1,856	0	2,881	22	612	3,052	1,344	9,772	7.4
Nature conservation reserve	113	5,569	15	4,378	1,698	1,544	3,367	5,035	21,719	17
Other Crown land[a]	5	755	881	1,308	91	380	241	7,382	11,042	8.4
Private forest	0	7,414	13,435	14,213	1,580	806	984	2,600	41,031	31
Unresolved tenure	0	81	38	666	20	0	0	0	805	0.6
Total native forest	130	19,925	23,686	51,580	4,856	3,342	7,645	20,450	131,615	100

[a] A total of 1.3 million hectares of native forest on Other Crown land tenure is managed by the Australian Government Department of Defence. A breakdown of this area by jurisdiction is given in Table 1.27, Indicator 1.1c.

Note: Totals may not tally due to rounding.
Source: ABARES, National Forest Inventory, PSMA Australia Ltd.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[29] Not all forest on leasehold land is privately managed. In Queensland, under the *Forestry Act 1959* the state owns forest products on certain parcels of state land leased under the *Land Act 1994*, such as grazing leases.

Table 1.8: Area of forest, by tenure and crown cover[a]

	Area ('000 hectares)						
Crown cover class	Leasehold forest	Multiple-use public forest	Nature conservation reserve	Other Crown land	Private forest	Unresolved tenure	Total
Woodland	40,217	3,591	12,445	9,649	25,090	463	91,455
Open forest	6,277	5,699	7,666	1,084	13,019	217	33,962
Closed forest	277	419	1,528	206	1,120	72	3,622
Unknown	475	63	79	103	1,802	53	2,576
Total native forest	**47,246**	**9,772**	**21,719**	**11,042**	**41,031**	**805**	**131,615**
Commercial plantation[a]	**18**	**810**	**4**	**14**	**1,102**	**0.4**	**1,949**
Other forest	**4**	**91**	**30**	**46**	**303**	**0.3**	**474**
Total forest	**47,268**	**10,673**	**21,752**	**11,102**	**42,436**	**806**	**134,037**

[a] Determined from the National Forest Inventory spatial coverage. See footnote on Commercial plantation areas under Table 1.1.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory, PSMA Australia Ltd.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

98% of native forest is under private or leasehold land tenure and relatively little is in nature conservation reserves.

Multiple-use public forests comprise 9.8 million hectares of native forest (7.4% of Australia's native forest area). Wood harvesting is permitted in some of this area, but not in informal reserves, and not in areas such as steep areas, riparian zones or special habitat zones where harvesting is restricted by jurisdictional code of practices (see Indicator 2.1a). Wood harvesting in multiple-use public native forest is not permitted in the Australian Capital Territory or South Australia[30] (see Indicators 1.1c and 2.1a). Victoria has the largest area of multiple-use public forest (3.1 million hectares, 31% of the national area) followed by Queensland (2.9 million hectares, 29%) and New South Wales (1.9 million hectares, 19%).

The total area of multiple-use public forest reported in SOFR 2018 is 0.45 million hectares less than that reported in SOFR 2013. A substantial portion of the decrease in area is in Tasmania, where areas of forest previously reported as multiple-use public forest are now classified as either 'Future Potential Production Forest' and reported in the tenure category 'Other Crown land'[31], or as nature conservation reserve. A decrease in the reported area of multiple-use public forest has also occurred in New South Wales resulting from the use of tenure data from the NSW Spatial Cadastre database, with areas of plantation on private freehold land that are managed by state agencies being reclassified as private tenure.

Victoria (40%) and Tasmania (18%) have the highest proportions of their native forest area as multiple-use public forests. The proportion of multiple-use public forest area in each of the other jurisdictions is less than 10% of their native forest area.

A total of 0.8 million hectares of forest is of unresolved tenure. Most of this area is in Queensland, and is land for which insufficient tenure information is available in the Queensland cadastral database to allow translation to an NFI tenure class. It mostly comprises forest (including mangrove forest) on intertidal zones, wetlands and mudflats, and forest on road easements and watercourse corridors.

There are notable differences in the distribution of forest with different crown cover classes (woodland forest, open forest and closed forest) across the six tenure categories used in SOFR 2018 (Table 1.8). The majority (40 million hectares, 85%) of leasehold native forest land carries woodland forests, with almost all the remainder carrying open forest; this is because leasehold forest is predominantly in the drier parts of the forest estate (Figure 1.4). Native forest on private land is also primarily (93% by area) woodland and open forests. However, woodland forest comprises only 38% of all multiple-use public native forests. Closed forest comprises only 2.6% of the total native forest area, but comprises 6.9% of native forest in nature conservation reserves.

Mallee-form eucalypt, Western Australia.

[30] There is no multiple-use public native forest in the Northern Territory.

[31] 'Future Potential Production Forest' (FPPF) is an area of Crown land in Tasmania for which administration was transferred from the former Forestry Tasmania to the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) under *The Forestry Act 2014*. Generally, no native forest harvesting is permitted in FPPF, but after 08 April 2020 FPPF land can be converted to 'Permanent Timber Production Zone' land, subject to Parliament approval and a range of legislated conditions.

Commercial plantations

Commercial plantations are stands of trees of either native or exotic species, created by the regular placement of seedlings or seeds, and managed primarily for commercial wood production (mainly sawlogs, veneer logs and pulplogs). Commercial plantations are identified in the National Plantation Inventory (NPI), and were reported as 'Industrial plantations' in SOFR 2013. Planted trees managed for other purposes, including oil production (e.g. sandalwood oil, eucalyptus oil and tea-tree oil), environmental services or bioenergy, are reported under the 'Other forests' category.

Commercial plantation areas reported in Indicator 1.1a of SOFR 2018 are derived from the most recent update of the National Plantation Inventory spatial dataset, dated June 2015, as reported in *Australian plantation statistics 2016* (ABARES 2016b). The spatial dataset used in *Australian plantation statistics 2016* is in vector format, and conversion of this to the raster (grid) format dataset used in SOFR 2018 resulted in the area figure for Commercial plantations reported in Table 1.1a (1.95 million hectares) being slightly (1.3%) lower than the area figure (1.97 million hectares) reported in *Australian plantation statistics 2016*. More recent tabular data on plantation areas as at June 2016 are available in *Australian plantation statistics 2017 update* (Downham and Gavran 2017) (area of 1.97 million hectares), and as at June 2017 in *Australian plantation statistics 2018* update (Downham and Gavran 2018) (area of 1.96 million hectares), and again differ only slightly from the figures reported here.

Determined from the National Forest Inventory spatial coverage, Australia has 1.95 million hectares of Commercial plantations, accounting for 1.5% of Australia's total forest area (Tables 1.1, 1.2, 1.5 and 1.8). They comprise 1.02 million hectares of softwoods, 0.92 million hectares of hardwoods, and 0.01 million hectares of other, unknown or mixed species. The area of Commercial plantations has decreased slightly over the last 5 years mainly due to plantation land being returned to agriculture or other uses on the expiration of hardwood plantation lease arrangements, and only a small area of new plantation establishment. Plantations deemed non-commercial are reported in the 'Other forest' category. Details of changes in Commercial plantation areas over time are given in *Australian plantation statistics 2016* (ABARES 2016b) and *Australian plantation statistics 2017 update* (Downham and Gavran 2017).

Victoria, Western Australia, New South Wales and Tasmania have the largest areas of commercial plantations, at 0.42 million hectares, 0.38 million hectares, 0.38 million hectares and 0.31 million hectares, respectively, each contributing more than 15% of the total area of Australia's commercial plantations (Tables 1.1 and 1.5). New South Wales, Victoria and Queensland have the highest proportions of Australia's commercial softwood plantation areas (29%, 21% and 19%, respectively). Western Australia, Tasmania and Victoria have the highest proportions of Australia's commercial hardwood plantation area (30%, 25% and 21%, respectively).

The majority of the area of Commercial plantations is on private tenure (57%) and multiple-use public forest (42%) (Table 1.8). Relatively more commercial plantations are on multiple-use public forest in New South Wales, Queensland and South Australia. Nationally, Commercial plantations comprise 7.6% of the area of multiple-use public forest, and 2.6% of the area of private tenure forest.

Taken together, the 'Commercial plantation' category, plus the 'Other forest' category excluding areas of forest dominated by introduced trees established without human intervention, comprise the 'Planted forests' category used by the Food and Agriculture Organization of the United Nations for the Global Forest Resources Assessment[32], and are reported as such in Australia's Country Reports to the five-yearly Global Forest Resources Assessment[33].

Other forest

SOFR 2018 shows that Australia has 0.47 million hectares of 'Other forests'. This National Forest Inventory category includes all forest that is not native forest or commercial plantation, and so comprises mostly non-commercial plantations, planted forests of various types, and non-planted forests dominated by trees of introduced species, none of which are reported through the National Plantation Inventory.

The planted forests in 'Other forests' include environmental plantings, farm forestry and agroforestry plantations (small woodlots typically less than 1000 hectares), sandalwood (*Santalum* spp.) plantations (which are generally not intended for sawlog or fibre production), plantations within the reserve system (such as plantations in New South Wales where the land tenure has changed to nature conservation reserve), and plantations regarded as not commercially viable. Areas of forest dominated by trees of introduced (exotic) species established without human intervention (that is, not planted) are also included in this category.

The largest areas of 'Other forest' are in Victoria (0.16 million hectares) and Western Australia (0.15 million hectares) (Table 1.1), with these states having the largest increases in reported area of 'Other forest' since SOFR 2013. These areas are dominated by plantations not reported in the National Plantation Inventory because they are not deemed to be or not reported to be commercial plantations.

The majority of the 'Other forest' category occurs on private tenure (64%) and multiple-use public forest (19%) (Table 1.8).

[32] www.fao.org/forestry/fra/en/
[33] www.fao.org/3/a-az156e.pdf

Forest cover in Regional Forest Agreement regions

Regional Forest Agreements (RFAs) were established to provide a framework for sustainable forest management and conservation in regions containing substantial forestry activities. Australia's 10 RFAs cover 11 RFA regions (in New South Wales, the Upper North East and Lower North East regions are covered by a single RFA) and 39.2 million hectares of south-western and south-eastern Australia, and total 5% of Australia's land area (see Introduction). Within these RFA regions, forests cover 21.9 million hectares, which is 16% of Australia's total forest area, and 56% of the total land area of the RFA regions (Table 1.9). The forest area in RFA regions comprises 20.4 million hectares of native forest, 1.2 million hectares of commercial plantations and 0.3 million hectares of 'Other forest'.

The national forest types are not evenly distributed between forest in RFA regions and forest outside RFA regions (Table 1.10). Although only 16% of Australia's forest area is within the RFA regions, these regions contain 92% of the area of Eucalypt tall open forests, and 41% of the area of the Eucalypt medium open forests, which are major wood-production forest types. On the other hand, the RFA regions contain only 1.5% of the area of Acacia forests, and 0.6% of Eucalypt mallee woodland forests. A total of 61% of Australia's commercial plantations is in the RFA regions (Table 1.10).

Similarly, forests on different tenures are not evenly distributed between forest in RFA regions and forest outside RFA regions. Although the combined RFA regions contain 16% of Australia's forest area, they contain 60% of the area of multiple-use public forest, 37% of the area of forest in nature conservation reserves, and 16% of the area of forest on private tenure, but only 0.1% of the area of forest on leasehold land (Table 1.11). This is again consistent with large areas of drier inland forest on private or leasehold tenure not being included in RFA regions.

Across all the RFA regions, 29% of forest is multiple-use public forest, 36% is forest in nature conservation reserve and 30% is forest on private tenure. However, the tenure composition of the forest differs between RFA regions. Three RFA regions in New South Wales (Southern, Upper North East and Lower North East) contain smaller proportions of their area as multiple-use public forest (15%, 18% and 14% respectively), and larger proportions of their areas as either forest in nature conservation reserve (Southern, 47%) or forest on private tenure (Upper North East and Lower North East, 52% and 44% respectively). This contrasts with four RFA regions in Victoria (Central Highlands, East Gippsland, Gippsland and North East), which contain larger proportions of their area as multiple-use public forest (55%, 52%, 53% and 54%, respectively) and smaller proportions of their area as forest on private tenure (17%, 6%, 14% and 12% respectively).

Table 1.9: Areas of forest in Regional Forest Agreement regions, by state

RFA region	Region area ('000 hectares)	Native forest		Commercial plantation		Other forest		Total forest	
		Forest area ('000 hectares)	Proportion of area of RFA region (%)	Forest area ('000 hectares)	Proportion of area of RFA region (%)	Forest area ('000 hectares)	Proportion of area of RFA region (%)	Forest area ('000 hectares)	Proportion of area of RFA region (%)
Eden	814	550	68	41	5	5	1	596	73
Upper North East	3,910	2,297	59	71	2	22	1	2,390	61
Lower North East	5,786	3,404	59	38	1	7	0.1	3,449	60
Southern NSW	4,512	2,510	56	141	3	18	0.4	2,668	59
Total RFA regions in NSW	**15,023**	**8,761**	**58**	**290**	**2**	**52**	**0.3**	**9,104**	**61**
Tasmanian[a]	6,796	3,319	49	310	5	46	1	3,676	54
Total RFA regions in Tasmania[a]	**6,796**	**3,319**	**49**	**310**	**5**	**46**	**1**	**3,676**	**54**
Central Highlands	1,125	699	62	12	1	8	1	719	64
East Gippsland	1,225	1,104	90	6	0.5	2	0.2	1,112	91
Gippsland	2,662	1,480	56	89	3	26	1	1,595	60
North East	2,318	1,281	55	56	2	18	1	1,355	58
West Victoria	5,779	1,074	19	251	4	80	1	1,404	24
Total RFA regions in Victoria	**13,109**	**5,638**	**43**	**412**	**3**	**135**	**1**	**6,185**	**47**
South-West Forest Region of WA	4,257	2,698	63	181	4	41	1	2,920	69
Total RFA regions in WA	**4,257**	**2,698**	**63**	**181**	**4**	**41**	**1**	**2,920**	**69**
Total RFA regions in Australia	**39,185**	**20,416**	**52**	**1,194**	**3**	**274**	**1**	**21,884**	**56**

[a] Areas for Tasmania are derived from the spatial boundary of the Tasmanian RFA region held by ABARES, and differ slightly from the areas derived from the spatial boundary of the state of Tasmania used in other tables.

RFA, Regional Forest Agreement. In NSW, the Upper North East and Lower North East regions are covered by a single RFA.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Differences in RFA forest areas reported in SOFR 2013 and in SOFR 2018

The total forest area for each RFA region remained largely unchanged between that reported in SOFR 2013 and that reported in SOFR 2018. The exceptions are the combined Upper and Lower North East RFA regions in New South Wales where the reported forest area in SOFR 2018 is 425 thousand hectares less than that reported in SOFR 2013, and the Southern RFA region in New South Wales where the reported forest area in SOFR 2018 is 63 thousand hectares less.

These changes in reported areas result from the use of new and more accurate datasets (such as SPOT5 FPC and NGGI), and applying the CRAFTI dataset to identify ecosystems that are naturally non-forest, together with validation with high-resolution imagery. This allowed the reclassification to non-forest of areas previously misclassified as forest; there have been only small actual on-ground forest area changes in these RFA regions. Details and examples are given in a subsequent section of this indicator (see Figures 1.8–1.10).

In the Upper and Lower North East RFA regions, the vast majority of the difference in the reported areas derives mainly from reclassification to non-forest of areas of heathlands, shrublands, wetlands and grasslands in coastal ecosystems, and areas of shrubland on western hill slopes. Minor areas of actual, on-ground forest loss derive from loss of woodland forest adjacent to mining areas in the Hunter Valley, and conversion of plantations to grazing land to the east of the Tia River in the northern tablelands.

In the Southern RFA region, the majority of the difference in the reported areas derives from reclassification to non-forest of areas of alpine grasslands, shrublands, sedgelands and heathlands; areas of coastal heathlands, shrublands and grasslands; and areas of tableland heathlands and shrublands.

Table 1.10: Areas of forest in Regional Forest Agreement regions, by forest type

Forest type	Area in RFA regions ('000 hectares)	Area in Australia ('000 hectares)	Area in RFA regions as proportion of area in Australia (%)
Acacia	167	10,813	2
Callitris	128	2,011	6
Casuarina	98	1,236	8
Eucalypt	17,761	101,058	18
Eucalypt mallee open	0.3	842	0.03
Eucalypt mallee woodland	72	12,530	0.6
Eucalypt low closed	26	58	46
Eucalypt low open	220	2,205	10
Eucalypt low woodland	231	8,227	3
Eucalypt medium closed	141	256	55
Eucalypt medium open	8,208	19,783	41
Eucalypt medium woodland	4,572	49,326	7
Eucalypt tall closed	139	140	100
Eucalypt tall open	4,572	4,945	92
Eucalypt tall woodland	439	746	59
Mangrove	4	854	0.5
Melaleuca	146	6,382	2
Rainforest	1,258	3,581	35
Other native forest	854	5,679	15
Total native forest	**20,416**	**131,615**	**16**
Softwood	545	1,015	54
Hardwood	645	922	70
Unknown or mixed species	4	11	33
Total Commercial plantation[a]	**1,194**	**1,949**	**61**
Other forest	**274**	**474**	**58**
Total forest	**21,884**	**134,037**	**16**

RFA, Regional Forest Agreement.

[a] Determined from the National Forest Inventory spatial coverage. See footnote on Commercial plantation areas under Table 1.1.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.11: Areas of forest by tenure in Regional Forest Agreement regions, by state

RFA region	Area ('000 hectares)						
	Leasehold forest	Multiple-use public forest	Nature conservation reserve	Other Crown land	Private forest	Unresolved tenure	Total forest
Eden	1	204	251	7	134	0.3	596
Upper North East	13	428	631	61	1,252	5	2,390
Lower North East	10	489	1,320	101	1,525	6	3,449
Southern NSW	13	411	1,266	85	887	5	2,668
Total RFA regions in NSW	**36**	**1,532**	**3,467**	**254**	**3,797**	**17**	**9,104**
Tasmanian[a]	0	733	1,532	380	1,032	0	3,676
Total RFA regions in Tasmania[a]	**0**	**733**	**1,532**	**380**	**1,032**	**0**	**3,676**
Central Highlands	0	398	179	21	121	0	719
East Gippsland	0	580	455	5	72	0	1,112
Gippsland	0	845	481	41	229	0	1,595
North East	0	733	412	42	168	0.1	1,355
West Victoria	0	302	475	83	544	0.1	1,404
Total RFA regions in Victoria	**0**	**2,859**	**2,001**	**191**	**1,134**	**0**	**6,185**
South-West Forest Region of WA	17	1,250	950	49	654	0	2,920
Total RFA regions in WA	**17**	**1,250**	**950**	**49**	**654**	**0**	**2,920**
Total RFA regions	**53**	**6,373**	**7,950**	**874**	**6,617**	**17**	**21,884**
Proportion of total forest in RFA regions (%)	**0.2**	**29**	**36**	**4**	**30**	**0**	**100**
Proportion of area of that tenure in all Australia's forests (%)	**0.1**	**60**	**37**	**8**	**16**	**2**	**16**

RFA, Regional Forest Agreement.

[a] Areas for Tasmania are derived from the spatial boundary of the Tasmanian RFA region held by ABARES, and differ slightly from the areas derived from the spatial boundary of the state of Tasmania used in other tables.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory, National Plantation Inventory.

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Change in total forest cover over time

The NFI forest cover dataset reported in the five reports in the SOFR series (from SOFR 1998 to SOFR 2018) provides the best available and most accurate representation of Australia's forest extent at the time of each publication. However, the methodology used for collecting forest area data, and for compiling the data into a single national dataset, has improved substantially through the SOFR series. The continual improvements in the accuracy and resolution of the input datasets mean that comparison of the total forest area figures published in different SOFRs cannot be used to measure actual, on-ground change in forest area over time.

The change between the forest area reported in SOFR 2013 and that reported in SOFR 2018 (Table 1.14) is therefore a combination of improvements in the forest area datasets and analysis methods (Figures 1.8–1.10, below), and on-ground change in forest cover (Figures 1.11–1.13).

The best quantitative measure of the actual change over time in Australia's total forest area is obtained from the annual forest area figures produced for the National Greenhouse Gas Inventory (NGGI) for the purposes of calculating net emissions from forest lands (see Indicator 5.1a). These figures are published by the Australian Government Department of the Environment and Energy (DoEE) in annual National Inventory Reports (NIRs). The NGGI area figures are derived from a remotely sensed Landsat satellite dataset that has been collected consistently since 1972, and analysed using a national methodology, thus giving a time-consistent dataset that allows calculation of forest area change over time.

The most recent NGGI data (from the National Inventory Report 2016, Volume 2; DoEE 2018a) were used to determine figures for forest area change over time (Figure 1.5a). Those change figures were then applied to Australia's total forest area of 134.0 million hectares as at June 2016, to show the best estimate of the trend over time in Australia's total forest area since 1990 (Figure 1.5b).

These data show that there was a gradual decline in Australia's forest area through the 1990s continuing until approximately 2008. This decrease was driven by a greater extent of land clearing than regrowth or plantation establishment. However, since 2008 Australia's forest area has increased, with a net increase of 3.9 million hectares between 2011 and 2016, the reporting period for SOFR 2018. This increase was driven by an increase in the regrowth of cleared forest and a slowing

in the rate of first-time forest clearing (Figure 5.3, Indicator 5.1a), together with an expansion of forest onto previously cleared areas, and establishment of environmental plantings and commercial plantations.

Improvements in NGGI data

There have been substantial improvements in the methodologies and algorithms used to produce the forest area change figures for Australia's NGGI since the forest area change figures reported in SOFR 2013. The improved methodologies and algorithms are described in Volume 2 of various National Inventory Reports (DoE 2015, DoEE 2017d, DoEE 2018a), and include:

- Improvements in processing of remotely sensed data, and adoption of a new, 3-class algorithm to determine the boundary between woodland forest and sparse woodland (a non-forest category).
- Inclusion only of human-induced change in forest area due to permanent alterations in land use or land cover, without incorporating short-term (transient) changes in forest area or canopy cover due to natural events such as dieback, drought, cyclone damage and subsequent regrowth, wildfire and subsequent regrowth, or forest harvesting and regeneration. This identification only of long-term changes in forest cover is consistent with the definition of forest used in the NFI.
- Identification and inclusion of the natural expansion of forest onto land that did not carry forest in 1972.

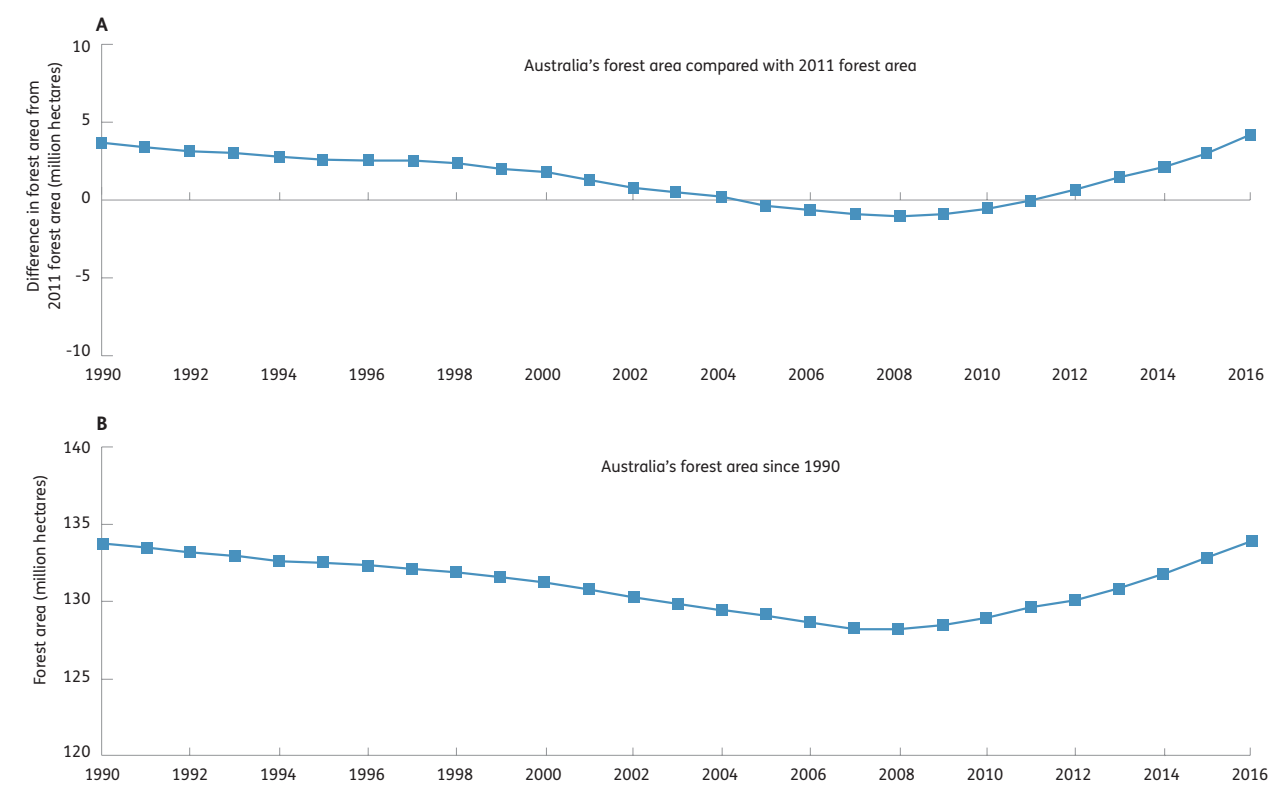
Each of these improvements is applied to the entire time-series of Landsat data. This allows the time-series to continue to be used for determination of forest area changes over time.

These improvements have also resulted in the total forest area reported in the NGGI data for 2016 (138.9 million hectares; DoEE 2018a) being similar to the total forest area reported for 2016 in SOFR 2018 through the NFI (134.0 million hectares; Table 1.1). This is the case even though the two spatial coverages differ, being derived from different datasets (Landsat satellite data for the NGGI, and multiple datasets for the NFI: see Table 1.12).

Forest clearing and regrowth

The NGGI data on the extent of forest clearing, regrowth and reclearing, for land on which clearing has occurred at some point since 1972, and published in Volume 2 of National

Figure 1.5: Australia's forest area change over time



Source: **A**, calculated by ABARES from data in the *National Inventory Report 2016* (DoEE 2018a). The forest area as at June 2011 is set at zero as this date is the start of the SOFR 2018 five-year reporting period. **B**, calculated by applying the change data in **A** to Australia's total forest area of 134.0 million hectares (Table 1.1).

These figures include data on annual clearing, regrowth and reclearing (Figure 5.3), plus data on the expansion of native forest onto areas that did not carry forest in 1972, and establishment of plantations and environmental plantings.

The data used to create this figure, together with other data for Indicator 1.1a, are available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Inventory Report 2016 (DoEE 2018a), were assembled to underpin calculations of greenhouse gas emissions by the Land-use, Land-Use Change and Forestry sector[34]. The time-series of annual forest area changes due to clearing, regrowth and reclearing is shown in Indicator 5.1a, Figure 5.3. For the NGGI dataset, 'clearing' includes clearing of native forest that has grown on previously cleared land, and harvesting of plantations that are not replanted; and 'regrowth' includes regrowth of native forests on cleared land.

For the period 2011–16, the NGGI data show:

- first-time clearing of 0.29 million hectares of forest
- regrowth of 2.69 million hectares of forest on land that has been cleared at some point since 1972
- re-clearing of 1.86 million hectares of forest that has regrown on land cleared at some point since 1972 (giving a total of 2.16 million hectares of forest cleared), and
- a net increase of 0.53 million hectares of forest due to clearing, regrowth and reclearing.

In the year 2015–16, the NGGI data show:

- first-time clearing of 60 thousand hectares of forest
- regrowth of 564 thousand hectares of forest on land that has been cleared at some point since 1972
- re-clearing of 395 thousand hectares of forest that has regrown on land cleared at some point since 1972 (giving a total of 455 thousand hectares of forest cleared), and
- a net increase of 108 thousand hectares of forest due to clearing, regrowth and reclearing.

However, these data on clearing, regrowth and reclearing do not equate to the total net change in Australia's forest area over this period, as they do not take account of forest expansion (which occurs when native forests grow on land that did not carry forest in 1972) or the smaller areas of newly established plantations and environmental plantings. Over the period 2011–16, the total area of forest expansion plus establishment of plantations and environmental plantings was 3.38 million hectares.

Summing these area changes for the period 2011–16 gives a total increase in Australia's total forest area over this period of 3.9 million hectares, as reported in Figure 1.5.

[34] Figure 6.5a of *National Inventory Report 2016 Volume 2* shows gross annual clearing and reclearing area data, as presented in Indicator 5.1a, Figure 5.3. However, Figure 6.5b of *National Inventory Report 2016 Volume 2* shows cumulative regrowth area data after accounting for any reclearing of that regrowth, and those area data are therefore different to the gross regrowth areas presented in Indicator 5.1a, Figure 5.3.

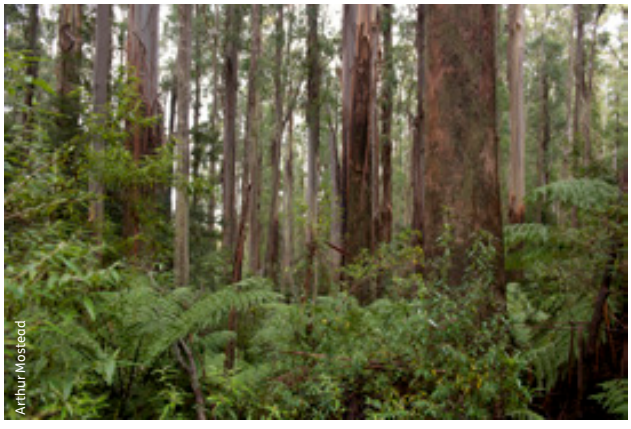
Forest mapping for SOFR 2018

Continual improvement in measuring the extent of Australia's forests, and in the reporting of forest area, has occurred since national figures were first reported in 1974 (Forwood 1975). Australia's reported forest area has fluctuated between 105 million hectares and 164 million hectares since that date. These historic fluctuations in reported areas did not represent actual changes in on-ground forest cover, but instead were largely due to changes in the area basis reported (from only commercial forests to all forests), changes prior to 1998 in the definition of forest, variability in state and territory data, correction of mapping errors, the progressive incorporation of a variety of remotely sensed datasets, and recent validation with high-resolution aerial and satellite imagery.

At 134.0 million hectares, Australia's forest area reported in SOFR 2018 differs from the forest area of 124.8 million hectares reported in SOFR 2013. The majority of this difference reflects the incorporation of new and updated data for all states and territories, delivered as a result of technological advances, including greater coverage of recent high-resolution imagery for validation of areas as forest or non-forest where confidence in other input datasets was low. The SOFR 2018 area statement also incorporates some updates due to on-ground change in forest cover over time when this is detected with the new datasets and imagery.

The Multiple Lines of Evidence process

A Multiple Lines of Evidence (MLE) process was used by ABARES to examine and combine forest cover data from multiple sources to produce the forest cover data reported in SOFR 2018. Appropriate independent datasets were intersected using analytical spatial (GIS) software, and the outputs validated using high-resolution aerial and satellite imagery. Input datasets for the MLE process included forest cover data sourced from relevant state or territory agencies, forest cover data from other national programs such as the National Greenhouse Gas Inventory (NGGI), and the forest cover dataset developed for SOFR 2013. Table 1.12 lists these datasets.



Forest of *Eucalyptus regnans* (mountain ash), Victoria.

Table 1.12: Key MLE input datasets

Dataset	Description
Forests of Australia (2013) v2.0	Forests of Australia (2013) v2.0 is an updated version of the forest cover dataset that was used in SOFR 2013. It is a continental dataset of forest extent by national forest categories and types, and was developed by a Multiple Lines of Evidence process from multiple forest, vegetation and land cover spatial data inputs, including contributions from relevant Australian, state and territory government agencies and external sources.
Landsat Foliage Projective Cover – Queensland; also known as QLD State-wide Land and Tree Study (SLATS), 2014–15.	The Queensland government SLATS method calculates Foliage Projective Cover (FPC) values from Landsat satellite Thematic Mapper™ and Enhanced Thematic Mapper Plus (ETM+) images. ABARES uses an empirically derived relationship between FPC and crown-cover values (Scarth et al. 2008) to delineate the landscape into forest and non-forest areas (an FPC of 11% is approximately equivalent to a crown cover of 20%). The SLATS dataset is produced at 30 m × 30 m resolution, and is supported by extensive on-ground validation. The dataset covers the whole of Queensland, was developed to support land-clearance legislation and monitoring of change, and is frequently updated using a consistent methodology and data source (data.qld.gov.au/dataset/statewide-landcover-and-trees-study-queensland-series)
NGGI 2016	NGGI datasets are produced from Landsat satellite Thematic Mapper™, Enhanced Thematic Mapper Plus (ETM+) and Operational Land Image (OLI) images for the Australian Government Department of the Environment and Energy, and identifies woody vegetation of height or potential height greater than 2 metres, crown cover greater than 20%, and with a minimum patch size of 0.2 hectares (DoEE 2017d). The dataset is compiled using time-series data since 1972, and is produced at a 25 m × 25 m resolution. It was designed for national carbon accounting and for monitoring changes in Kyoto-compliant forests over long time-periods, and is updated annually using a consistent methodology and data source. The NGGI dataset used was the 2016 data from the 'Woody Extent & Change (version 1.0)' spatial dataset from the Australian Government Department of the Environment and Energy, published in March 2017, which was produced using the algorithms for land-use change allocation developed for the *National Inventory Report 2015* (DoEE 2017d).
SPOT5 Foliage Projective Cover (FPC) – New South Wales; also known as the NSW SLATS 2012	The New South Wales Foliage Projective Cover (FPC) dataset is derived from Satellite Pour l'Observation de la Terre 5 (SPOT5) High Resolution Geometric satellite imagery, using the SLATS methodology described in Scarth et al. (2008). The SPOT5 FPC product used to derive forest cover is produced at 5 m x 5 m resolution. ABARES uses an empirically derived relationship between FPC and crown cover values (Scarth et al. 2008) to delineate the landscape into forest and non-forest areas (an FPC of 11% is approximately equivalent to a crown cover of 20%). The dataset is supported by extensive on-ground validation, and covers the whole of New South Wales. It was developed to support land-clearance legislation and monitoring of change, and is frequently updated using a consistent methodology and data source (datasets.seed.nsw.gov.au/dataset/nsw-woody-vegetation-extent-fpc-20119bb42)
Persistent Green-Vegetation Fraction (PGVF) (TERN)	PGVF is a national Foliage Projective Cover (FPC) dataset derived from Landsat 5 TM and Landsat 7 ETM+ satellite imagery using an algorithm developed by the Terrestrial Ecosystem Research Network (TERN) (www.auscover.org.au/xwiki/bin/view/Product+pages/Persistent+Green-Vegetation+Fraction)
Catchment Land Use Mapping (CLUM) 2017 land-use mask	The CLUM land-use mask was used to exclude from the MLE forest cover dataset land uses deemed to be not suitable to carry forests, for example urban residential, industrial, mining, horticulture and intensive agriculture. CLUM dataset is produced by ABARES.
NPI 2016 spatial dataset	NPI data were used to identify the area of Commercial plantations. The spatial vector dataset was converted to a raster format before being integrated with the MLE forest cover raster dataset. The NPI dataset is produced by ABARES.
Google Earth Pro and Bing Maps	The most recent high-resolution imagery from Google Earth Pro and Bing Maps were used for validation of forest and non-forest allocation in areas where confidence in other datasets was low.
Qld 2007–2016 Land Clearing dataset	This dataset is produced by the Queensland government for the purposes of tracking vegetation clearing in the state. It was used by the NFI to identify and classify as non-forest cleared areas that would otherwise have been incorrectly reported as forest in SOFR 2018.
ACT 2016 Vegetation Map	This spatial vegetation dataset, including forest cover, was provided by the Australian Capital Territory government for use in SOFR 2018.
Western Australia South West Forest Management Area dataset	This spatial forest cover dataset was provided by the Western Australia government for use in SOFR 2018. The dataset covers only the south-west region of the state.
Tasmania 2016 Forest Cover	This statewide forest cover dataset was provided by the Tasmanian government for use in SOFR 2018.
Victoria SOFR 2013 Forest Cover dataset	This spatial forest cover dataset (developed for the Victorian SOFR 2013) was provided by the Victorian government for use in the national SOFR 2018. It was developed for Victoria's SOFR 2013 from Landsat satellite data using Victoria's Machine Learning Algorithm.
NSW CRAFTI Upper and Lower North East (1999), Eden CRA Forest Ecosystems (1998) and Southern CRA Forest Ecosystems (2000)	These datasets, developed for the Comprehensive Regional Assessment (CRA) process, were used to delineate and mask naturally treeless areas (grasslands, heathlands and shrublands). Such areas are often classified as tree cover by remote-sensing datasets including SLATS and NGGI.

CLUM, Catchment Scale Land Use of Australia – Update September 2017[35]; CRA, Comprehensive Regional Assessment; CRAFTI, Comprehensive Regional Assessment Aerial Photographic Interpretation; FPC, Foliage Projective Cover; MLE, Multiple Lines of Evidence; NFI, National Forest Inventory; NGGI, National Greenhouse Gas Inventory; NPI, National Plantation Inventory; NIR, National Inventory Report; SPOT, Satellite Pour l'Observation de la Terre.

Note: Forest area, cover and extent are used interchangeably in this work.

[35] data.gov.au/dataset/catchment-scale-land-use-of-australia-update-2017

In the MLE process, intersection of the datasets identifies areas where datasets agree on the allocation of land as forest or non-forest. For areas for which the datasets disagree, allocation as forest or non-forest is made through an assessment of the accuracy and/or currency of individual datasets, through using ancillary data from the National Vegetation Information System, and through validation with recent high-resolution aerial and satellite imagery. Validation also involves input from and checking by the relevant state and territory agencies. The product from the most recent MLE process is a 100-m resolution forest/non-forest binary raster (grid) at 100 metre resolution (each cell or pixel thus being 1 hectare in area), and is the NFI forest cover dataset as at June 2016 that is used for reporting in SOFR 2018.

Attribution of the forest area dataset for SOFR 2018

The updated forest cover dataset is given a number of attributes, most important being forest type and tenure. The datasets used for this attribution are described in Table 1.13.

Forest area differences between SOFR 2013 and SOFR 2018

Australia's forest area determined by the above MLE process for SOFR 2018 was 134 million hectares, which is 9.3 million hectares (7.4%) greater than the forest area reported in SOFR 2013 (Table 1.14). This increase occurred for all jurisdictions excepting New South Wales and Tasmania, but the majority of the increase (8.5 million hectares, 92%) was in the Northern Territory. The majority of these area differences do not reflect actual changes of forest area (whether gain or loss), but instead reflect improved forest cover data, and improved coverage of the high-resolution aerial and satellite imagery used for validation.

This net increase in reported area of 9.3 million hectares is the sum of 16.1 million hectares identified as forest for SOFR 2018 that was reported as non-forest in SOFR 2013, and 6.8 million hectares that was been reported as forest in SOFR 2013 but identified as non-forest for SOFR 2018 (Table 1.14). These changes are generally driven by different factors in the different jurisdictions.

Table 1.13: Data sources for forest area attribution

Parameter	Data sources	Notes
Forest type	• NPI 2016, then • TASVEG, or ACT 2016 Vegetation Map, then • NVIS 5.0 or Forests of Australia (2013) v2.0, as used for SOFR 2013	A hierarchical approach was used to derive and allocate NFI forest types to the NFI 2016 forest cover dataset in the following order as applicable: 1. the NPI 2016 spatial dataset was used to allocate types to Commercial plantations 2. native forest types were allocated as follows: • Tasmania, from floristics information in TASVEG • ACT, from floristics information in the ACT 2016 Vegetation Map • for Victoria, and NSW Lower and Upper North East RFA regions, from SOFR 2013 forest cover dataset 'Forests of Australia (2013) v2.0' (and from NVIS 5.0 where appropriate information could not be derived from SOFR 2013 dataset) • for all other states and territories, from Major Vegetation Subgroup (MVS), Major Vegetation Group (MVG), Level V and Level VI categories of the NVIS 5.0 dataset. 3. where forest types could not be allocated from the above sources, forest types used in the SOFR 2013 forest cover dataset were allocated 4. any remaining native forest areas not allocated a forest type were allocated as "Other native forest". Planted forest areas not allocated a type were also allocated as "Other forest".
Forest tenure	• Jurisdictional land tenure datasets from relevant land titles registries and spatial data agencies • National land tenure data from PSMA Australia Limited • Australian Government Department of Defence • Tenure of Australia's Forests (2013) v2.0, as used for SOFR 2013	The process to allocate tenure categories to the NFI 2016 forest cover dataset used a combination of national tenure information from PSMA, data from the Australian Government Department of Defence, and data from all jurisdictions except South Australia. Data sources used for each jurisdiction were prioritised based on the assessed accuracy of each dataset.
Forest height and cover	• NVIS 5.0 • ACT 2016 Vegetation Map • Tasmania 2016 Forest Cover • SOFR 2013	

NFI, National Forest Inventory; NPI, National Plantation Inventory; NVIS, National Vegetation Information System; PSMA, PSMA Australia Ltd; TASVEG, Tasmanian Vegetation Monitoring and Mapping Program.

Table 1.14: Forest area differences between SOFR 2013 and SOFR 2018

	SOFR 2013	SOFR 2018	SOFR 2018 difference from SOFR 2013		Non-forest in SOFR 2013 but forest in SOFR 2018		Forest in SOFR 2013 but non-forest in SOFR 2018		Forest in SOFR 2013 and forest in 2018		
Jurisdiction	Area ('000 ha)	Area ('000 ha)	Area ('000 ha)	% of SOFR 2013 area	Area ('000 ha)	% of total	Area ('000 ha)	% of total	Area ('000 ha)	% of SOFR 2013 area	% of SOFR 2018 area
ACT	139	142	4	3	9	0.1	6	0.1	133	96	93
NSW	22,682	20,368	-2,314	-10	343	2	2,657	39	20,024	88	98
NT	15,207	23,735	8,528	56	9,293	58	765	11	14,442	95	61
Qld	51,036	51,830	795	2	3,017	19	2,222	33	48,814	96	94
SA	4,563	5,060	496	11	595	4	99	1.4	4,464	98	88
Tas.	3,706	3,699	-8	-0.2	96	0.6	104	1.5	3,603	97	97
Vic.	8,192	8,222	30	0.4	629	4	599	9	7,593	93	92
WA	19,223	20,981	1,758	9	2,140	13	382	6	18,841	98	90
Australia	**124,748**	**134,037**	**9,289**	**7**	**16,123**	**100**	**6,834**	**100**	**117,915**	**95**	**88**

This table, together with other data for Indicator 1.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.14 also shows that, nationally, 118 million hectares reported as forest in SOFR 2013 (95% of the SOFR 2013 forest area) is again reported as forest in SOFR 2018. Furthermore, both nationally and in all jurisdictions with the exception of the Northern Territory, 88% or more of the area reported as forest in SOFR 2018 was also as reported as forest in SOFR 2013. These results give a high level of confidence in the areas classified as forest by the MLE process, and demonstrate the improved consistency that the MLE methodology has brought to the mapping of Australia's forest cover.

Identification of additional forest areas in northern Australia

The largest area identified as forest for SOFR 2018 that had been reported as non-forest in SOFR 2013 is in the Northern Territory (9.3 million hectares). Allocation of these areas as non-forest for SOFR 2013 was driven by the absence of datasets delineating areas of tree cover within otherwise large NVIS polygons, and by the poor coverage at that time of high-resolution imagery. The availability of Foliage Projective Cover (FPC) data from the Persistent Green-Vegetation Fraction dataset produced by TERN, the 2015 NGGI forest cover dataset, and supporting high-resolution imagery (Bing Maps and Google Earth Pro), has enabled delineation of these areas as forest for reporting in SOFR 2018.

Figure 1.6 shows the extent of the additional forest areas identified across the Northern Territory, and Figure 1.7 tracks the reallocation of non-forest to forest of an example area in the Northern Territory.

These new datasets also account for much of the additional 2.1 million hectares in Western Australia that were reported as non-forest in SOFR 2013 but identified as forest for SOFR 2018. Similarly, in Queensland, a total of 3.0 million hectares were reported as non-forest in SOFR 2013 but identified as forest for SOFR 2018 as a result of new data from the Landsat FPC dataset (as the Queensland State-wide Land and Tree Study (SLATS) dataset) and the 2015 NGGI forest cover dataset, supported by validation using recent high-resolution imagery.

Reallocation to non-forest of areas previously reported as forest, and to forest of areas previously reported as non-forest

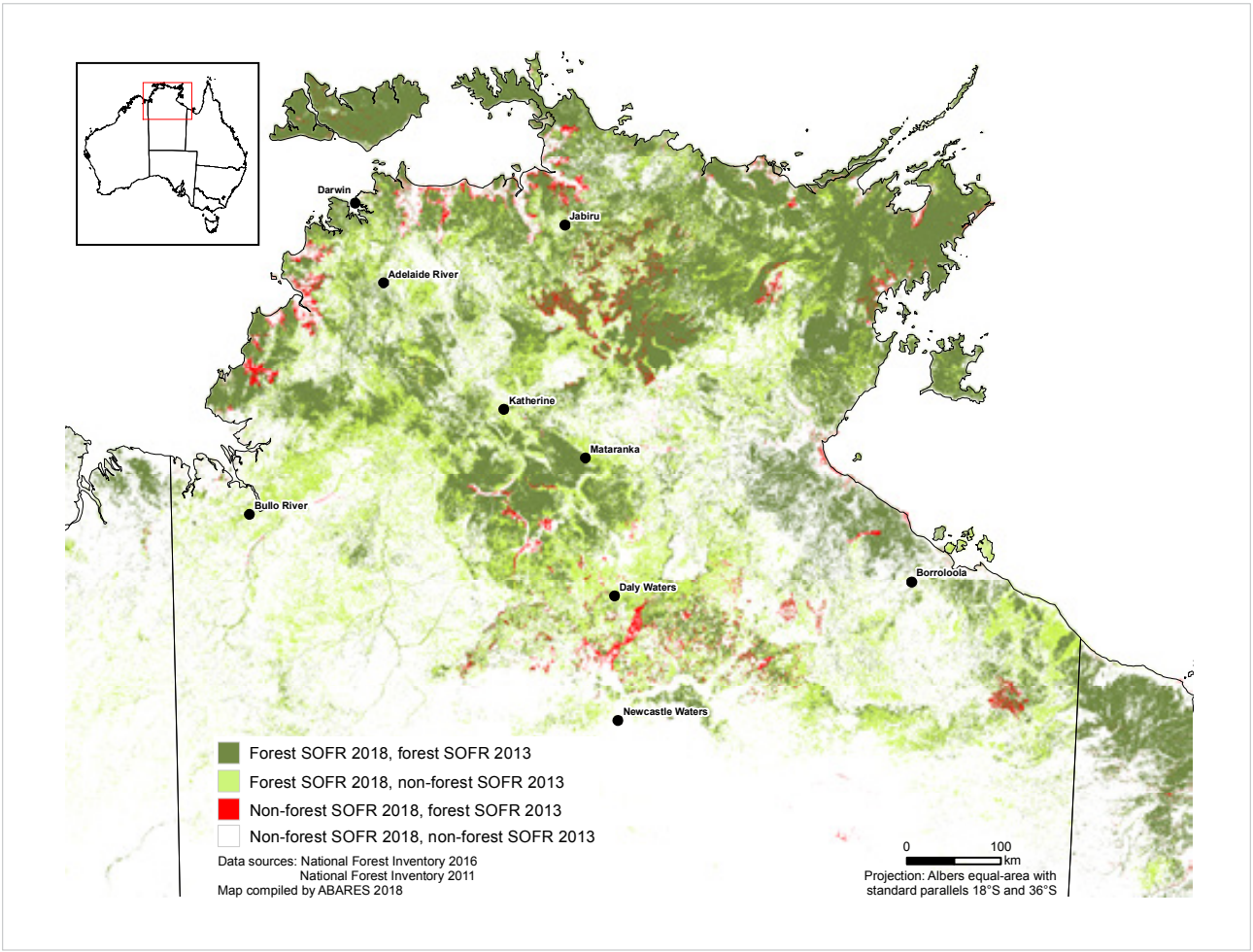
Access to a wider range of datasets, more accurate datasets, and high-resolution imagery, identified areas that were incorrectly mapped in SOFR 2013. Also identified were areas mapped as forest in SOFR 2013 but reported as non-forest in SOFR 2018, and where clearing of forest has occurred since the SOFR 2013 reporting period. It was more difficult to identify specific areas that were mapped as non-forest in SOFR 2013 but are reported as forest in SOFR 2018 specifically due to forest regrowth or forest expansion, probably because transitions from non-forest to forest are generally gradual, whereas transitions from forest to non-forest are generally abrupt.

Firstly, reallocation as non-forest of areas incorrectly mapped as forest in SOFR 2013 occurred for naturally treeless areas (grasslands, heathlands and shrublands) in coastal and alpine landscapes, mostly in RFA regions (see section above); areas of historical land clearing in New South Wales and Queensland; and areas of historical urban, mining and residential development (see Figures 1.8–10).

Secondly, reallocation to non-forest due to clearing of forest during the reporting period of SOFR 2018 occurred due to agriculture, mining or urban residential development (see Figures 1.11–13). A more detailed national view of the extent of forest clearing is covered in Indicator 5.1a (see above and Figure 5.3).

The largest areas reported as forest in SOFR 2013 but identified as non-forest in SOFR 2018 are in New South Wales (2.7 million hectares) and Queensland (2.2 million hectares). In New South Wales, this is due to incorporation of FPC data from the SPOT5 (Satellite Pour l'Observation de la Terre 5) dataset, and the 2015 NGGI forest cover data, as well as better coverage of high-resolution imagery, considered alongside the late 1990s and early 2000s Comprehensive Regional Assessments (CRA) datasets. In Queensland, this is due to incorporation of FPC data from the SLATS dataset, the 2015 NGGI forest cover data, and the Queensland 2007–2016 Land Clearing dataset, as well as the improved availability of high-resolution imagery.

Figure 1.6: Differences between forest mapping in SOFR 2018 and SOFR 2013 in the northern part of the Northern Territory



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

Three examples (Figures 1.8–1.10) are provided for areas of forest incorrectly reported as forest in SOFR 2013 that have been reallocated to non-forest in SOFR 2018.

The Upper and Lower North East CRA, Southern CRA and Eden CRA datasets, supported by high-resolution imagery, were used to identify ecosystems in New South Wales that do not support tree cover and that were incorrectly classified as forest in the SOFR 2013 dataset but are correctly classified as non-forest for SOFR 2018. These included ecosystems described as natural grasslands, herblands, sedgelands or rushlands, occurring both along the New South Wales coast and in alpine areas (see section above), and are mainly in RFA regions of New South Wales. Figures 1.8 and 1.9 track the reallocation of forest to non-forest for two example areas.

In the coastal areas of Queensland, the NVIS 5.0 dataset was used to identify non-forest ecosystems incorrectly classified as forest in the SOFR 2013 dataset, and that are correctly classified as non-forest for SOFR 2018. These include ecosystems described as in NVIS 5.0 as natural grasslands, herblands, sedgelands or rushlands and shrublands.

In New South Wales, the SPOT5 and NGGI datasets identified areas of isolated trees and green pastures in grazing landscapes (in the Upper Hunter, Namoi and Border Rivers-Gwydir Natural Resource Management (NRM) regions) that were reported as forest in SOFR 2013. The SPOT5 dataset, and inspection of new and historical high-resolution imagery, identified cleared forest areas in the Western NRM region of New South Wales with complex vegetation management regimes involving various intensities of tree clearing followed by periods of regrowth; these areas were reported as forest in SOFR 2013 but classified as non-forest in SOFR 2018. It is not yet clear how the land management regime in these systems (cycles of clearing followed by regrowth: see Figure 5.3) affects their long-term status as forest or non-forest.

In Queensland, the SLATS FPC dataset and the 2015 NGGI forest cover dataset, supported by the Queensland Land Clearing dataset (2007–2016) and new and historical high-resolution imagery, identified areas reported as forest in SOFR 2013 that were classified as non-forest in SOFR 2018. Significant areas of cleared forest were identified mainly in inland Queensland NRM regions including Northern Gulf (Gilbert River), Burdekin, Fitzroy, Maranoa Balonne and Border Rivers and South West Queensland. Clearing in the Maranoa Balonne and Border Rivers NRM and the South West Queensland NRM shows complex vegetation management regimes involving various intensities of tree clearing followed by periods of regrowth, similar to clearing in western New South Wales as discussed above.

Figure 1.7: Example of an area reported as non-forest in SOFR 2013 but as forest in SOFR 2018 due to new datasets and high-resolution imagery. Mataranka, central Northern Territory. Area in image **A** is shown in red square on images **B** and **C**. Individual mid-green and pale-green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

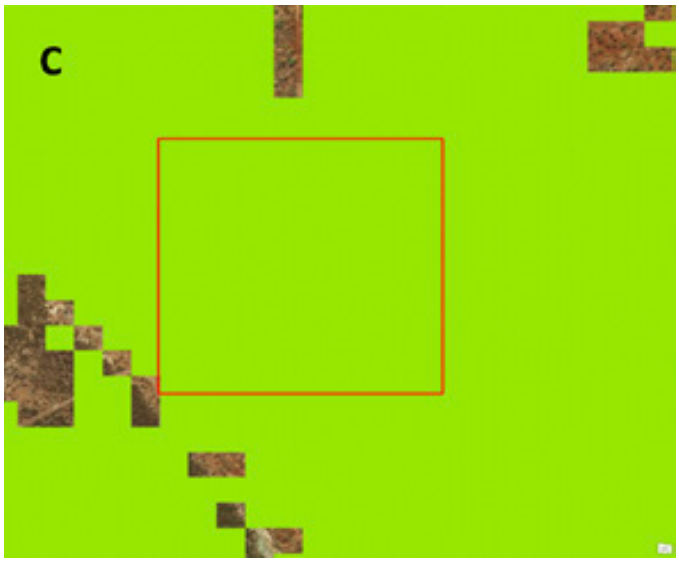
A High-resolution Google Earth Pro imagery (2016).

NVIS Major Vegetation Subgroup (MVS) for this area is 'Eucalyptus woodlands with a tussock grass understorey'. Upper stratum tree height code is '7' indicating a height range of 10–30 m, and cover code is 'i' indicating a crown cover range of 20–50%. Both codes are consistent with allocation of the area as forest, validated by imagery.

Area in this image is shown in red square on images **B** and **C**.

B Bing Maps imagery (circa 2011). Mid-green squares, areas reported as forest in SOFR 2013.

Red square in this image shows area depicted in image **A**. Large areas of woodland forest were incorrectly reported as non-forest in SOFR 2013.



C Bing Maps imagery (circa 2011). Pale green squares, areas reported as forest in SOFR 2018.

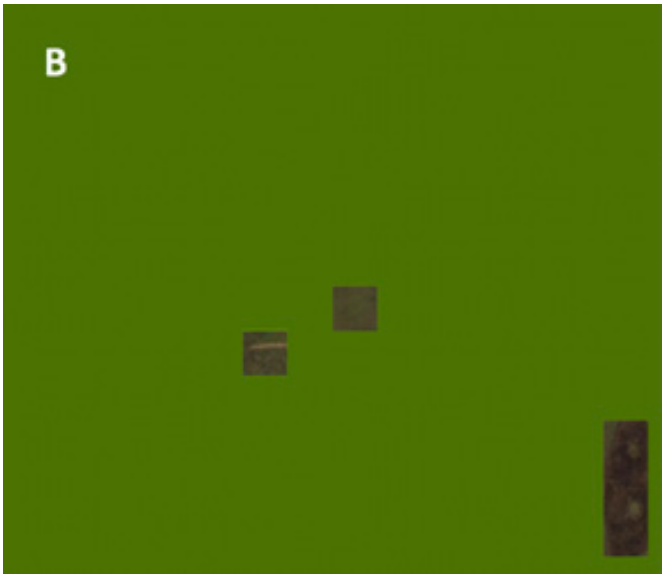
Reclassification of areas to forest supported by NGGI 2015 and TERN PGF datasets in conjunction with NVIS data and high-resolution imagery.

Red square in this image shows area depicted in image **A**.

Figure 1.8: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to better floristics information and high-resolution imagery. Evans Head, north coast New South Wales. Individual mid-green and pale green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

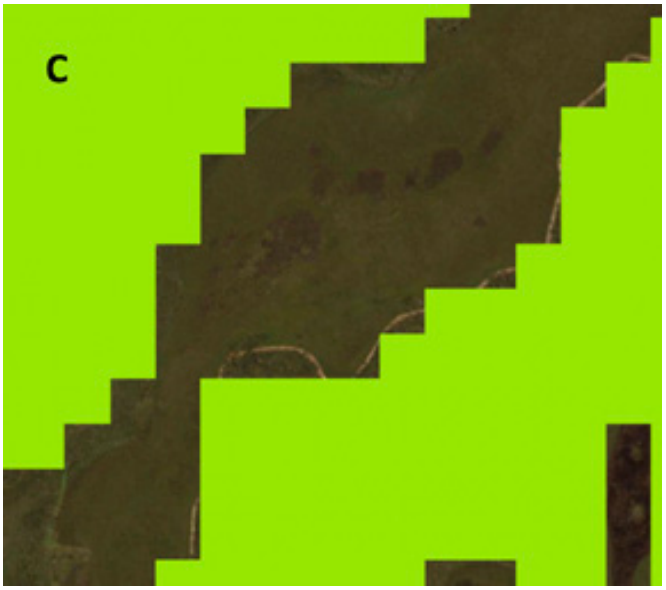
A High-resolution Google Earth Pro imagery (2013), showing areas of heath, shrub and sedge within the wider forest landscape.

NVIS Major Vegetation Subgroup (MVS) for area 1 is 'Eucalyptus open forests with fine shrubby understorey', for area 2 is 'Heathlands', and for area 3 is 'Eucalyptus tall open forest with a shrubby understorey'. Upper stratum tree height and cover codes are consistent with forest in areas 1 and 3 but not area 2.



B Bing Maps imagery. Mid-green squares, areas reported as forest in SOFR 2013.

Areas of heathlands were incorrectly reported as forest in SOFR 2013.



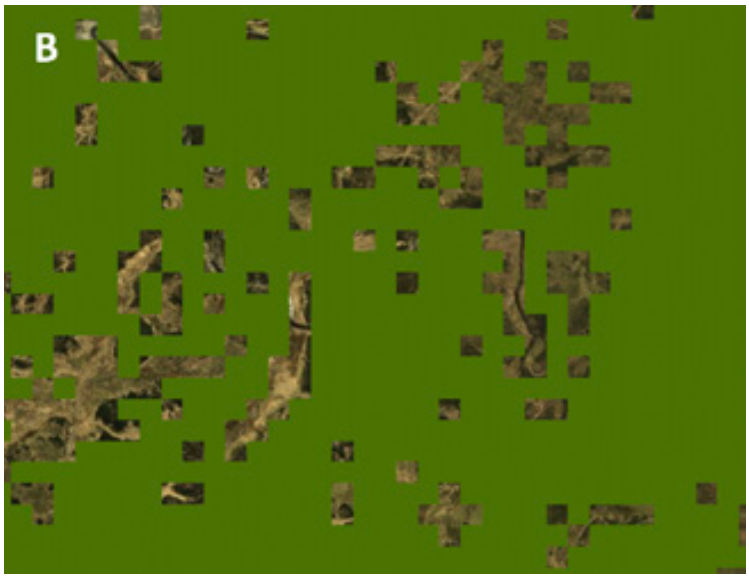
C Bing Maps imagery. Pale green squares, areas reported as forest in SOFR 2018.

Areas of heathland, shrub and sedge, as described in the Upper and Lower North East CRAFTI datasets, are correctly reported as non-forest in SOFR 2018.

Figure 1.9: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to better floristics information and high-resolution imagery. Khancoban, New South Wales. Individual mid-green and pale green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

A High-resolution Google Earth Pro imagery (2015), showing forest and non-forest areas.

NVIS Major Vegetation Subgroup (MVS) for area 1 is 'Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses', for area 2 is 'Eucalyptus open forests with shrubby understorey', and for area 3 is 'Other tussock grassland'. Upper stratum tree height and cover codes are consistent with forest in areas 1 and 2 but not consistent with forest in area 3.



B Bing Maps imagery. Mid-green squares, areas reported as forest in SOFR 2013.

Areas of grassland were incorrectly reported as forest in SOFR 2013.

C Bing Maps imagery. Pale green squares, areas reported as forest in SOFR 2018.

Non-forest areas of 'Grassland' and 'Sub-alpine Herbfield', as described in the Southern CRA Forest Ecosystems dataset, are correctly reported as non-forest in SOFR 2018.

The NVIS dataset was used in a similar way in other jurisdictions to identify and mask out ecosystems that do not support tree cover and that were incorrectly classified as forest in the SOFR 2013 dataset.

In addition, a new land-use mask, based on the *Catchment Scale Land Use of Australia—Update September 2017* dataset[36], identified as residential and urban land-use some areas that were incorrectly reported as forest in SOFR 2013 (Figure 1.10).

Three examples are also provided for areas of forest reallocated as non-forest due to detection of actual on-ground change in forest cover.

Figure 1.11 shows an example of an area that was correctly reported as forest in SOFR 2013, but subsequently cleared for agriculture and therefore reported in SOFR 2018 as non-forest. This type of on-ground forest cover change is more common in northern and western New South Wales and southern and western Queensland, and less common in other states and territories. New datasets (QLD SLATS FPC 2014–15 and NSW SPOT5 FPC 2012), supported by the improved coverage of high-resolution imagery (Bing maps and Google Earth Pro) enabled the identification of this type of cover change, and allowed reallocation of forest areas to non-forest.

Figure 1.12 shows a mining development in an area that was correctly reported as forest in SOFR 2013. Expansion over time of the mine and associated infrastructure resulted in forest being cleared. The cleared areas are reported as non-forest in SOFR 2018.

Figure 1.13 shows the detection of on-ground forest cover change due to urban development, resulting from consideration of new forest cover datasets and an updated land-use mask. Such areas are reported as non-forest in SOFR 2018. This type of forest clearance occurs more commonly on the fringes of capital cities and also coastal towns. An area of 34 thousand hectares allocated as forest in SOFR 2013 was removed from the SOFR 2018 dataset with the application of the updated (September 2017) Catchment Land Use Mapping mask.

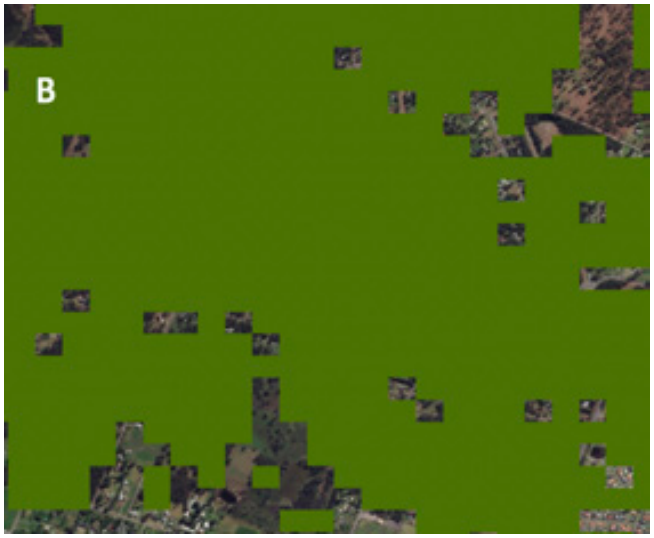
Forest of *Eucalyptus camaldulensis* (river red gum), Woohlpooer State Forest, Victoria. This forest is predominantly even-aged open forest of river red gum with a grassy understorey. The majority of trees established following the removal of grazing in 1890. (DNRE 2002: vhd.heritagecouncil.vic.gov.au/places/23412/download-report).

[36] data.gov.au/dataset/catchment-scale-land-use-of-australia-update-2017

Figure 1.10: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to application of an updated land-use mask. Medowie, north coast New South Wales. Individual mid-green and pale green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

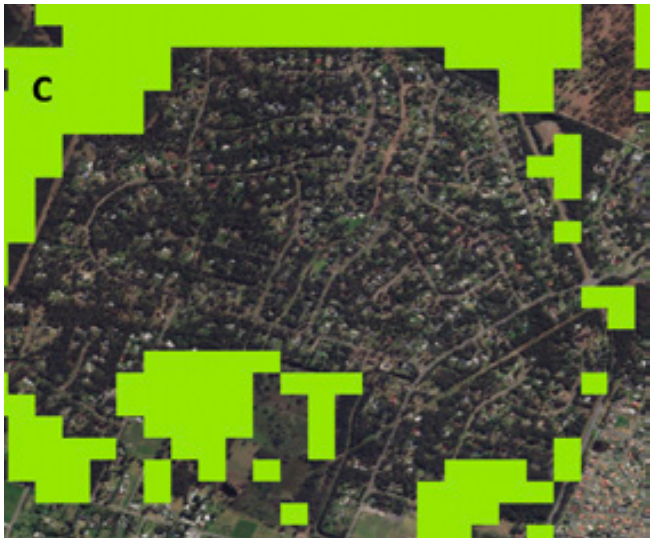
A High-resolution Google Earth Pro imagery (2011), showing urban and residential areas with patches of remaining forest.

Area 1, high-density residential. Area 2, low-density residential. Area 3, NVIS Major Vegetation Subgroup (MVS) is 'Eucalyptus open forests with a shrubby understorey', with height and cover codes consistent with the definition of forest.



B Bing Maps imagery. Mid-green squares, areas reported as forest in SOFR 2013.

Land-use mask used from *Catchment Scale Land Use of Australia—Update May 2012* (ABARES, unpublished), resulting in urban areas being incorrectly reported as forest in SOFR 2013.



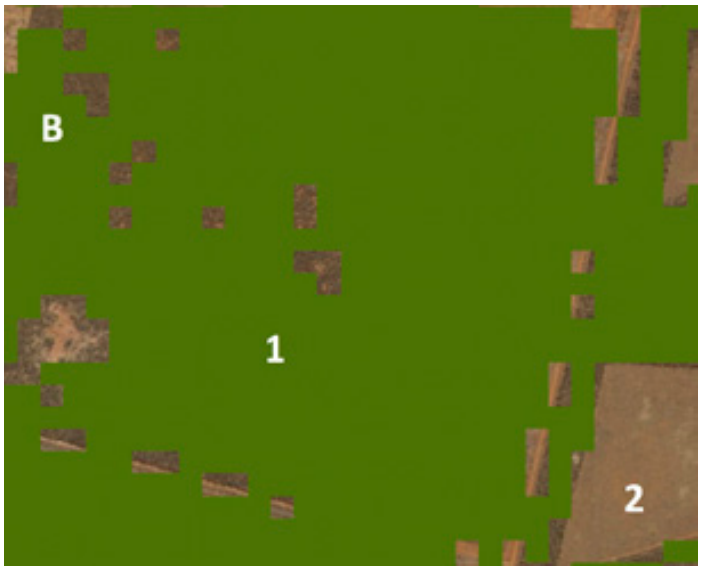
C Bing Maps imagery. Pale green squares, areas reported as forest in SOFR 2018.

Updated land-use mask from *Catchment Scale Land Use of Australia—Update September 2017* now correctly identifies urban and residential areas. Urban areas are correctly reported as non-forest in SOFR 2018.

Figure 1.11: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to land clearing. St George, central southern Queensland. Individual mid-green and pale green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

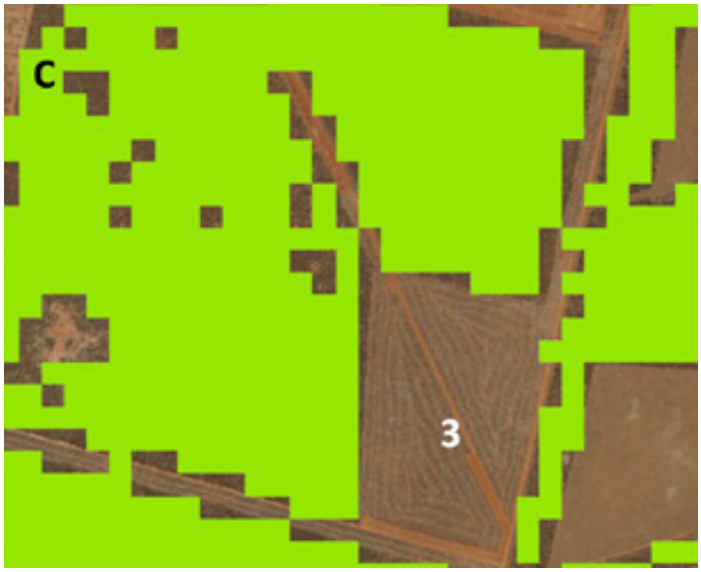
A High-resolution Google Earth Pro imagery (2012), showing landscape before land clearing.

Area 1, NVIS Major Vegetation Subgroup (MVS) is 'Mulga (*Acacia aneura*) woodlands and shrublands +/- tussock grass +/- forbs (with Eucalypt emergents)', with height and cover codes consistent with the definition of forest. Area 2 was cleared prior to 2012.



B Bing Maps imagery. Mid-green squares, areas reported as forest in SOFR 2013.

SOFR 2013 correctly reports area 1 as forest and area 2 as non-forest.



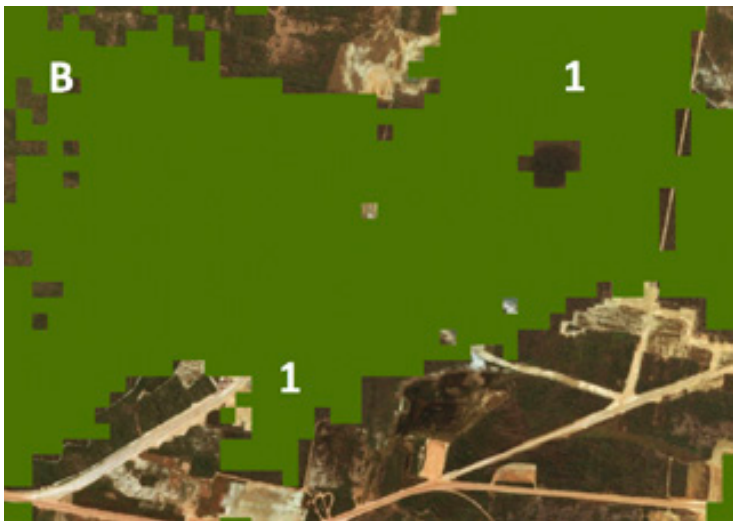
C Bing Maps imagery. Pale green squares, areas reported as forest in SOFR 2018.

SOFR 2018 correctly reports only the forest remaining after clearing, and reports cleared areas (such as area 3) as non-forest. Allocation is supported by QLD SLATS Land Clearing (2012–16) dataset. Clearing occurred in the 5-year reporting period for SOFR 2018.

Figure 1.12: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to mining development or expansion. Weipa, north Queensland. Individual mid-green and pale green squares on images **B** and **C** have an area of 1 hectare (100 m x 100 m).

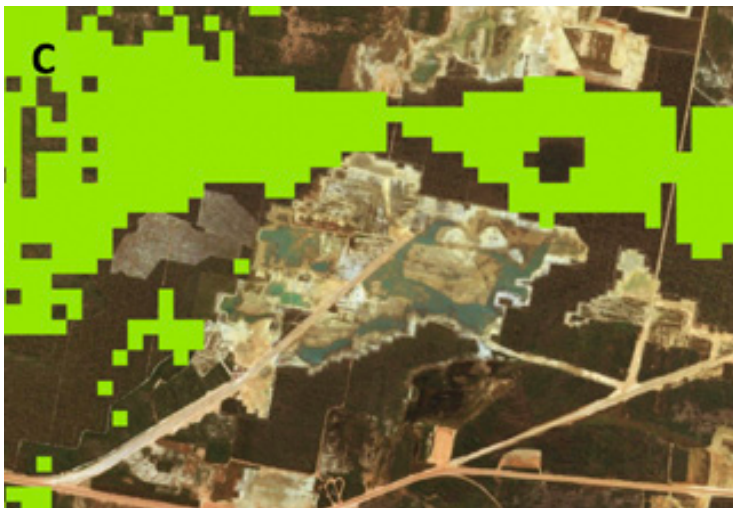
A High-resolution Google Earth Pro imagery (after 2005 but before 2012), showing a small area of mining development.

Area 1 NVIS Major Vegetation Subgroup (MVS) is 'Eucalyptus woodlands with a tussock grass understorey'. Upper stratum tree height code is '7' indicating a height range of 10–30 m, and cover code is 'i' indicating a crown cover range of 20–50%. Both codes are consistent with allocation as forest, validated by imagery.



B Bing Maps imagery (2012–16). Mid-green squares, areas reported as forest in SOFR 2013

Forest areas identified from QLD SLATS 2010 and NGGI 2011 datasets. Forest clearing for mining commenced before 2012. The areas of forest and non-forest were correctly reported in SOFR 2013.



C Bing Maps imagery (2012–16). Pale green squares, areas reported as forest in SOFR 2018.

Expansion of mining development has resulted in further clearing of forest. Following incorporation of the SLATS 2014–15 and NGGI 2015 datasets, SOFR 2018 reports these additional cleared areas as non-forest.

Figure 1.13: Example of an area reported as forest in SOFR 2013 but as non-forest in SOFR 2018 due to urban residential expansion. Redbank Plains, Ipswich, south-east Queensland. Red square shows same area on all maps. Individual pale green squares on image **C** have an area of 1 hectare (100 m x 100 m).

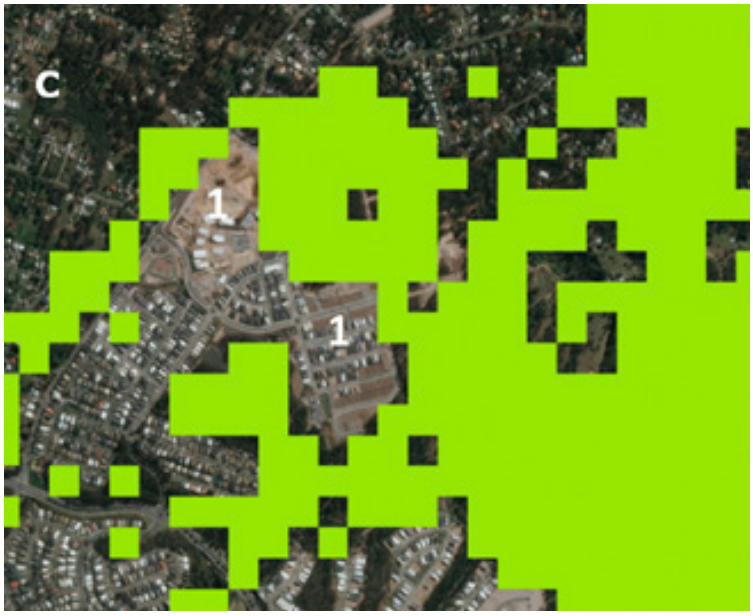
A High-resolution Google Earth Pro imagery (2011).

SOFR 2013 correctly reports area 1 as forest.

Landscape contains forest and urban components. Land-use mask from *Catchment Scale Land Use of Australia—Update May 2012* (ABARES, unpublished) allowed areas of forest to be correctly reported in SOFR 2013.

B High-resolution Google Earth Pro imagery (2016).

Forest has been cleared for urban residential development from area 1.



C Bing Maps Imagery (after 2011 but before 2017)

Area 1 correctly reported as non-forest in SOFR 2018.

Expansion of urban residential development has resulted in further clearing of forest. Updated land-use mask from *Catchment Scale Land Use of Australia —Update September 2017* has allowed SOFR 2018 to correctly report additional cleared areas as non-forest.

Indicator 1.1b

Area of forest, by growth stage

Rationale

This indicator measures the change in area of forest by growth stage to reflect how ecological processes and species associated with those processes change as forests grow. The age and size of trees is important in maintaining forest biodiversity.

Key points

- Australia's native forests comprise stands at regeneration, regrowth, mature and senescent growth stages, as well as stands of uneven-aged forest. Old-growth forest is not a specific growth stage, but is defined in relation to stand structure, as 'ecologically mature forest where the effects of disturbance are now negligible'.
  - Current information on native forest growth stage is available only for Tasmania, and current information on the area of old-growth forest is available only for Tasmania and Western Australia.
- Data collected over the period 1995–2000 as part of Comprehensive Regional Assessments in eleven forested regions of five states showed that all forest growth stages were present on all tenures.
  - On average, multiple-use public forest had a greater proportion of younger growth stages (regeneration and regrowth) and uneven-aged forest than did forest in nature conservation reserves, which had a greater proportion of senescent forest.
  - Considering the long time-spans over which forest development occurs, those general patterns are unlikely to have changed substantially since the data on growth stage were collected.
- The total area of old-growth forest in the Regional Forest Agreement (RFA) regions, which are the regions for which data were collected as part of Comprehensive Regional Assessments, is calculated to have decreased from 5.0 million hectares at the signing of the RFAs to 4.5 million hectares as at 2016.
  - The majority of the decrease in old-growth forest area occurred in Victoria, and was almost entirely due to bushfires in the decade to 2009.

Growth stage

The growth stage of a native forest[37] is one determinant of its biodiversity and ecological values. Growth stage assessment also indicates the balance of different age classes across a forest estate. Both the sustainable production of wood and the maintenance of values (such as species diversity, maximum carbon stocks or uniform water flows) can be improved when an area contains a mix of forest stands in different age classes, forming a mosaic of growth stages in the landscape. In addition, some species depend on more than one growth stage: for example, Leadbeater's possum (*Gymnobelideus leadbeateri*) requires trees at one growth stage for nesting and an understorey or midstorey at different growth stage at the same site or nearby for feeding.

Almost all Australian eucalypt forests are characterised by regular disturbance, predominantly by fire. The disturbance regime that characterises a forest type or site is defined as the pattern of fire extent and intensity over time in that forest type or at that site. Attempting to manage Australian eucalypt forests to achieve a particular balance of growth stages across a given area thus requires working with, and being guided by, the natural disturbance regime. This can be a management goal both in multiple-use forests and in nature conservation reserves.

State and territory governments have developed various methods for describing the different growth stages or age classes of native forest that result from disturbance, especially for wetter eucalypt forests in which individual stands are often even-aged as a result of a severe disturbance event. Commonly, four main growth stages are identified in native forests: regeneration (generally taken as less than 20 years since disturbance), regrowth (generally taken as 20–80 years since disturbance), mature (generally taken as 80 or

[37] Plantation growth stages are reported by ABARES (2016b).

more years since disturbance) and senescent (various ages after 80 years since disturbance, when irregular crowns form, while hollows may take over 100 years to develop) (Figure 1.14); these numerical values can differ substantially between forest types.

These four categories apply reasonably well to even-aged forests. However, substantial areas of forests are mixtures of more than one growth stage, resulting from less severe or less uniform disturbance events that lead to mixed-aged or uneven-aged stands containing trees of different ages. This is especially the case for drier eucalypt forests, or forests dominated by non-eucalypt species such as rainforest or open acacia woodlands.

Information on forest growth stage

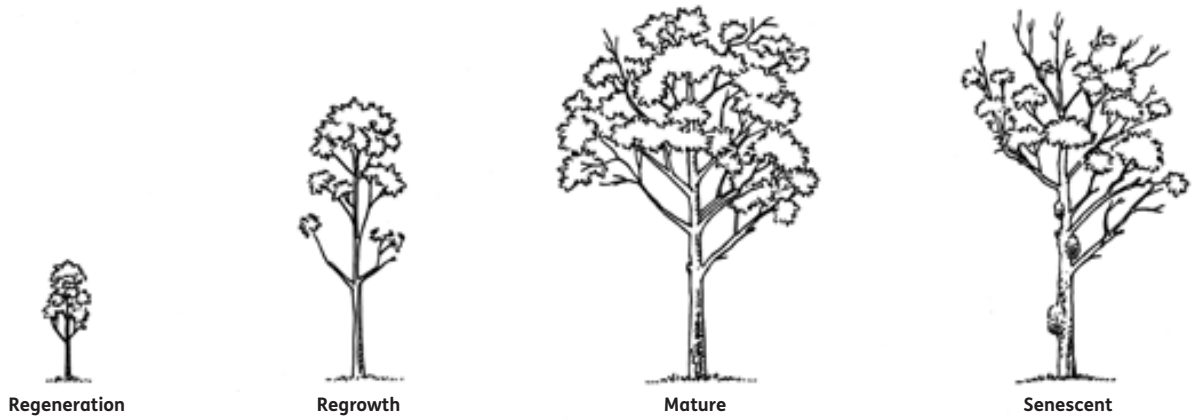
Growth stage information was collected over the period 1995–2000, as part of the Comprehensive Regional Assessments (CRAs) undertaken in eleven forested regions of five states in preparation for signing of various Regional Forest Agreements (RFAs). This information covered 15.4 million hectares of Australia's native forest, and was presented in previous SOFRs. Growth stages were best characterised for multiple-use public native forests used for wood production, because the mapping of growth stages in such forests is important for ongoing forest resource assessments. Gaps in the data existed on all other tenures.

However, this growth-stage information has not been updated, except for forests in Tasmania (see Table 1.16).

In data collected as part of the CRA process for RFAs, all native forest growth stages were found to be present on all tenures. Nearly half of the area of native forest was categorised as mature forest, with large areas of mature forest in nature conservation reserves, multiple-use public forest, and private land. Native forest mapped as senescent was predominantly found in nature conservation reserves, often because forest of this age was placed in reserves due to its particular values. A greater proportion of multiple-use public native forest was at younger growth stages (regeneration and regrowth) than forests in nature conservation reserves, largely because less forest of this age has been placed in reserves, but also because some multiple-use public forests are managed on a cycle of harvesting and regeneration to provide an ongoing forest resource for wood production.

These general patterns of forest growth stages across tenure categories are unlikely to have changed substantially since the RFA data were collected. However, a considerable proportion of forest in the regeneration category will have progressed to the regrowth category, and some of the regrowth forest will have progressed to the mature category. Some mature and senescent forest has been burnt by bushfire (especially in Victoria) and will therefore now be regeneration or regrowth forest (although containing significant quantities of standing dead trees). Some mature forests have also been harvested and regenerated, and will therefore now also be forest in the regeneration growth stage.

Figure 1.14: Classification of growth stages in native forests



Regeneration: includes juvenile and sapling stages, when trees are very small and crowns exhibit apical dominance. (Apical dominance is where the main central stem of the tree is growing more strongly than the side branches.)

Regrowth: trees have well-developed stems with crowns of small branches but are below mature stand height. Apical dominance is apparent in vigorous trees. Includes 'pole' and 'early mature' stages.

Mature: trees are at maximum height and crowns at full lateral development. Branch thickening can occur.

Senescent: crowns are contracting, and crown diameter and crown leaf area are decreasing.

Uneven-aged forests can contain a mixture of two of more of these growth stages.

Source: adapted from Clode and Burgman (1997).

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

Old-growth forest

Old-growth forest is not a growth stage defined by time since disturbance, but rather is defined in relation to stand structure and features. In Australia, old-growth forest is defined as '*ecologically mature forest where the effects of disturbance are now negligible*' (ANZECC and MCFFA 1997).

The conservation and protection of old-growth forest is a requirement of the *National Forest Policy Statement* (Commonwealth of Australia 1992) and is incorporated in the RFAs. The concept of old-growth forest is captured in Pitman et al. (1996), and in an updated diagram in Davey (2018a), which both show that areas of old-growth forest are a subset of the areas of mature and senescent growth stages.

Old-growth forests typically contain large, old trees, and are also characterised by habitat features such as stem and branch hollows, dead standing trees, and large logs and woody debris on the forest floor. They have low average tree growth rates and rates of carbon sequestration, and relatively low rates of change in composition and structure, but contribute significantly to carbon storage. Old-growth forests also typically transpire less water, have higher soil moisture content, and have higher stream water flow than do younger growth stages of forests of the same type. In summary, old-growth forests have significant habitat, nature conservation and aesthetic values that are not found in forests in earlier stages of development, and contribute significantly to carbon storage and water production.

The regional extent of old-growth forests changes over time due to the effects of forest growth, disturbance (most generally bushfire, but also cyclones in northern Australia), ageing, disease or lack of fire, and occasionally due to limited wood harvesting where that is permitted. Jurisdictions have policies that exclude harvesting from old-growth forest, or management prescriptions to reduce harvesting effects and limit harvest areas.

In the period 1995–2000, one of the projects under the CRAs was to map old-growth forests in eleven forested regions around Australia as part of the RFA process. These assessment results have been updated for some regions from time to time (Case Study 1.1 describes an update to the extent of jarrah (*Eucalyptus marginata*) and karri (*E. diversicolor*) old-growth forests in Western Australia), but there has been no national survey of old-growth forest since that period. The areas of old-growth forest as assessed in the CRAs that led to RFAs, and the areas of old-growth forest in currently available data for each jurisdiction, are summarised by RFA region in Table 1.15.

Table 1.15: Old-growth forest areas in RFA regions ('000 hectares)

	Areas from CRAs (1995–2000)			Areas in most recent data[a]	
RFA region	Forest	Old-growth forest	Old-growth forest as proportion of total forest (%)	Old-growth forest	Old-growth as proportion of total forest at CRA (%)
Eden	533	98	18	98	18
Upper North East	2,167	655	30	655	30
Lower North East	3,175	1,030	32	1,030	32
Southern NSW	2,446	753	31	753	31
Total RFA regions in NSW	**8,320**	**2,536**	**30**	**2,536**	**30**
Tasmanian	3,205	1,239	39	1,206	38
Total RFA region in Tasmania	**3,205**	**1,239**	**39**	**1,206**	**38**
Central Highlands	692	26	4	9	1
East Gippsland	1,078	225	21	109	10
Gippsland	1,426	209	15	78	5
North East	1,252	259	21	141	11
West Victoria	968	122	13	91	9
Total RFA regions in Victoria	**5,415**	**841**	**16**	**428**	**8**
South-West Forest Region of WA	2,235	347	8	334	15
Total RFA regions in WA	**2,235**	**347**	**8**	**334**	**15**
Total RFA regions in Australia	**19,175**	**4,963**	**26**	**4,504**	**23**

CRA, Comprehensive Regional Assessment.

[a] Dates of most recent data: Victoria, 2009; New South Wales, 2001; Tasmania 2017; Western Australia, 2017. Data include public and private land (including private land protected by conservation covenant).

Sources: National Forest Inventory, data provided by states for Australia's State of the Forests Report 2018, and state forest management planning documentation interpreted by ABARES.

This table, together with other data for Indicator 1.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Large decaying and hollow logs on the forest floor are a characteristic feature of old-growth forests.

As assessed for the CRAs, there was a total of 5.0 million hectares of old-growth forest in the RFA regions (26% of Australia's forest area in those regions at that time) (Table 1.15). Since that date, areas of old-growth forest have reduced in several regions. The area of old-growth forest in Victoria reduced by 413 thousand hectares (49%), caused almost entirely by bushfires in 2003, 2007 and 2009. The 13 thousand hectare (4%) reduction of old-growth forest area in Western Australia was due to a combination of harvesting prior to 2001 (when harvesting of old-growth forest ceased), improved mapping, bushfire and disease, while the 33 thousand hectare (3%) reduction of old-growth forest area in Tasmania was caused by limited wood harvesting, bushfire, and conversion to plantations and agricultural land uses. Updated data on old-growth forest areas are not available for New South Wales.

Information on forest growth stage and old-growth forest in Tasmania

Data on forest growth stage in Tasmania are based on growth stage mapping on all tenures. This was completed state-wide in 1996, and has since been updated periodically with data from public and private forest practices plans that show areas proposed for wood harvesting or conversion for other purposes. This same approach has been applied to mapping old-growth forest in Tasmania. These data therefore do not generally reflect changes due to natural processes.

The most recent data were published in *State of the forests Tasmania 2017* (FPA 2017a). Table 1.16 presents a combination of data from two tables in that report, in which the area of old-growth eucalypt forest has been extracted from the area of eucalypt forest in the Tasmanian growth stage 'Mature and over-mature', and reported separately. The area of old-growth non-eucalypt forest (such as rainforest) has also been extracted from the area of non-eucalypt forest in the 'Unknown' growth stage, and reported separately.

Across Tasmania, 99 thousand hectares (3%) of native forests are in the regeneration category, 549 thousand hectares (18%) are regrowth, 932 thousand hectares (31%) are mature, and 1.21 million hectares (40%) are old-growth (Table 1.16). A total of 267 thousand hectares of native forest are of unknown growth stage, mostly in the non-eucalypt RFA forest type, which are often multi-aged forests or forests that regenerate without episodic disturbance and for which no growth-stage category is appropriate.

In Tasmania's dry eucalypt forests, the proportion of regeneration and regrowth forests averages 21% across all tenures. However, these forests often grow in multi-aged stands, and forests mapped as regeneration or regrowth usually contain a proportion of older trees.

In Tasmania's wet eucalypt forests, the proportion mapped as regeneration and regrowth across all tenures is higher, at 41%. This is due in part to the ecology of wet eucalypt

communities, which tend to grow in single-age stands, so that regrowth stands are readily identifiable. It also reflects the history of disturbance by fire and wood harvesting in wet eucalypt forests. The proportion of wet eucalypt forest mapped as regeneration and regrowth ranges from 20% in nature conservation reserves to 54% on private land and 57% on Permanent Timber Production Zone land.

The transfer of large areas of multiple-use public forests in Tasmania into nature conservation reserves and Future Potential Production Forest (classified nationally as 'Other Crown land', or in Tasmania as 'Other publicly managed land') since the publication of *State of the Forests Tasmania 2012* (FPA 2012) led to substantial changes in the growth-stage distribution of forests by tenure.

Table 1.16: Area of native forest types by tenure and growth stage (including old-growth forest), Tasmania ('000 hectares)

Tenure category[a] / RFA forest type	Growth stage (including old-growth forest)[b]					
	Regeneration	Regrowth	Mature	Old-growth	Unknown	Total
Conservation reserves						
Dry eucalypt forest	0	60	144	240	10	455
Wet eucalypt forest	5	53	60	165	3	287
Sub-alpine eucalypt forest	0	11	1	35	4	51
Non-eucalypt forest	0	0	0	423	40	463
Sub-total	**5**	**124**	**205**	**863**	**57**	**1,256**
Permanent Timber Production Zone land						
Dry eucalypt forest	15	67	84	26	7	199
Wet eucalypt forest	49	126	87	36	9	306
Sub-alpine eucalypt forest	0	0	1	1	0	2
Non-eucalypt forest	0	0	0	40	51	91
Sub-total	**64**	**193**	**172**	**103**	**67**	**599**
Other publicly managed land						
Dry eucalypt forest	7	24	80	53	7	171
Wet eucalypt forest	7	29	41	22	3	100
Sub-alpine eucalypt forest	0	0	1	2	1	5
Non-eucalypt forest	0	0	0	56	26	82
Sub-total	**14**	**53**	**122**	**133**	**37**	**358**
Private freehold land						
Dry eucalypt forest	13	122	395	89	59	678
Wet eucalypt forest	3	56	34	6	11	110
Sub-alpine eucalypt forest	0	1	3	2	1	7
Non-eucalypt forest	0	0	0	10	35	45
Sub-total	**16**	**179**	**432**	**107**	**106**	**840**
All tenures						
Dry eucalypt forest	35	273	703	408	83	1,502
Wet eucalypt forest	64	264	222	229	26	805
Sub-alpine eucalypt forest	0	12	6	40	6	64
Non-eucalypt forest	0	0	0	529	152	681
Total	**99**	**549**	**932**	**1,206**	**267**	**3,052**

RFA, Regional Forest Agreement. Tasmania does not use the growth stage category 'senescent'.

[a] Tenure data are as at 30 June 2016, and are reported by Tasmanian tenure categories. The Tasmanian category 'Permanent Timber Production Zone land' is broadly equivalent to the national tenure category 'Multiple-use public forest'. The Tasmanian category 'Other publicly managed land' includes land classified by Tasmania as Future Potential Production Forest, and which is classified nationally as 'Other Crown land'.

[b] Growth stage data are as at 30 June 2016 for publicly managed land, and as at 31 December 2015 for private land.

Notes:

Data are adapted from *State of the forests Tasmania 2017* (FPA 2017a) Table 1.1.b.1 *Area of native forest types by growth stage and tenure* and Table 1.1.e.1 *Old-growth by forest type and tenure*. For each eucalypt RFA forest type in each tenure category, the old-growth forest area from Table 1.1.e.1 was subtracted from the 'Mature and over-mature' growth stage area on Table 1.1.b.1, to give the area of the 'Mature forest' growth stage presented above. For the non-eucalypt RFA forest type in each tenure category, the old-growth forest area from Table 1.1.e.1 was subtracted from the of 'Unknown' growth stage area on Table 1.1.b.1, to give the area of 'Unknown' growth stage presented above. The old-growth forest areas for each eucalypt RFA forest type and the non-eucalypt RFA forest type were then presented separately. The total native forest area above (3.052 million hectares) is the total native forest area reported in *State of the forests Tasmania 2017* (FPA 2017a).

This table, together with other data for Indicator 1.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Case study 1.1: Updating the extent of jarrah and karri old-growth forests

In the south-west of Western Australia, old-growth forests on lands vested in the Conservation and Parks Commission are protected from disturbances such as timber harvesting, road and track construction, or infrastructure development. However, the extent of old-growth forest can change over time as a consequence of natural events, such as stand-replacing bushfires in karri (*Eucalyptus diversicolor*) forests or the spread of *Phytophthora* dieback disease in jarrah (*E. marginata*) forests. Improved mapping and site-specific information on the extent and intensity of past disturbance events can also change the area of old-growth forests reported.

The planning and approvals process for disturbance activities requires all proponents to check for the presence of unmapped old-growth forest. Maintaining an up-to-date and accurate depiction of the presence of old-growth forest is thus essential, and old-growth forest extent is therefore mapped at a 2-hectare spatial resolution (using information derived from field transects chosen using a 0.5-hectare grid). The planning and approvals process can also involve field inspection and, if necessary, referral of an area to the Department of Biodiversity, Conservation and Attractions[38] (DBCA) for a detailed assessment of the status of the forest.

The assessment combines historical data and aerial photography, recent high-resolution digital imagery, field surveys of *Phytophthora cinnamomi* occurrence, and measurements of stump frequency and stand condition, to determine the presence and boundaries of previously unmapped old-growth forest (Figure 1.15). A process for nomination by the public of areas for assessment is also maintained, and annual updates of the mapped extent of old-growth forest are published[39].

During the period 2011 to 2016, a total of 1,251 hectares of jarrah forest, 69 hectares of karri forest and 83 hectares of wandoo (*E. wandoo*) forest were added to the recorded extent of old-growth forest. The size of the individual patches of previously unmapped old-growth forest ranged from 2 to 256 hectares.

Figure 1.15: A systematic grid of cell size 0.5 hectare used to record the occurrence of stumps, landings, snig tracks and other disturbance features for the assessment of old-growth forest status in karri forest near Pemberton, Western Australia

[38] From July 2017, the Department of Parks and Wildlife.

[39] www.dpaw.wa.gov.au/management/forests/about-our-forests/171-protecting-our-biological-diversity

Indicator 1.1c

Area of forest in protected area categories

Rationale

This indicator uses the area and proportion of forest ecosystems reserved through formal and informal processes as a measure of the emphasis placed by society on the preservation of representative ecosystems as a strategy to conserve biodiversity.

Key points

- This indicator reports on forests reserved in protected areas and on forests otherwise managed for the protection of biological diversity.
- A range of formal and informal processes are used on public and private land in Australia to protect areas of forest for the conservation of biodiversity. Many areas of forest are protected by, and reported under, more than one process.
  - Australia's National Reserve System includes 33.6 million hectares of forest (almost all native forest) that have a primary management intent of nature conservation. This is a total of 25% of Australia's forest area, and 26% of Australia's native forest area.
  - A total of 21.8 million hectares of Australia's forest is in the national land tenure category 'Nature conservation reserve', which is 16% of Australia's total forest area.
  - Australia's Comprehensive, Adequate and Representative (CAR) reserve system comprises public forest in formal reserves, in informal reserves, and in areas in which values are protected by prescription, as well as forest in CAR reserves on private land. In the CAR reserve system, the area of native forest in the Australian Capital Territory is 0.1 million hectares, in New South Wales is 6.4 million hectares, in Tasmania is 2.1 million hectares, and in Victoria is 4.3 million hectares. In addition, the CAR reserve in Western Australia contains 5.8 million hectares of forest.
  - Areas of multiple-use public forest not in the CAR reserve system are managed for multiple objectives, including timber production, water production, recreation, amenity, and biodiversity conservation, with management regulated by codes of forest practice to maintain forest values, and therefore are also reported in this indicator.
  - The Australian Government Department of Defence manages 1.32 million hectares of forest on the national land tenure category 'Other Crown land'. This area comprises forest managed as CAR informal reserves and forest protected by prescription.
  - A total of 3.2 million hectares of forest are on private or leasehold lands with nature conservation covenants.
  - A total of 4.7 million hectares of Australia's native forests are on sites on the World Heritage List established under the World Heritage Convention.
  - A total of 1.8 million hectares of Australia's native forests are on Ramsar wetland sites established under the Convention on Wetlands of International Importance (the Ramsar Convention).
- Across all the above categories, within and outside the National Reserve System, the total area of native forest managed for the protection of biodiversity through formal and informal processes is 46.0 million hectares (35% of Australia's native forest area).
  - SOFR 2013 reported a total of 39.2 million hectares of native forest managed for the protection of biodiversity (32% of Australia's native forest area as reported at that time).
- Aichi Biodiversity Targets are articulated in the Strategic Plan for Biodiversity 2011–2020 under the international Convention on Biological Diversity, and include the target that at least 17% of terrestrial areas are protected. Australia has therefore met the Aichi Biodiversity Target with respect to native forests.

This indicator reports on the area of Australia's forests reserved in protected areas or otherwise managed for the conservation of biological diversity. The area of forest managed specifically for protection of soil and water values is reported in Indicator 4.1a.

Creation of protected areas is the principal global mechanism for the conservation of biodiversity, as was recognised during development of the Convention on Biological Diversity (Worboys 2015). Three definitions for protected areas are used nationally and/or internationally:

- *A geographically defined area which is designated or regulated and managed to achieve specific conservation objectives* (Article 2 of the Convention on Biological Diversity 1992[40]).
- *An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means* (IUCN[41] 1994; Dudley and Phillips 2006).
- *A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values* (revised IUCN definition, Dudley 2008).

Australia's public and private forests are protected through a combination of conservation mechanisms, including formal and informal reserves, management by prescription, conservation covenants, and other management arrangements for the conservation of biodiversity. Some of these areas are recognised in Australia's National Reserve System, but there are also areas outside that system that are managed for protection of biodiversity. This indicator therefore presents data for protected forests in the following categories:

- forests in Australia's National Reserve System[42], as described in the Collaborative Australian Protected Areas Database (CAPAD)[43]. This includes most areas of forest in nature conservation reserves, some forests in the national land tenure category 'Multiple-use public forest', and forests on private land managed under the National Reserve System. Land in the National Reserve System is allocated to one of a number of protection categories set up by the International Union for Conservation of Nature (IUCN)
- forests in the national land tenure category 'Nature conservation reserve'
- forests in the Comprehensive, Adequate and Representative (CAR) reserve system, which comprises public formal reserves, informal reserves, and areas in which values are protected by prescription, as well as private CAR reserves
- native forests on public land in the national land tenure category 'Multiple-use public forest'. These include formal reserves, informal reserves, and areas protected by prescription; the balance of multiple-use public forest is managed for multiple objectives, including timber production, recreation, amenity, water production, and protection of biodiversity, with management regulated by codes of forest practice in order that the values of the forest including biodiversity are maintained (see Indicator 7.1b)
- forests on Australia's Defence estate
- areas of private forest under nature conservation covenants
- areas of forest protected on sites listed on the World Heritage List
- areas of forest protected on Ramsar Wetland sites.

The total area of forest in Australia protected for biodiversity conservation by one or more of the above mechanisms is then calculated and presented.

Forests in Australia's National Reserve System

Australia's National Reserve System is a network of protected areas based on a scientific framework, and comprises Commonwealth, state and territory reserves, Indigenous land and protected areas run by non-profit organisations[44]. Protected areas are terrestrial or marine areas especially dedicated to the protection and maintenance of biological diversity, and are formally protected through "legal or other effective means"[45] and managed in perpetuity. Every two years, the Australian Government collects information on these protected areas, and publishes the information in the Collaborative Australian Protected Areas Database (CAPAD) as a spatial representation of Australia's National Reserve System.

A total of 33.6 million hectares of Australia's forest (almost all of which – 99.9% – is native forest) is protected in the National Reserve System (Table 1.17). This is 25% of Australia's forest area, and 26% of Australia's native forest area. A total of 97% of the area of forest on nature conservation reserve tenure in Australia is in the National Reserve System, as well as 19% of the area of forest on private land tenure. The Australian Capital Territory has the greatest proportion of its forest area formally protected in the National Reserve System (80%), with South Australia having 52%, Tasmania 44% and Victoria 40% formally protected in this way.

Inclusion of an area in Australia's National Reserve System reflects the management intent of that area rather than the underlying land tenure. Forest on nature conservation reserve tenure comprises 21.0 million hectares (62%) of the forest in the National Reserve System, with substantial contributions to the National Reserve System also from forest on private (23%) and leasehold (11%) tenures. For example, some large national parks, including Kakadu National Park in the Northern Territory, are classified as private land tenure but are included in the National Reserve System because they are formally managed for conservation values. Areas of multiple-use public native forest are included in the National

[40] www.cbd.int/convention/text/default.shtml
[41] IUCN, International Union for Conservation of Nature.
[42] www.environment.gov.au/land/nrs
[43] www.environment.gov.au/topics/land/nrs/science/capad/2010
[44] www.environment.gov.au/land/nrs
[45] www.environment.gov.au/land/nrs/about-nrs/requirements

Table 1.17: Area of forest in the National Reserve System, by national forest category, tenure and jurisdiction

Forest category and tenure[a]	Australia Area ('000 hectares) Total forest	Forest in National Reserve System	Proportion of forest that is in the National Reserve System (%)	Proportion of total National Reserve System forest (%)	Forest in National Reserve System Area ('000 hectares) ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia
Native forest													
Leasehold forest	47,246	3,763	8	11	0.7	155	1,042	1,952	417	0	0	195	3,763
Multiple-use public forest	9,772	127	1.3	0.4	0	40	0	55	13	0	16	2	127
Nature conservation reserve[b]	21,719	21,009	97	62	112	5,553	14	4,363	1,680	1,540	3,282	4,465	21,009
Other Crown land	11,042	941	9	2.8	0.4	6	196	112	0.4	2	19	605	941
Private forest[c]	41,031	7,762	19	23	0	22	4,594	2,400	502	81	5	157	7,762
Unresolved tenure	805	8	1.0	0	0	0.1	1.1	7	0.1	0	0	0	8
Total native forest	**131,615**	**33,609**	**26**	**99.9**	**114**	**5,776**	**5,847**	**8,889**	**2,613**	**1,622**	**3,322**	**5,426**	**33,609**
Commercial plantation	**1,949**	**2**	**0.1**	**0**	**0**	**0.2**	**0**	**0**	**0.1**	**0.4**	**0.2**	**0.6**	**2**
Other forest	**474**	**30**	**6**	**0.1**	**0.3**	**0.2**	**0**	**0.3**	**0.5**	**0.2**	**8**	**20**	**30**
Total forest	**134,037**	**33,640**	**25**	**100**	**114**	**5,776**	**5,847**	**8,889**	**2,614**	**1,623**	**3,331**	**5,446**	**33,640**
Proportion of forest that is in the National Reserve System (%)					**80**	**28**	**25**	**17**	**52**	**44**	**40**	**26**	**25**

[a] National land tenure category (see Introduction)

[b] These area figures are lower than the area figures for nature conservation reserve tenure on Table 1.6 (Indicator 1.1a) because not all areas of nature conservation reserve tenure are captured in the National Reserve System.

[c] As in SOFR 2013, area figures for native forest on private land in the National Reserve System are in some jurisdictions less than the area figures for native forest on private land protected by conservation covenants (Table 1.28). The reasons for this are unknown, but may include state-based and territory-based private land conservation covenant programs not being captured by the National Reserve System.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory for forest area; Collaborative Australian Protected Area Database 2016 (Australian Government Department of the Environment and Energy) for National Reserve System data.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Woodland forest of snowgum (*Eucalyptus pauciflora* ssp. *niphophila*), Kosciuszko National Park, New South Wales.

Reserve System if they are principally managed for the conservation of biodiversity (Dudley and Phillips 2006; see IUCN category VI, Table 1.18).

Under *Australia's Strategy for the National Reserve System 2009–2030* (NRMMC 2009), all the state and territory governments and the Australian Government agreed to adopt international standards for the definition of a protected area and for management categories for protected areas. The seven categories used by the International Union for Conservation of Nature (IUCN) for protected areas are:

Ia Strict nature reserve – protected area managed mainly for science

Ib Wilderness area – protected area managed mainly for wilderness protection

II National park – protected area managed mainly for ecosystem conservation and recreation

III Natural monument – protected area managed for the conservation of specific natural features

IV Habitat/species management area – protected area managed mainly for conservation through management intervention

V Protected landscape/seascape – protected area managed mainly for landscape/seascape conservation and recreation

VI Managed resource protected area – protected area managed mainly for the sustainable use of natural ecosystems.

Table 1.18 classifies the areas of forest in Australia's National Reserve System by these IUCN protected area categories. The spatial distribution of forest in Australia's National Reserve System, by IUCN protected area category, is shown in Figure 1.16.

In 1982, the IUCN recommended that at least 10% of each biome[46] should be in one of these reserve categories[47]. SOFR 2018 reports against this target by forest type. Of Australia's 18 national native forest types and subtypes, 17 have reservation levels exceeding this target (Table 1.19), the same number as reported in SOFR 2013. Only Acacia forests are represented below this target level, with 9.6% of their area protected.

[46] The IUCN defines a 'biome' as "A major portion of the living environment of a particular region (such as a fir forest or grassland), characterized by its distinctive vegetation and maintained largely by local climatic conditions."

[47] The target of 10% was proposed at the Third World Congress on National Parks in Bali, Indonesia, in 1982 and endorsed as a target "that protected areas cover at least 10 percent of each biome by the year 2000" in the Caracas Action Plan at the IVth IUCN World Parks Congress held in Caracas, Venezuela in 1992

Table 1.18: Area of forest in the National Reserve System by IUCN protected area category, forest category and jurisdiction

Forest category Jurisdiction	Area ('000 hectares)											Proportion of forest in all IUCN categories[c] (%)
	Forest by IUCN protection category										Total forest	
	Ia	Ib	II	III	IV[a]	V	VI	ND[b]	I–IV	I–VI, ND[b]		
Native forest												
ACT	0	28	77	0	8	0	0	0	114	114	**130**	87
NSW	781	1,732	3,083	6	142	21	3	9	5,744	5,776	**19,925**	29
NT	9	0	1,785	1.4	49	1,331	2,433	239	1,844	5,847	**23,686**	25
Qld	49	41	5,806	212	59	337	2,302	83	6,167	8,889	**51,580**	17
SA	235	477	96	511	314	115	855	9	1,634	2,613	**4,856**	54
Tas.	8	8	821	48	265	118	343	12	1,149	1,622	**3,342**	49
Vic.	258	142	2,627	171	30	25	69	0	3,229	3,322	**7,645**	43
WA	1,764	0.8	2,262	14	70	317	877	122	4,110	5,426	**20,450**	27
Total native forest	**3,103**	**2,429**	**16,557**	**964**	**937**	**2,264**	**6,881**	**474**	**23,990**	**33,609**	**131,615**	**26**
Commercial plantation	**0.2**	**0**	**0.5**	**0.1**	**0.3**	**0**	**0.5**	**0**	**1.1**	**2**	**1,949**	**0.1**
Other forest	**5**	**0**	**7**	**0.9**	**1.5**	**0.9**	**13**	**0.2**	**15**	**30**	**474**	**6**
Total forest	**3,109**	**2,429**	**16,565**	**965**	**939**	**2,265**	**6,895**	**474**	**24,006**	**33,640**	**134,037**	**25**
Proportion of total forest area in National Reserve System (%)	**9**	**7**	**49**	**3**	**3**	**7**	**20**	**1**	**71**	**100**		

IUCN, International Union for Conservation of Nature; NRS, National Reserve System.

[a] Multiple-use public forest could arguably be classified under IUCN category VI; however, multiple-use public forest is only classified in CAPAD if it is principally managed for the conservation of biodiversity (see Dudley and Phillips 2006).

[b] 'ND' areas are protected in the National Reserve System but are not yet classified into an IUCN category.

[c] Includes protected forest areas with an IUCN listing of ND.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory for forest area; Collaborative Australian Protected Area Database 2016 (Australian Government Department of the Environment and Energy) for IUCN data.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.19: Area of forest in IUCN protected-area categories, by forest type

Forest category Forest type	Area ('000 hectares)											Proportion of forest in all IUCN categories[c] (%)
	Forest by IUCN protection category										Total forest	
	Ia	Ib	II	III	IV	V	VI[a]	ND[b]	I–IV	I–VI, ND[b]		
Native forest												
Acacia	68	9	633	25	9	30	242	16	745	1,034	**10,813**	9.6
Callitris	89	1.4	127	2	15	0.1	17	1.4	235	253	**2,011**	13
Casuarina	57	70	165	4	13	19	82	0.1	309	411	**1,236**	33
Eucalypt	2,785	2,132	12,666	848	807	1,886	5,871	441	19,237	27,435	**101,058**	27
Eucalypt closed	6	2	88	1.5	0.8	16	16	0.8	99	132	**534**	25
Eucalypt open	456	1,164	5,106	153	176	395	1,388	35	7,055	8,873	**27,695**	32
Eucalypt woodland	2,323	966	7,472	693	630	1,475	4,467	405	12,084	18,430	**72,829**	25
Mangrove	15	0.1	101	17	4	34	49	3	137	224	**854**	26
Melaleuca	10	6	623	15	8	203	169	4	663	1,038	**6,382**	16
Rainforest	25	164	1,582	12	72	74	311	5	1,855	2,246	**3,581**	63
Other native forest	53	47	659	40	9	18	140	2	807	968	**5,679**	17
Total native forest	**3,103**	**2,429**	**16,557**	**964**	**937**	**2,264**	**6,881**	**474**	**23,990**	**33,609**	**131,615**	**26**
Commercial plantation	**0.2**	**0**	**0.5**	**0.1**	**0.3**	**0**	**0.5**	**0**	**1.1**	**2**	**1,949**	**0**
Other forest	**5**	**0**	**7**	**0.9**	**1.5**	**0.9**	**13**	**0.2**	**15**	**30**	**474**	**0**
Total	**3,109**	**2,429**	**16,565**	**965**	**939**	**2,265**	**6,895**	**474**	**24,006**	**33,640**	**134,037**	**25**

IUCN, International Union for Conservation of Nature.

[a] Multiple-use public forest could arguably be classified under IUCN category VI; however, multiple-use public forest is only classified in CAPAD this way if it is principally managed for biodiversity conservation (Dudley and Phillips 2006).

[b] 'ND' areas are protected in the National Reserve System but are not yet classified into an IUCN category.

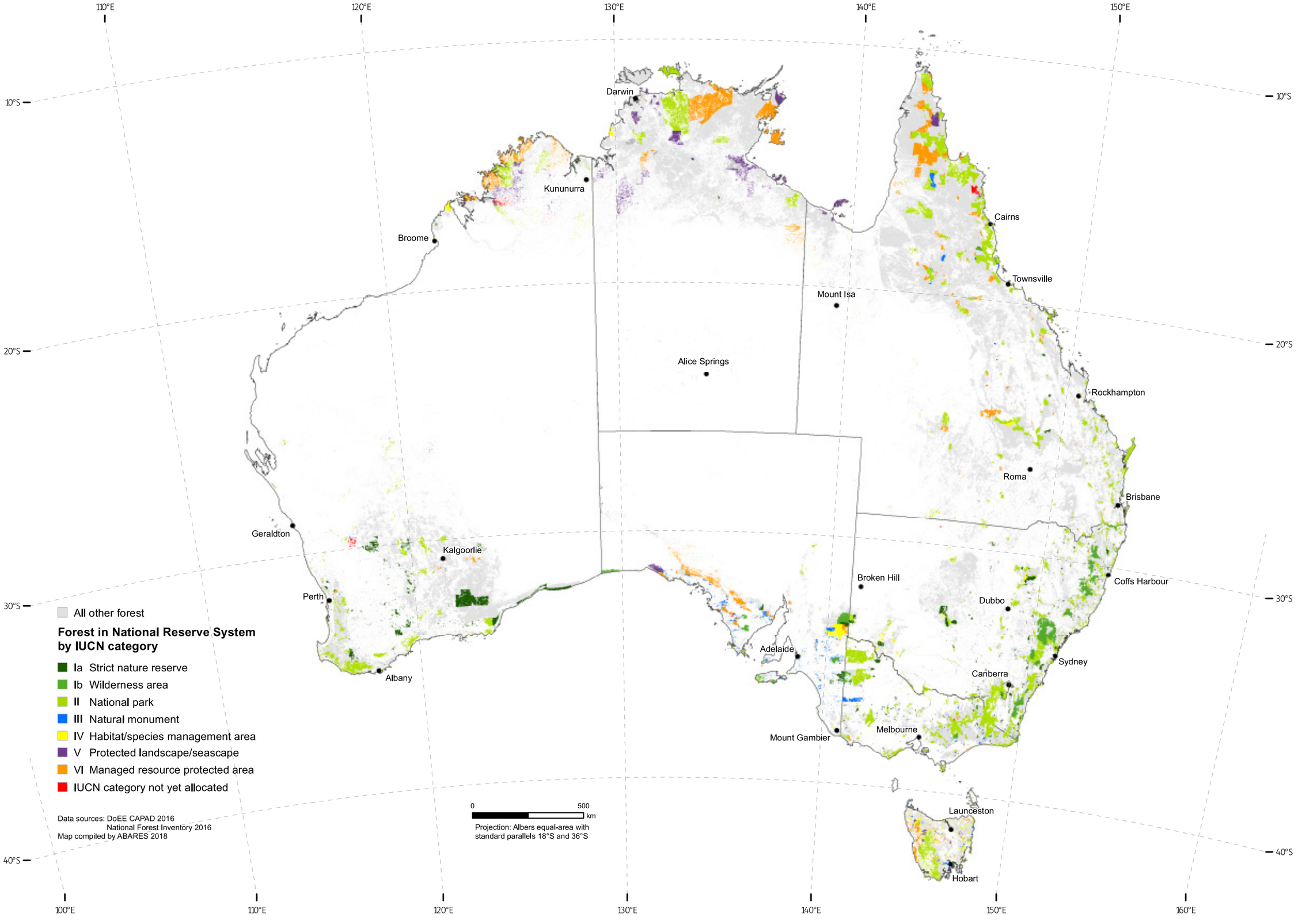
[c] Includes protected forest areas with an IUCN listing of ND.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory for forest area; Australian Government Department of the Environment and Energy (Collaborative Australian Protected Area Database 2016) for IUCN data.

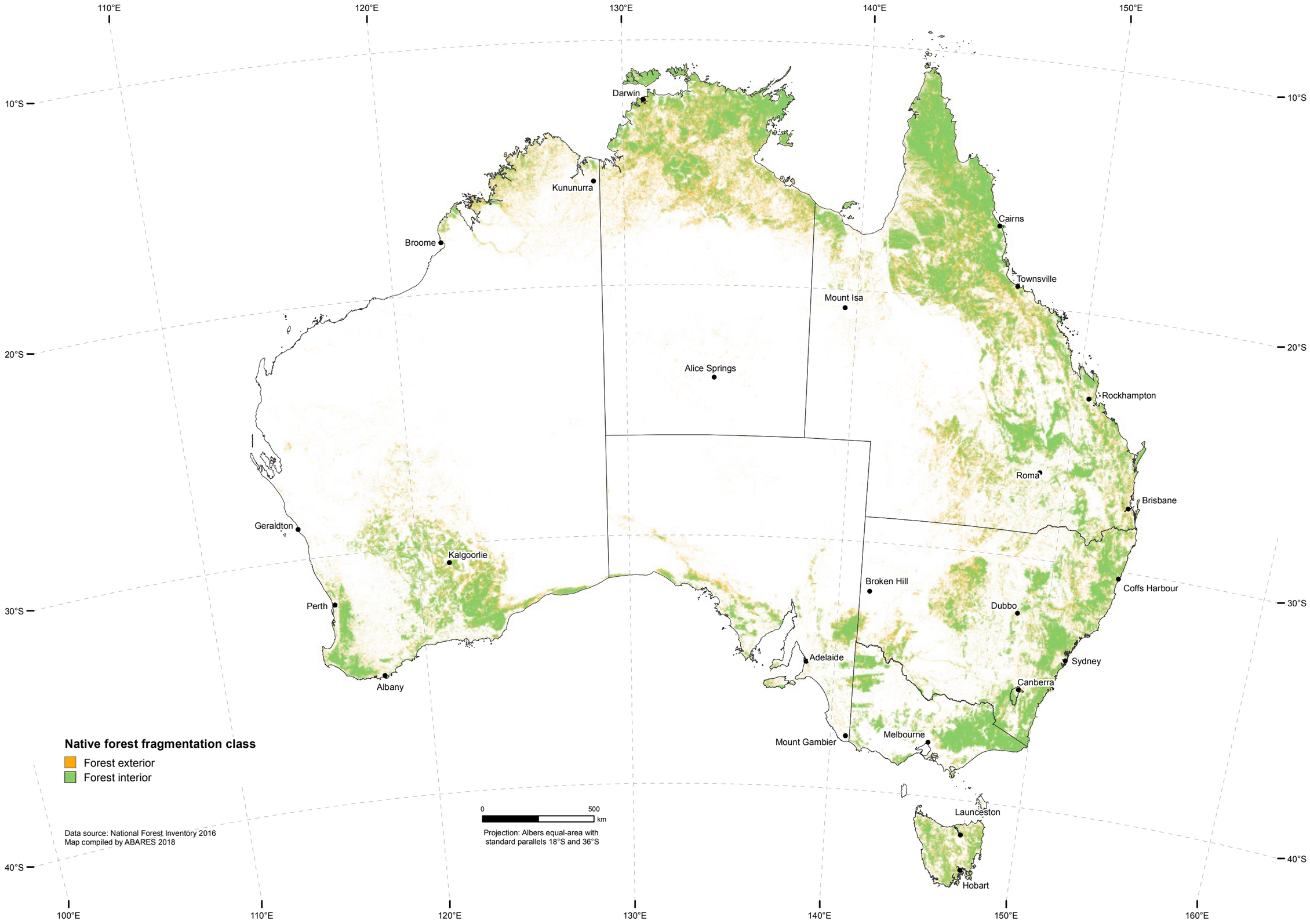
This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.16: Australia's forests in the National Reserve System, by IUCN protected area category



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

Figure 1.18: Native forest fragmentation class distribution across Australia



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

Nature conservation reserve tenure

The national land tenure category of nature conservation reserve comprises publicly owned lands formally reserved for environmental, conservation and recreational purposes that are managed by state and territory governments (see Introduction).

There are 21.8 million hectares of forest on nature conservation reserve tenure (16% of Australia's total forest area), almost all of which (99.8%) is native forest. This is 0.3 million hectares larger than the figure reported in SOFR 2013 (Table 1.20).

Increases in the area of forest reported in nature conservation reserves occurred in Western Australia (0.4 million hectares), Tasmania (0.3 million hectares) and South Australia (0.2 million hectares), while there was no substantial change in the area reported for the Australian Capital Territory, New South Wales, the Northern Territory or Victoria. In Queensland, a change in land tenure designation resulted in approximately 0.7 million hectares of forest identified in SOFR 2013 as the national land tenure category 'Nature conservation reserve' (mostly national parks on Cape York Peninsula Aboriginal lands) being reclassified as the national land tenure category 'Private forest' in SOFR 2018 (see Indicator 1.1a); this area continues to be managed for conservation purposes.

Australia's total area of forest reported in SOFR 2018 (134 million hectares) is larger than the area reported in SOFR 2013 (125 million hectares), due to the use of improved data and methods (see Indicator 1.1a). Most of the newly reported forest area is in the Northern Territory, and is not in the NFI national land tenure category of nature conservation reserve. This increase in the reported area of forest in SOFR 2018 results in 16.2% of Australia's total forest area being classified in the land tenure category nature conservation reserve, compared with 17.2% in SOFR 2013 (Table 1.20).

Australia's Comprehensive, Adequate and Representative (CAR) reserve system

The *National Forest Policy Statement* (Commonwealth of Australia 1992) describes Australia's approach to forest conservation:

> *The nature conservation objectives are being pursued in three ways. First, parts of the public native forest estate will continue to be set aside in dedicated nature conservation reserve systems to protect native forest communities, based on the principles of comprehensiveness, adequacy and representativeness (CAR reserves). The reserve system will safeguard endangered and vulnerable species and communities. The terms 'reserves' and the 'reservation system' mean National Parks and all other areas that have been specifically dedicated by government for the protection of conservation values. Other areas of forest will also be protected to safeguard special areas and to provide links where possible between reserves or other protected areas. Second, there will be complementary management outside reserves, in public native forests that are available for wood production and other commercial uses and in forests on unallocated or leased Crown land. Third, the management of private forests in sympathy with nature conservation goals will be promoted.*

The goal of a CAR reserve system for Australia was endorsed by all Australian governments as signatories to the *National Forest Policy Statement* (1992) and the *National Strategy for Conservation of Australia's Biological Diversity* (2010). The CAR reserve system is built on nationally agreed criteria (Commonwealth of Australia 1997), forms the scientific framework for the National Reserve System[48], and applies throughout Australia for both terrestrial and marine areas at Commonwealth, state and territory levels.

The development of Regional Forest Agreements (RFAs) (see Introduction) implemented the CAR (comprehensive, adequate and representative) principles in the allocation

Table 1.20: Forest in nature conservation reserve tenure

Forest area	Unit	SOFR 2013	SOFR 2018
Total forest[a]	**million hectares**	**124.7**	**134.0**
Forest in nature conservation reserve[b]	million hectares	21.5	21.8
Proportion of forest in nature conservation reserves	%	17.2	16.2
Native forest[c]	**million hectares**	**122.6**	**131.6**
Native forest in nature conservation reserve[b]	million hectares	21.5	21.7
Proportion of native forest in nature conservation reserve	%	17.5	16.5

[a] 'Total forest' includes all categories of forest. For SOFR 2018, total forest is reported under the three categories: native forest, commercial plantation, and other forest. Reasons underpinning changes in how Australia's forest area is reported over time are discussed in Indicator 1.1a.

[b] Nature conservation reserve tenure, as described in Indicator 1.1a. Does not include formal or informal reserves on other tenures.

[c] Reasons underpinning changes in how Australia's native forest area is reported over time are discussed in Indicator 1.1a

Note: Figures may differ from those reported in state, territory or regional reports, such as Regional Forest Agreement reports, due to different input datasets.

Source: ABARES, National Forest Inventory (NFI), for forest area and national land tenure (see Indicator 1.1a).

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[48] www.environment.gov.au/land/nrs/science/scientific-framework

Kosciuszko National Park, New South Wales.

of forest areas to the nature conservation reserve system or to multiple-use public forests (including land where wood production can be a management objective). All states that undertook comprehensive regional assessments as part of the RFA process (New South Wales, Queensland, Tasmania, Victoria and Western Australia) have developed approaches to forest protection and conservation that include the four components of the CAR reserve system:

- **Formal reserves** are publicly managed land tenures that cannot be revoked without parliamentary approval. "Dedicated" formal reserves exclude mining. Publicly owned reserves are an integral part of the total area protected for biodiversity conservation, and include the areas reported above under the land tenure category nature conservation reserve.
- **Informal reserves** on public land are protected through administrative instruments by public agencies. Informal reserves are an integral part of the CAR reserve system, and many are part of the National Reserve System.
- **Values protected by prescription**: some states and territories, where the nature of a forest value on public land makes inclusion in either formal or informal reserves impractical, provide protection for these values as prescribed in codes of practice, forest management plans or systems, or other regulatory instruments. Examples of such values include very rare values, values with fragmented distributions, values occurring in linear form such as riparian vegetation, or values that are not otherwise mappable. Examples of areas managed by prescription include Harvest Exclusion and Special Prescription Zones in multiple-use public forest in New South Wales, and fauna habitat zones in multiple-use public forest in Western Australia[49]. (Special Protection Zones in Victorian state forests are informal and formal reserves.) Areas managed by prescription are also an integral part of the CAR reserve system.
- **Private CAR reserves** are areas of private land that are managed in the long term for the protection of CAR values under secure arrangements, including proclamation under legislation and contractual agreements such as management agreements and conservation covenants. They also include reserves set aside under independently certified forest management systems. Private CAR reserves are also an integral part of the CAR reserve system.

CAR reserves are present on a variety of tenures within and outside RFA regions. CAR reserves are also present across a range of other categories of protected forest (such as the National Reserve System, formal nature conservation reserves, and forest under privately managed covenants). Management arrangements and approaches differ between the four different components of the CAR reserve system and between different tenure categories.

The area of forest in formal and informal CAR reserves on public land in the Australian Capital Territory, New South Wales, Tasmania, Victoria and Western Australia, and on private land in New South Wales and Tasmania, is shown in Tables 1.21–1.25. Areas of forest on public land not in formal or informal reserves, but included in the CAR reserve system as they are managed by prescription, are also presented for the Australian Capital Territory, New South Wales, Victoria and Western Australia. As with SOFR 2013, data for CAR reserves in Queensland were incomplete and are not reported here. All multiple-use public native forest in South Australia is protected under jurisdictional legislation that excludes harvesting of any native forest, but is not reported here as part of the CAR reserve system.

The total area of public native forest in the Australian Capital Territory that is protected in formal and informal CAR reserves, and in areas protected by prescription, is 120 thousand hectares. This is 92% of the total native forest area in the Australian Capital Territory (Table 1.21).

In New South Wales, the total area of public and private native forest protected in CAR reserves (formal and informal reserves, areas protected by prescription, and private reserves) is 6.39 million hectares. This includes 51% of the area of native forest on public land (Table 1.22), as well as 3% of the area of native forest on private land. Together, 32% of the total area of native forest in New South Wales is protected in the CAR reserve system (Table 1.22).

[49] Fauna habitat zones in Western Australia are described at www.dpaw.wa.gov.au/management/forests/about-our-forests/171-protecting-our-biological-diversity.

The total area of public and private native forest protected in formal, informal and private CAR reserves in Tasmania is 2.10 million hectares, which is 63% of the total native forest area in that state (Table 1.23). This is an increase of almost 0.60 million hectares of forest in reserves over the area reported in SOFR 2013. Table 1.23 includes the area of forest on other formal reserves on public land, such as those established under the 2005 Tasmanian Community Forest Agreement, which have the official land tenure of multiple-use public forest rather than nature conservation reserve. A total of 17% of Tasmania's native forest is in either informal public CAR reserves or privately owned CAR reserves; the area of forest in private CAR reserves has increased by 10,000 hectares over that reported in SOFR 2013.

Table 1.21: Area of native forest in the CAR reserve system on public land in the Australian Capital Territory, by CAR reserve type

		Components of public CAR reserve system			
Forest area	Unit	Formal reserves	Informal CAR reserves	Values protected by prescription	Total native forest in CAR reserve system
Native forest	'000 hectares	113[a]	6[b]	1.3[c]	120
Proportion of total native forest[d,e]	%	86	5	1	92

CAR, Comprehensive, Adequate and Representative.

[a] Native forest with tenure type 'Nature conservation reserve' (Indicator 1.1a).

[b] Includes areas of 'multiple-use public forest', and areas of forest on 'other Crown land'.

[c] Native forest in areas managed by the Australian Government Department of Defence.

[d] Calculated based on ACT native forest area of 130 thousand hectares (Indicator 1.1a).

[e] The national land tenure category 'private' does not apply in the ACT.

Source: ABARES, National Forest Inventory (NFI) for forest area; ACT Environment, Planning and Sustainable Development Directorate.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.22: Area of native forest in the CAR reserve system on public and private land in New South Wales, by CAR reserve type

		Components of public CAR reserve system				
Forest area	Unit	Formal reserves	Informal reserves	Values protected by prescription	Private CAR reserves	Total native forest in CAR reserve system
Native forest	'000 hectares	5,602[a]	188[b]	355[b]	244	6,389
Proportion of native forest on public land[c]	%	45	2	3	n.a.	51
Proportion of total native forest[d]	%	28	1	2	1	32

CAR, Comprehensive, Adequate and Representative; n.a., not applicable.

[a] Native forest in tenure type 'nature conservation reserve' (Indicator 1.1a), plus native forest in Special Protection Zones in tenure type 'multiple-use public forest'.

[b] Includes some native forest on 'other Crown land' managed by the Australian Government Department of Defence. Reported area figures for informal reserves are lower than reported for SOFR 2013, and reported area figures for values protected by prescription are higher than for SOFR 2013, as a result of the correction of a data coding error for data reported in SOFR 2013.

[c] Calculated based on NSW native forest area on public land (leasehold, multiple-use public forest, nature conservation reserve, other Crown land) of 12.43 million hectares (Indicator 1.1a).

[d] Calculated based on NSW total native forest area of 19.93 million hectares (Indicator 1.1a).

Source: ABARES, National Forest Inventory (NFI) for forest area, Forestry Corporation of NSW, Australian Government Department of Defence.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.23: Area of native forest in the CAR reserve system on public and private land in Tasmania, by CAR reserve type

		Components of public CAR reserve system				
Forest area	Unit	Dedicated formal reserves	Other formal reserves	Informal reserves	Private CAR reserves	Total native forest in CAR reserve system
Native forest	'000 hectares	881	661[a]	459[b]	93	2,093[c]
Proportion of native forest on public land[d]	%	35	26	18	n.a.	79
Proportion of total native forest[e]	%	26	20	14	3	63

CAR, Comprehensive, Adequate and Representative; n.a., not applicable.

[a] Areas subject to the *Mineral Resources Development Act 1995* (Tas.).

[b] Includes areas of native forest on other Crown land that are managed by the Australian Government Department of Defence.

[c] Total does not include 'values protected by prescription', because these are not reported by the state in this format.

[d] Calculated based on Tasmania native forest area on public land (multiple-use public forest, nature conservation reserve, other Crown land) of 2.54 million hectares (Indicator 1.1a).

[e] Calculated based on reported native forest area in Tasmania of 3.34 million hectares (Indicator 1.1a).

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI) for forest area; Forest Practices Authority Tasmania.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

In Victoria, the total area of public native forest in formal reserves, informal CAR reserves and areas protected by prescription is 4.32 million hectares, which is 65% of the area of native forest on public land and 56% of the total native forest area in that state (Table 1.24). Since SOFR 2013, there was an overall increase in native forest protected on public land in both formal and informal CAR reserves of 67 thousand hectares, but a net decrease of 70 thousand hectares in the reported area protected by prescription mainly due to a revision of outdated fire management zones in the East Gippsland Forest Management Area.

Data on forests on private CAR reserves in Victoria are incomplete. However, the available data indicate that the area of such reserves has increased. For example, the organisation Trust for Nature[50] has established more than 1,300 conservation covenants across Victoria that offer legally binding protection to 61 thousand hectares of native vegetation on private land, which includes forested land (Trust for Nature 2016). This is an increase of 16 thousand hectares over the figure reported in SOFR 2013.

In Western Australia, the total area of public forest in formal reserves, informal CAR reserves and areas protected by prescription is 5.8 million hectares, which is 33% of the area of forest on public land and 28% of the total forest area in that state (Table 1.25). Most of this protected area is in the south-west of the state.

A key tenet of the RFA process was the development and implementation of the CAR reserve system. A total of 70% of native forest on public land (48% of the area of native forests on all tenures) is protected by these mechanisms in the 11 RFA regions (Table 1.26). Tasmania and East Gippsland RFA regions are the RFA regions with the greatest proportion of native forest in the CAR reserve system (both 56%), with 53% of the native forest in the South-West Forest Region of Western Australia and 51% of the native forest in the Southern RFA region (New South Wales) in the CAR reserve system. Data on forests located on private CAR reserves in Western Australia are incomplete. However, the data provided indicate that the area of such reserves has increased.

Table 1.24: Area of native forest in the CAR reserve system on public land in Victoria, by CAR reserve type

		Components of public CAR reserve system			
Forest area	Unit	Dedicated formal reserves	Informal CAR reserves	Values protected by prescription	Total native forest in CAR reserve system
Native forest	'000 hectares	3,366[a]	764[b]	186[b]	4,316
Proportion of native forest on public land[c]	%	51	11	3	65
Proportion of total native forest[d]	%	44	10	2	56

CAR, Comprehensive, Adequate and Representative.

[a] Native forest in tenure type 'Nature conservation reserve' (Indicator 1.1a).

[b] Includes areas of native forest on other Crown land managed by the Australian Government Department of Defence.

[c] Calculated based on reported native forest on public land (multiple-use public forest, nature conservation reserve, other Crown land) in Victoria of 6.66 million hectares (Indicator 1.1a).

[d] Calculated based on reported native forest area in Victoria of 7.64 million hectares (Indicator 1.1a).

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI) for forest area; Victorian Department of Environment, Land, Water and Planning; Australian Government Department of Defence.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.25: Area of forest in the CAR reserve system on public land in Western Australia, by CAR reserve type

		Components of public CAR reserve system			
Forest area	Unit	Dedicated formal reserves	Informal CAR reserves	Values protected by prescription	Total forest in CAR reserve system
Forest	'000 hectares	5,418[a]	99[b]	328[c]	5,845
Proportion of forest on public land[d]	%	n.d.	n.d.	n.d.	33
Proportion of total forest[e]	%	26	0	1	28

CAR, Comprehensive, Adequate and Representative; n.d., data not available.

[a] Calculated from the total forest area figures supplied by WA for CAR reserve areas inside the WA RFA region plus the native forest area in tenure type 'Nature conservation reserve' (Indicator 1.1a) outside the WA RFA region.

[b] Forest in the 'CAR informal reserves' category in tenure type 'Multiple-use public forest', plus the area of 'CAR informal reserves' on other Crown land that are managed by the Australian Government Department of Defence.

[c] Forest in the 'Other informal reserves and fauna habitat zones' category in tenure type 'Multiple-use public forest', plus the area of native forest with values protected by prescription on 'other Crown land' that are managed by the Australian Government Department of Defence.

[d] Calculated from the reported total forest area on public land (leasehold, multiple-use public forest, nature conservation reserve, other Crown land) in Western Australia of 17.98 million hectares (Indicator 1.1a)

[e] Calculated from the reported total forest area in Western Australia of 20.98 million hectares (Indicator 1.1a).

Source: ABARES, National Forest Inventory (NFI) for forest area; Western Australian Department of Parks, Attractions and Wildlife; Australian Government Department of Defence.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[50] www.trustfornature.org.au

Table 1.26: Area of native forest in the CAR reserve system in RFA regions, on public and private land tenure

	Area of native forest ('000 hectares)										
	Public CAR reserve system										
RFA region	Dedicated formal reserve	Informal CAR reserve	Values protected by prescription	Other formal reserve	Total public CAR reserve system	Private CAR reserve system	Total CAR reserve system	Total RFA region	Proportion that is in CAR reserve system (%)	Total public land in RFA region[c]	Proportion that is in CAR reserve system[c] (%)
Eden	270	4	18	n.a.	292	3	295	550	54	425	69
Upper North East	636	57	90	n.a.	783	15	798	2,297	35	1,100	71
Lower North East	1,324	79	80	n.a.	1,483	14	1,497	3,404	44	1,886	79
Southern NSW	1,272	26	48	n.a.	1,346	11	1,357	2,510	54	1,672	81
Total RFA regions in NSW	**3,503**	**166**	**235**	**n.a.**	**3,904**	**42**	**3,947**	**8,761**	**45**	**5,083**	**77**
Tasmanian[a]	871	450	n.a.	658	1,979	92	2,071	3,319	62	2,521	78
Total RFA region in Tasmania	**871**	**450**	**n.a.**	**658**	**1,979**	**92**	**2,071**	**3,319**	**62**	**2,521**	**78**
Central Highlands	178	92	20	n.a.	290	n.d.	290	699	41	589	49
East Gippsland	455	106	60	n.a.	621	n.d.	621	1,104	56	1,039	60
Gippsland	479	250	13	n.a.	742	n.d.	742	1,480	50	1,329	56
North East	411	173	24	n.a.	608	n.d.	608	1,281	47	1,133	54
West Victoria	471	137	37	n.a.	645	n.d.	645	1,074	60	810	80
Total RFA regions in Victoria	**1,994**	**758**	**154**	**n.a.**	**2,906**	**n.d.**	**2,906**	**5,638**	**52**	**4,900**	**59**
South-West Forest Region of WA[b]	1,311	83	162	n.a.	1,556	n.d.	1,557	2,698	58	2,235	70
Total RFA regions in WA	**1,311**	**83**	**162**	**n.a.**	**1,556**	**n.d.**	**1,557**	**2,698**	**58**	**2,235**	**70**
Total RFA regions	**7,679**	**1,457**	**552**	**658**	**10,346**	**134**	**10,480**	**20,416**	**51**	**14,740**	**70**

RFA, Regional Forest Agreement. In NSW, the Upper North East and Lower North East regions are covered by a single RFA.

n.a., not applicable to this jurisdiction; n.d., data not available.

[a] Areas for Tasmania are derived from the spatial boundary of the Tasmanian RFA region held by ABARES, and differ slightly from the areas derived from the spatial boundary of the state of Tasmania used in other tables.

[b] For Western Australia, area figures in the CAR reserve system are for total forest.

[c] Public land includes national land tenure categories of 'Leasehold forest', 'Nature conservation reserve', 'Multiple-use public forest' and 'Other Crown land'.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Protected native forests in Australia's Defence estate

The Australian Government Department of Defence manages 1.32 million hectares of land with native forest. This is classified under the national land tenure category 'Other Crown land' (see Indicator 1.1a). A total of 40% of the native forest in the Defence estate is in the Northern Territory, 37% is in Queensland and 14% is in Western Australia.

A total of 58 thousand hectares of native forest in Tasmania, New South Wales and Western Australia in the Defence estate was identified as 'Informal CAR reserve' through the RFA process (Table 1.27). The Buckland Military Training Area in Tasmania is an example of land in his category. The remaining 1.26 million hectares of native forest in the Defence estate are outside RFA regions, for example the Shoalwater Bay Training Area in Queensland, and are classified in the CAR system as 'Values protected by prescription'; the largest of these areas are in the Northern Territory, Queensland and Western Australia (Table 1.27).

Together, all native forest on the Defence estate is classified as protected. In 2016 a twenty-year Defence Environmental Strategy[51] was released that describes the process the Department is implementing to deliver sustainable environmental management on the land that it manages.

Conservation covenants on private forests

Private reserves established under a conservation covenant are important because they are often selected to protect rare or endangered species or other important values, and can complement protected areas on publicly managed land. A conservation covenant is a voluntary, permanent, legally binding agreement made between a landholder and a Covenant Scheme Provider that aims to protect and enhance the natural, cultural and/or scientific values of an area of land[52]. The owner can continue to own, use and live on the land while the natural values of an area are conserved by the landholder in partnership with the Covenant Scheme Provider. Providers can include not-for-profit organisations, government agencies or local Councils. Conservation covenant programs can apply to privately managed forest on private freehold or leasehold tenure.

A number of national and state and territory organisations undertake conservation covenanting programs. For SOFR 2018, data describing conservation covenants on private forests were supplied by a number of state- and territory-based conservation covenant organisations, including Trust for Nature (Victoria), the Nature Conservation Trust (New South Wales) and the National Trust of Australia (Western Australia), and were assembled into the National Forest Inventory. Data on the national programs managed by the Australian Wildlife Conservancy[53], Bush Heritage Australia[54] and the Nature Conservancy[55] have not been included; however, the areas managed by the Australian Wildlife

Table 1.27: Area of native forest in Australia's Defence estate, by jurisdiction and CAR reserve type

	Area ('000 hectares)			
		Native forest in Defence estate in CAR reserve system		
Jurisdiction	Total native forest in Defence estate	Informal CAR reserve[a]	Values protected by prescription[b]	Total CAR reserve system
ACT	1.3	0	1.3	1.3
NSW	39	18	21	39
NT	531	0	531	531
Qld	487	0	487	487
SA	35	0	35	35
Tas.	24	24	0	24
Vic.	22	0	22	22
WA	181	16	165	181
Australia	**1,321**	**58**	**1,263**	**1,321**

[a] Informal CAR reserves are in RFA regions.

[b] Values are protected by prescription outside RFA regions.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI); Australian Government Department of Defence.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[52] www.defence.gov.au/estatemanagement/Governance/Policy/Environment/Policy/EnvironmentStrategy2016.PDF

[52] www.environment.gov.au/biodiversity/conservation/covenants

[53] www.australianwildlife.org/

[54] www.bushheritage.org.au/

[55] www.nature.org/ourinitiatives/regions/australia/index.htm?redirect=https-301

Conservancy and Bush Heritage Australia are captured in the National Reserve System (see above). The National Conservation Lands Database, which was used as a data source for SOFR 2013, has not been maintained.

The area of forest in Australia over which a legally binding private conservation covenant is in place is identified in the National Forest Inventory as 3.2 million hectares (Table 1.28). SOFR 2013 reported that 1.8 million hectares of forest were protected through private conservation covenant programs.

The largest areas of forest under private conservation covenant are in Queensland and South Australia (Table 1.28)[56]. Nationally, 69% of the total area of forest identified in the National Forest Inventory as protected under private conservation covenant is on leasehold land tenure, 30% is on private tenure and 1% on other Crown land. The most common forest types on conservation covenanted land are Eucalypt woodland forests (2.5 million hectares), Eucalypt open forests (0.3 million hectares) and Acacia forests (0.2 million hectares) (Table 1.28).

Many covenanting schemes are recognised under the National Reserve System. Of the 3.2 million hectares of forested land under private conservation covenant, 3.1 million hectares are listed in CAPAD as protected areas in the National Reserve System (compare Tables 1.28 and 1.31). However, the private covenanted forest dataset and CAPAD are assembled using different criteria, and data are collected using different methods.

Except for Tasmania and New South Wales, data describing conservation covenants on privately managed forests are not included in the figures on CAR reserve areas above, because they are derived from different datasets with an undetermined degree of overlap.

UNESCO[57] World Heritage List

The World Heritage Convention[58] establishes a list of places that have natural and/or cultural values of outstanding global significance. Inclusion of a place on the World Heritage List does not affect ownership rights, and a country's jurisdictional and local government laws still apply. However, as a signatory to the convention, Australia has an obligation to identify places for, and protect and conserve places on, the World Heritage List. Australia's forested World Heritage List areas include Kakadu National Park (Northern Territory), the Wet Tropics of Queensland, Shark Bay (Western Australia), Fraser Island (Queensland), Gondwana Rainforests (New South Wales), the Greater Blue Mountains Area (New South Wales), and the Tasmanian Wilderness World Heritage Area.

Table 1.28: Area and type of forest on land protected by private conservation covenants

	Area ('000 hectares)								
Forest type	**ACT**	**NSW[a]**	**NT**	**Qld**	**SA**	**Tas.**	**Vic.**	**WA**	**Australia**
Native forest									
Acacia	0	1	0	196	1.3	2	0	2	202
Callitris	0	19	0	15	2	0	0	0	36
Casuarina	0	15	0	2	3	1.3	0.5	0.1	22
Eucalypt	0.7	201	0	1,512	768	80	34	142	2,738
Eucalypt closed	0	0	0	0	0	0	0.2	1	1
Eucalypt open	1.6	94	0	101	52	17	15	5	284
Eucalypt woodland	0.1	106	0.1	1,411	716	64	19	137	2,454
Mangrove	0	0	0	3	0	0	0	0	3
Melaleuca	0	0	0	59	3	0.5	0.2	0.1	64
Rainforest	0	3	0	62	0	8	0	0	72
Other native forest	0	4	0	50	9	0.7	2	2	68
Total native forest	**0.8**	**243**	**0.1**	**1,899**	**787**	**93**	**37**	**145**	**3,205**
Commercial plantation	**0**	**0**	**0**	**0**	**0**	**1.3**	**0**	**0**	**2**
Other forest	**0**	**0**	**0**	**0**	**0**	**2**	**0.7**	**0.2**	**3**
Total forest	**0.8**	**243**	**0.1**	**1,899**	**787**	**96**	**38**	**145**	**3,209**

[a] The difference between the area reported for land protected by private conservation covenants in SOFR 2018 and that reported in SOFR 2013 is due to inconsistent input datasets, as well as differences in the forest extent (see Indicator 1.1a). In the five years since SOFR 2013, there has been no removal of protection status from areas of private land in New South Wales that were legally protected in perpetuity, nor any revocations in private conservation mechanisms.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[56] All native vegetation on privately managed land in South Australia (except in parts of metropolitan Adelaide) is protected under the *Native Vegetation Act 1991* (South Australia): see www.environment.sa.gov.au/topics/native-vegetation/clearing

[57] United Nations Educational, Scientific and Cultural Organization.

[58] whc.unesco.org/en/conventiontext

Table 1.29: Area of native forest in World Heritage Areas, by forest type and jurisdiction

	Area ('000 hectares)										
	Native forest in World Heritage Areas										
Native forest type	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia	Total	Proportion of native forest in World Heritage Areas (%)
Acacia	0	0.2	0.2	15	0	5	0	0.4	21	10,813	0.2
Callitris	0	0.7	0	0	0	0	0	0	1	2,011	0.03
Casuarina	0	58	0	26	0	0	0	0	84	1,236	6.8
Eucalypt	0	1,138	1,054	396	0.2	517	0	18	3,124	101,058	3.1
Eucalypt closed	0	0	3	10	0	4	0	0	17	534	3.2
Eucalypt open	0	767	363	271	0	315	0	0	1,716	27,695	6.2
Eucalypt woodland	0	370	689	115	0.2	198	0	18	1,391	72,829	1.9
Mangrove	0	0	11	62	0	0	0	0.4	73	854	8.6
Melaleuca	0	0	102	16	0	9	0	0.9	129	6,382	2.0
Rainforest	0	132	46	678	0	301	0	0	1,157	3,581	32
Other native forest	0	16	5	79	0	32	0	5	136	5,679	2.4
Total native forest	**0**	**1,345**	**1,218**	**1,272**	**0.2**	**865**	**0**	**24**	**4,724**	**131,615**	**3.6**
Native forest in World Heritage Area as proportion of total native forest in World Heritage Areas (%)	0	28	26	27	0	18	0	0.5	100		
Native forest in World Heritage Area as proportion of total native forest in jurisdiction (%)	0.0	6.7	5.1	2.5	0.0	26	0.0	0.1	3.6		
Total native forest in jurisdiction	**130**	**19,925**	**23,686**	**51,580**	**4,856**	**3,342**	**7,645**	**20,450**	**131,615**		

Notes: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI); Australian Government Department of the Environment and Energy.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Upper reaches of Jim Jim Creek, Kakadu National Park, Northern Territory.

In 2016, Australia had 19 areas on the World Heritage List. Excluding those offshore or in urban areas, the 12 World Heritage Areas on mainland Australia covered a total of 7.7 million hectares, of which 4.7 million hectares carries native forest (Table 1.29). A total of 3.6% of Australia's native forest area is in World Heritage Areas. The most recent additions of Australian sites on the list were the extensions to the Tasmanian Wilderness World Heritage Area.

New South Wales has the largest area of native forest listed as World Heritage Areas (1.35 million hectares), followed by Queensland (1.27 million hectares), and the Northern Territory (1.22 million hectares). Tasmania has the highest proportion of its total native forest area (26%) listed in World Heritage Areas.

The area of forest in World Heritage Areas as at 2016 (4.7 million hectares) is 0.44 million hectares more than was reported in SOFR 2013. This is due to increases in the reported area of forest in the Northern Territory (mostly in Kakadu National Park), and consequently the area of forest in World Heritage Areas in that jurisdiction; and to extensions to the Tasmanian Wilderness World Heritage Area.

Australia's World Heritage Areas contain a high representation of rainforest: 32% of the area of the Rainforest forest type is in World Heritage Areas (Table 1.29).

Most (4.5 million hectares, 95%) of the native forest in World Heritage Areas is also protected through the National Reserve System. The 0.2 million hectares of native forest in World Heritage Areas outside the National Reserve System are predominantly on private land, other Crown land and leasehold tenures.

Ramsar List of Wetlands of International Importance

The Convention on Wetlands of International Importance (the Ramsar Convention)[59], signed in Ramsar, Iran, in 1971, aims to prevent worldwide loss of wetlands, and to achieve conservation and wise use of wetlands through international cooperation and responsible national land management. The Ramsar definition of wetlands include waterbodies such as lakes, reservoirs, rivers, estuaries, swamps and marshes, bogs, salt pans, mud flats, mangroves and coral reefs.

As a Contracting Party to the Convention, Australia has a commitment to list wetlands that meet the Ramsar criteria for inclusion in the List of Wetlands of International Importance. Australia is committed to the protection, conservation, and promotion of wise use of Ramsar wetland sites, and designated the world's first Ramsar site, the Cobourg Peninsula in the Northern Territory[60], in 1974.

Australia has 65 Ramsar sites which cover about 5.7 million hectares of the Australian mainland. A total of 1.8 million

[59] www.ramsar.org/about/the-ramsar-convention-and-its-mission

[60] www.environment.gov.au/water/wetlands/publications/cobourg-peninsula-ramsar-site-ecological-character-description

hectares of Ramsar sites carry native forest (Table 1.30), which is 1.3% of Australia's native forest. The Northern Territory contains most (1.4 million hectares, 79%) of Australia's native forest on Ramsar sites, of which 1.2 million hectares are in Kakadu National Park. Most of Australia's forest in Ramsar sites is Eucalypt medium woodland, Eucalypt medium open and Melaleuca forest types. Over 10% of Australia's mangrove forests are within Ramsar sites (Table 1.30).

Most (1.6 million hectares, 92%) of the native forest on Ramsar sites is also protected through the National Reserve System. The 0.14 million hectares of native forest on Ramsar sites outside the National Reserve System are predominantly on other Crown land, multiple-use public forest and unresolved tenure.

Forest in areas managed for protection of biodiversity

A range of formal and informal processes, detailed above, are used on public and private land in Australia to protect areas of forest for the conservation of biodiversity. Table 1.31 presents the total area of native forest on land reserved or managed for protection of biodiversity, by jurisdiction. These areas are derived from a spatial analysis of data assembled in the National Forest Inventory, comprising native forest in the National Reserve System, in formal nature conservation reserves, in the CAR reserve system, in multiple-use public forests, in the Defence estate, under privately managed covenants, in World Heritage Areas, and on Ramsar wetland sites.

Together there is a total of 46.0 million hectares of native forest on land protected for biodiversity conservation, or where biodiversity conservation is a specified management intent (Table 1.31). This represents 35% of Australia's native forest estate. The Australian Capital Territory, Victoria and Tasmania have the highest proportion of forest area managed for protection of biodiversity.

SOFR 2013 reported a total of 39.2 million hectares of native forest managed for the protection of biodiversity (32% of Australia's native forests as reported at that time).

International targets for the proportion of forest protected for biodiversity

There are international targets for the proportion of land protected for biodiversity conservation, whether inside or outside the national reserve system. In 2010, Parties to the Convention on Biological Diversity, including Australia, agreed a Strategic Plan for Biodiversity 2011–2020 including Aichi Biodiversity Targets[61]. Under the Plan's strategic goal "to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity", Aichi Biodiversity Target 11[62] specifies:

> *By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape.*

The 35% of Australia's native forest estate on land managed for protection of biodiversity (Table 1.31), which includes Australia's forest area in IUCN protected area categories I–VI in the National Reserve System (Table 1.19) as well as other forest land managed for protection of biodiversity, therefore represents achievement of Aichi Biodiversity Target 11 with respect to Australia's native forests.

View from the walk to the top of Barrk Marlam (Jim Jim Falls), Kakadu National Park, Northern Territory. Kakadu National Park is included on the World Heritage List for both cultural and natural outstanding universal values.

[61] Conference of Parties to the Convention on Biological Diversity (Tenth Meeting, Nagoya, Japan, 18–29 October 2010) Decision X/2 – The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets.

[62] www.cbd.int/sp/targets/rationale/target-11/

Table 1.30: Area of native forest on Ramsar wetland sites, by forest type and jurisdiction

	Area ('000 hectares)										
	Native forest on Ramsar wetland sites										
Native forest type	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia	Total	Proportion of native forest on Ramsar wetland sites (%)
Acacia	0	1	0	27	0	0	1	0	29	10,813	0.3
Callitris	0	0	0	0	0	0	0	0	0	2,011	0
Casuarina	0	1	0	5	0	0	0	0	6	1,236	0.5
Eucalypt	0.3	108	1,217	50	12	0.6	55	15	1,459	101,058	1.4
Eucalypt closed	0	0	5	7	0	0	0	0	12	534	2.3
Eucalypt open	0	32	510	18	3	0	30	2	595	27,695	2.1
Eucalypt woodland	0.2	77	702	25	10	0	25	13	852	72,829	1.2
Mangrove	0	0	29	51	0	0	1	12	93	854	11
Melaleuca	0	3	106	11	0	0	1	1	123	6,382	1.9
Rainforest	0	1	54	3	0	0	0	0	58	3,581	1.6
Other native forest	0	2	6	5	2	0	3	3	20	5,679	0.4
Total native forest	**0.3**	**116**	**1,411**	**152**	**15**	**1**	**61**	**32**	**1,788**	**131,615**	**1.4**
Total native forest in jurisdiction	**130**	**19,925**	**23,686**	**51,580**	**4,856**	**3,342**	**7,645**	**20,450**	**131,615**		
Native forest on Ramsar sites as a proportion of total native forest (%)	**0.2**	**0.6**	**6.0**	**0.3**	**0.3**	**0**	**0.8**	**0.2**	**1.4**		
Native forest on Ramsar sites as a proportion of total native forest on Ramsar sites (%)	**0.02**	**7**	**79**	**9**	**1**	**0.08**	**3**	**2**	**100**		

Notes: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI); Australian Government Department of the Environment and Energy.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.31: Area of native forest on land managed for protection of biodiversity, by jurisdiction

	Area ('000 hectares)								
		Native forest not in the National Reserve System but managed for protection of biodiversity[a]							
Jurisdiction	Native forest in the National Reserve System	Nature conservation reserve tenure[b]	Areas under private covenant[c]	Multiple-use public forests[d]	Protected areas in Defence estate[e]	Protected areas not otherwise reported[f]	Total native forest managed for protection of biodiversity	Total native forest	Proportion of native forest managed for protection of biodiversity (%)
ACT	114	0	0	5	1	2	122	130	93
NSW	5,776	17	86	1,816	34	33	7,762	19,925	39
NT	5,847	1.1	0	0	526	0	6,374	23,686	27
Qld	8,889	16	3	2,826	448	189	12,371	51,580	24
SA	2,613	17	0.1	8	35	4	2,678	4,856	55
Tas.	1,622	4	17	612	24	324	2,603	3,342	78
Vic.	3,322	86	35	3,036	22	26	6,527	7,645	85
WA	5,426	569	8	1,342	181	3	7,528	20,450	37
Australia	**33,609**	**710**	**148**	**9,645**	**1,272**	**581**	**45,965**	**131,615**	**35**

[a] Native forest areas in the CAR reserve system are either in the National Reserve System or in one of the other categories listed in this table.

[b] Comprises native forest on nature conservation reserve tenure not included in the National Reserve System.

[c] Comprises areas of native forest under private conservation covenant not in the National Reserve System. These areas are on predominantly leasehold and private land tenures.

[d] Multiple-use public native forests are included where biodiversity conservation is a specified management intent, either through jurisdictional legislation designating protection of the forest area and conservation of biodiversity being specified in legislation, or through conservation of biodiversity being regulated or managed through a management planning instrument.

[e] Comprises forest on the Defence estate (on other Crown land tenure) not included in other categories.

[f] Comprises forest in the CAR reserve system, World Heritage Areas and Ramsar wetland sites not included in other categories; includes CAR reserves on Future Potential Production Forest land in Tasmania.

Note: Totals may not tally due to rounding.

Source: ABARES, National Forest Inventory (NFI) for forest area; Australian Government Department of the Environment and Energy (CAPAD); Australian Government Department of Defence.

This table, together with other data for Indicator 1.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Indicator 1.1d

Fragmentation of forest cover

Rationale

This indicator describes the loss of forest cover and the spatial configuration of that loss. Fragmentation can impact on forest-dwelling species and gene pools through changes in the connectivity of populations and the loss of species genetic variability.

Key points

- Simple metrics of forest fragmentation were calculated for Australia's current forest coverage. These metrics were based on whether each hectare of forest has an edge to an area of non-forest, and on forest patch size.
  - Fragmentation is expected in some unmodified landscapes, while additional fragmentation results from human modification of the landscape.
  - It is not possible with available data to determine the rate of change of forest fragmentation over time, or its impact on species. Information on loss and gain of forest cover is presented in Indicator 1.1a.
- A total of 72% of Australia's native forest area is comprised of one hectare cells that are completely bounded by forest. These are named 'forest-interior' cells.
  - The jurisdictions in which the highest area proportion of native forest is in forest-interior cells are the Australian Capital Territory (89%) and Victoria (88%).
  - The areas of forest with the lowest proportion of forest-interior cells, and thus the highest proportions of fragmentation, are found in ecoregions where woodland forest intergrades into woody non-forest vegetation, and in areas with the highest impacts of historical land clearing for agriculture and for urban development.
- A total of 68% of Australia's native forest is in patches of over 100,000 hectares
  - All jurisdictions have 44% or more of their native forest in patches of over 100,000 hectares.
  - The jurisdictions with the largest proportion of their native forest in patches of less than 10,000 hectares (South Australia and Western Australia) are also the jurisdictions with the highest area proportions of native forest that is woodland forest, and that borders areas carrying woody non-forest vegetation.
- The majority of Australia's forest cover is therefore continuous, not fragmented.
  - Native forest that is not fragmented is found in forested areas of higher rainfall, as well as in regions that have experienced the least clearing for agricultural land use, and in nature conservation reserves and in multiple-use public forests.
  - The main component of fragmented forest cover occurs in woodland forest, likely from the interspersion of woodland forest with areas of non-forest vegetation, as occurs in drier ecoregions of Australia. Fragmentation is also associated with stands of remnant forest in mostly cleared agricultural landscapes.
- Fragmentation statistics are also reported by Tasmania and Victoria in their respective 'State of the Forests' reports.

Otherwise continuous tracts of native forest can be naturally fragmented because of the presence of non-forest vegetation where soils or local climate are not suitable for forest, or because of features such as rock outcrops, cliffs, wetlands, lakes, streams and rivers. Fragmentation also occurs naturally around the boundary between woodland forest (which has 20–50% crown cover) and woody non-forest vegetation (with less than 20% crown cover, often called sparse woodland). Successional change can occur in both directions between forest and non-forest vegetation types, for example as forest invades grassland, or as forest dieback results in larger areas of grass-dominated ecosystems.

In addition, areas of individual forest types can be fragmented within a continuous area of forest, due to differences in soil type or rainfall. Even within a forest type, fragmentation of the spatial arrangement of age-classes, associated with successional changes and driven by response to disturbance, has also always been a feature of Australian native forests. These types of fragmentation are not considered in this indicator.

The main cause of increasing forest fragmentation over the past 200 years has been forest clearing associated with land-use change, mainly for agriculture, mining and urban development, but also for infrastructure such as roads, railways, pipelines and electricity transmission lines. As much as one-third of Australia's native vegetation in intensively used areas (mainly the agricultural and urban zones) has been cleared or substantially modified over that time. As a result, some ecological communities now occupy less than 1% of their original extent, and others have become highly fragmented (DoEE 2016a)[63].

An increase in forest fragmentation in previously continuous forest can increase edge effects, reducing habitat quality for species adapted to forest interiors. Fragmentation involving permanent clearing of forested land can thus reduce the habitat available for those plant, mammal, reptile, bird and amphibian species that require large areas of continuous forest; the impact varies considerably by species and community. On the other hand, an increase in forest fragmentation could improve habitat quality for species that live at forest edges or in open country. Threats from non-native species, including weeds and predators, also generally increase when forests are divided into smaller patches. Consequently, historical fragmentation is a key threat to some forest-dwelling species (see Indicators 1.2c and 1.3a).

References on forest fragmentation studies in Australia are given in Bradshaw (2012), and a global meta-analysis of the effect of fragmentation on biodiversity and ecosystem function is presented by Haddad et al. (2015). However, impacts due to habitat fragmentation may be confounded by impacts due to changes in the total area of habitat (Fahrig 2013).

The general cessation of broadscale clearing of native forest in much of Australia (Indicator 1.1a, Indicator 5.1a) and increased protection of forests (Indicator 1.1c) have been critical in reducing the rate of forest fragmentation. Native trees and shrubs planted in corridors can re-establish connectivity between patches of forest in agricultural landscapes.

Analysis of fragmentation involves measuring one or more of a number of parameters derived from spatial analysis of the configuration of forest cover (Tickle et al. 1998; Lindenmayer et al. 1999). Fragmentation parameters can include the relative amounts of edge and interior forest, and the size and shape of forest patches. Connectivity is generally taken to be the converse of fragmentation, with a high level of connectivity being associated with large, contiguous patches of forest.

This indicator reports a circumscribed set of spatial variables that can form the basis of tracking forest fragmentation nationally and regionally over time. However, no simple fragmentation metric can be used as a surrogate for habitat quality for forest-dwelling species, as species respond to more complex habitat features and landscape patterns (Lindenmayer et al. 2003).

National forest fragmentation statistics

Australia's forests are mapped at a one-hectare scale in the National Forest Inventory (NFI), with each one-hectare cell or 'pixel' across Australia being scored as forest or non-forest (Indicator 1.1a). This dataset is suitable for analysis of native forest fragmentation. Two sets of metrics were calculated, one set derived from the number of forest cells that each native forest cell has as (edge-to-edge) neighbours, and the other set derived from the size of patches of native forest in which every cell is a neighbour (edge-to-edge) to another forest cell (Figure 1.17).

Forest fragmentation analysed as the extent to which forest is adjacent to forest or non-forest

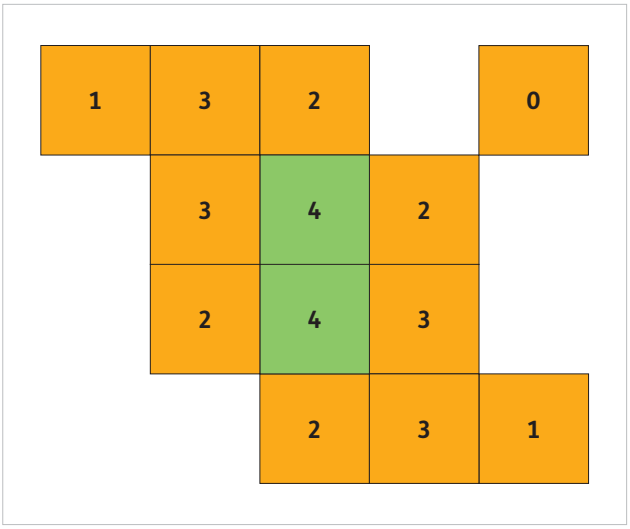
This metric distinguishes two fragmentation classes of cells (Figure 1.17):

- 'Forest-interior' cells are native forest cells that has have all their four neighbouring (edge-adjacent) cells as forest, whether native forest, commercial plantation or other forest. A higher proportion of forest-interior cells implies a forest that is relatively unfragmented, and not affected by any nearby non-forest area.
- 'Forest-exterior' cells are native forest cells that have one or more non-forest neighbouring cells, and are therefore at a boundary between forest and non-forest. They could also be named 'forest-edge' cells. A more fragmented forest has a higher proportion of forest-exterior cells and a lower proportion of forest-interior cells.

  The non-forest adjacent to forest-exterior cells may be land cleared for agricultural land use, urban development or infrastructure, with potential to affect the forest ecosystem; may be woody non-forest vegetation such as sparse woodland with under 20% crown cover, and representing a natural vegetation transition with a lesser impact on the native forest area; or may be other non-forest vegetation.

[63] soe.environment.gov.au/theme/biodiversity/topic/2016/terrestrial-ecosystems-and-communities#figure-bio11a-total-loss-of-extent-of-vegetation-communities-in-australia-from-pre-1750-extents-b-a-fragmentation-measure-reflecting-the-change-in-proportion-of-vegetation-patches-made-up-of-less-than-5000hectares--119566

Figure 1.17: Schematic diagram illustrating fragmentation metrics



Notes: Diagrammatic representation of a small area of forest. White, non-forest; orange, forest-exterior cells; green, forest-interior cells (same colour scheme as Figures 1.18–20). The figures in each forest cell are the number of neighbouring (edge) cells that are forested. Each cell is one hectare (100 metres x 100 metres).

The area comprises two patches of forest. The top-right cell is a patch containing just one hectare of forest, not being edge-connected to any other forest cell, while the remaining forest cells are all edge-connected and make up a 12-hectare patch of forest.

The 13 cells in this area of forest comprise 11 forest exterior cells (coloured orange) and 2 forest interior cells (coloured green and containing the number '4'): the latter are the cells that have all four of their neighbouring (edge) cells as forest. In this area of forest, the mean number of neighbouring cells forested is 2.3, and the proportion of forest interior cells is 2/13 = 15%.

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

Table 1.32 shows the area proportions of each of these types of forest-interior and forest-exterior cells in the native forest of each jurisdiction. A total of 72% of Australia's native forest area is comprised of one-hectare cells completely bounded by forest. Equally, 28% of Australia's native forest area adjoins (has an edge with) an area of non-forest. The jurisdictions in which the highest area proportion of native forest that is forest-interior are the Australian Capital Territory (89%) and Victoria (88%), whereas South Australia (64%), Northern Territory (64%) and Western Australia (66%) have the lowest area proportions of native forest that is forest-interior.

The distribution of native forest by fragmentation class is shown in Figures 1.18–20, at increasing scales. Nationally (Figure 1.18, see page 88), native forest that is not fragmented is found in the forested regions of higher rainfall, as well as in regions that have experienced least clearing for agriculture, and in nature conservation reserves and in multiple-use public forests. Regionally, such as in south-west Western Australia (Figure 1.19), native forest that is not fragmented is present through forest regions of higher rainfall, while fragmented native forest is present at the drier inland margins and scattered through the agricultural zone. Locally, such as in south-western Sydney, a similar pattern is seen (Figure 1.20), where the native forest in cleared agricultural and urban areas and at the margins of more continuous forest comprises almost completely forest-exterior cells.

Table 1.33 compares these fragmentation metrics to the area proportion of woodland forest in each jurisdiction. Woodland forest, with a crown cover 20–50%, typically occurs in the drier regions of Australia (see Indicator 1.1a). The Australian Capital Territory and Victoria, which have the highest proportion of native forest area that is forest interior, have the lowest area proportions of native forest that is woodland forest. Equally, South Australia and Western Australia, which are two of the jurisdictions with the lowest proportions of native forest that is forest interior, have the highest area proportions of native forest that is woodland forest. This indicates that, as would be expected, the highest proportions of forest edge and therefore fragmented forest are found in regions where woodland forest intergrades into the non-forest category of sparse woodland (that is, woody vegetation with a crown cover below 20%).

Other drivers of forest configuration occur in the sub-tropical forests of the Northern Territory, which has a relatively high area proportion of open and closed forest adjacent to non-forest areas (Table 1.33).

Table 1.33 also compares these fragmentation metrics between the 2011 forest coverage published in SOFR 2013, and the 2016 forest coverage published in SOFR 2018. There is a slight decrease in the extent of native forest fragmentation over time. However, as only two time-points are compared, and as improved (more accurate) datasets were used to compile the 2016 coverage (see Indicator 1.1a), this difference does not necessarily represent meaningful on-ground

Table 1.32: Native forest area by fragmentation class, by jurisdiction

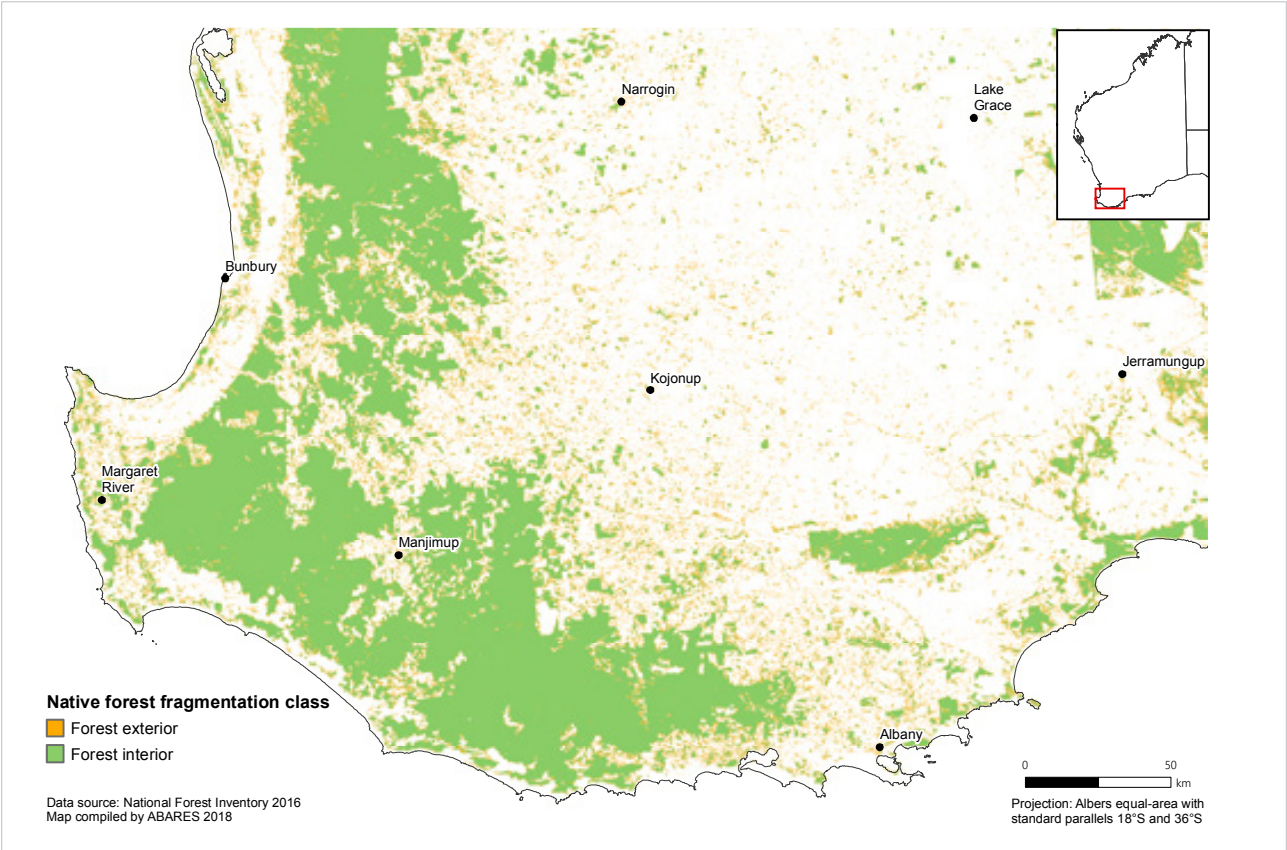
Number of neighbouring cells forested	Fragmentation class	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia
		Area as proportion of total native forest area (%)								
4	Forest interior	89	73	64	74	64	75	88	66	72
3	Forest exterior	6	12	17	13	15	14	6	15	14
2	Forest exterior	3	8	11	8	11	7	3	10	8
1	Forest exterior	1.0	4	6	3	7	3	1.5	5	4
0	Forest exterior	0.3	2	3	1.3	4	0.7	0.6	3	2
Mean number of neighbouring cells forested[a]		**3.83**	**3.49**	**3.34**	**3.57**	**3.27**	**3.61**	**3.80**	**3.37**	3.49

[a] The 'Mean number of neighbouring cells forested' is the average number of neighbouring forested cells for each forested cell in that jurisdiction.

Notes: The cells for this analysis are the 100 m x 100 m grid cells used by the National Forest Inventory. Forest coverage as at 2016 is from SOFR 2018, Indicator 1.1a. Totals may not tally due to rounding.

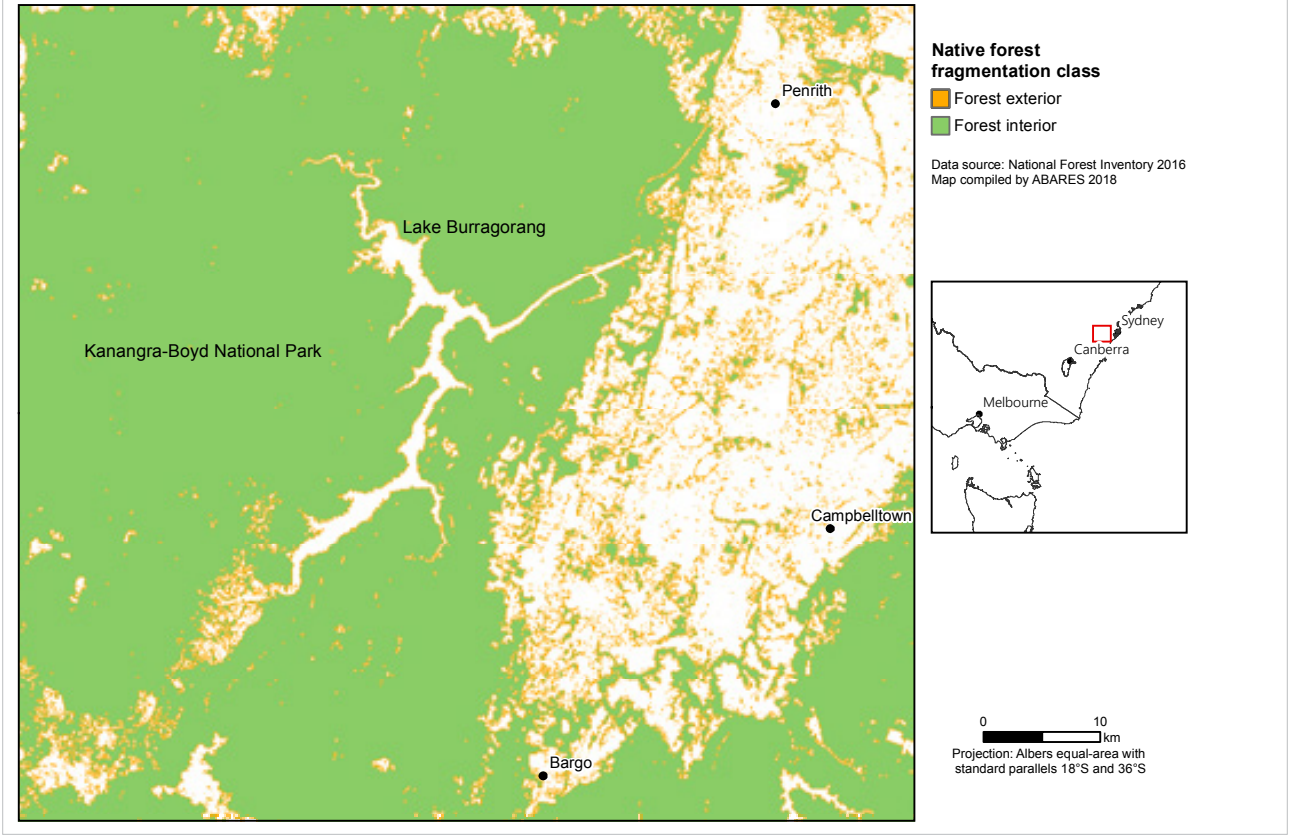
This table, together with other data for Indicator 1.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.19: Native forest fragmentation class distribution across south-west Western Australia



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

Figure 1.20: Native forest fragmentation class distribution across an area near Lake Burragorang (Warragamba Dam), south-west of Sydney, New South Wales



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

Table 1.33: Native forest fragmentation, by jurisdiction

	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia
Forest coverage as at 2016									
Native forest area ('000 ha)	130	19,925	23,686	51,580	4,856	3,342	7,645	20,450	131,615
Area proportion woodland forest	29%	47%	65%	77%	93%	41%	37%	89%	69%
Mean number of neighbouring cells forested[a]	3.83	3.49	3.34	3.57	3.27	3.61	3.80	3.37	3.49
Proportion forest interior[b]	89%	73%	64%	74%	64%	75%	88%	66%	72%
Forest coverage as at 2011									
Native forest area ('000 ha)	128	22,270	15,173	50,782	4,377	3,361	7,729	18,752	122,574
Area proportion woodland forest	29%	47%	51%	76%	94%	40%	36%	88%	67%
Mean number of neighbouring cells forested[a]	3.80	3.36	3.32	3.57	3.22	3.57	3.71	3.38	3.47
Proportion forest interior[b]	89%	68%	64%	75%	62%	74%	84%	66%	71%

[a] 'Mean number of neighbouring cells forested' is the average number of neighbouring forested cells for each forested cell in that jurisdiction.

[b] 'Proportion forest interior' is the proportion of forest cells that are interior. A forest interior cell is a native forest cell that has all of its four neighbouring (edge-adjacent) cells forested (with native forest, other forest or commercial plantation).

Note: the cells for this analysis are the 100 m x 100 m grid cells used by the National Forest Inventory. Forest coverage as at 2016 is from SOFR 2018, Indicator 1.1a. Forest coverage as at 2011 is from SOFR 2013, Indicator 1.1a.

This table, together with other data for Indicator 1.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.34: Native forest fragmentation, by IBRA ecoregion

					Fragmentation metrics	
IBRA ecoregion[a]	Land area[b] ('000 ha)	Native forest area ('000 ha)	Native forest as proportion of land area	Woodland forest as proportion of native forest area	Mean number of neighbouring cells forested[c]	Proportion forest interior[d]
Deserts, xeric shrublands	356,971	5,019	1.4%	98%	2.89	49%
Temperate grasslands, savanna, shrublands	52,978	7,835	15%	75%	3.05	51%
Tropical/subtropical grasslands, savannas, shrublands	220,744	70,750	32%	78%	3.49	71%
Mediterranean. forests, woodlands, scrub	78,278	20,388	26%	84%	3.55	74%
Temperate broadleaf, mixed forest	55,255	24,034	43%	31%	3.65	80%
Tropical/subtropical moist broadleaf forests	3,456	2,489	72%	26%	3.82	89%
Montane grasslands, shrublands	1,233	1,100	89%	47%	3.91	94%
Australia	**768,915**	**131,615**	**17%**	**69%**	**3.49**	**72%**

[a] IBRA ('Interim Biogeographic Regionalisation of Australia') ecoregions are from www.environment.gov.au/land/nrs/science/ibra/australias-ecoregions. The ecoregion 'Montane grasslands, shrublands' contains areas of alpine and subalpine forest.

[b] The total land area differs slightly from that in Table 1.1, Indicator 1.1a, because of differences in coastlines used

[c] 'Mean number of neighbouring cells forested' is the average number of neighbouring forested cells for each forested cell in that jurisdiction.

[d] 'Proportion forest interior' is the proportion of forest cells that are interior. A forest interior cell is a native forest cell that has all of its four neighbouring (edge-adjacent) cells forested (with native forest, other forest or commercial plantation).

Note: The cells for this analysis are the 100 m x 100 m grid cells used by the National Forest Inventory. Forest coverage is from SOFR 2018, Indicator 1.1a.

This table, together with other data for Indicator 1.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

change. Analysis of a different dataset, such as the National Greenhouse Gas Inventory dataset used to assess the extent of forest cover change over time (see Indicator 1.1a), would be needed to assess any change in fragmentation over time.

Ecoregions are regions that contain geographically distinct groups of animals and plants, and are another approach to distinguishing different broad vegetation types across Australia[64]. Table 1.34 presents fragmentation metrics for native forest in the seven ecoregions present on mainland Australia. The most fragmented native forest is found in those ecoregions ('Deserts, xeric shrublands'; and 'Temperate grasslands, savanna, shrublands') that contain the lowest proportion of forest, which also are the ecoregions with the highest proportions of native forest as woodland forest. This is to be expected, as forests in environments that are drier, or where other vegetation types such as grassland are dominant, attain a lower canopy cover. The least fragmented native forest is found in the wettest ecoregion ('Tropical/subtropical moist broadleaf forests'), and in the 'Montane grasslands, shrublands' ecoregion that contains Australia's subalpine and mountain forests; large areas of both these ecoregions are in nature conservation reserves or in multiple-use public forests.

Analysis by ecoregion thus confirms that variation in the extent and configuration of native forest across the wider Australian landscape, driven by large-scale ecological considerations, is a major determinant of the extent to which forest and non-forest areas are interspersed, and thus of the extent of forest fragmentation. At smaller scales, the impacts of land clearing

[64] A full list, descriptions and maps of Australia ecoregions under the Interim Biogeographic Regionalisation for Australia (IBRA) is available at www.environment.gov.au/land/nrs/science/ibra/australias-ecoregions

for agricultural land use, infrastructure and urban development are also determinants of the extent of forest fragmentation. Quantitative analysis of human-induced fragmentation at a national or regional scale is difficult in the absence of historical spatial forest coverages to act as baselines for comparison.

Forest fragmentation analysed as the size of forest patches

Fragmented forests generally occur in smaller patches of isolated forest, whereas forests that are less fragmented occur in larger patches of continuous forest. The proportion of native forest in patches of different size is therefore another measure of forest fragmentation and its converse, forest connectivity.

Table 1.35 presents the area proportion of native forest in patches of different size, by jurisdiction, and Figure 1.21 shows the distribution of native forest by patch size across Australia. Forest in patch sizes of over 100,000 hectares has a similar geographic distribution to that of forest in the forest-interior fragmentation class (compare Figure 1.18 and Figure 1.21). This indicate that the two fragmentation metrics (proportion of forest that is forest-interior, and forest patch size) are correlated, and likely influenced by similar landscape variables.

Nationally, 68% of native forest is in patches of over 100,000 hectares. All jurisdictions have 44% or more of their forest in patches of over 100,000 hectares. The Australian Capital Territory has 90% of its native forest in one patch of over 100,000 hectares, which includes Namadgi National Park. South Australia and Western Australia are the jurisdictions with the lowest proportion of their native forest in patches of over 100,000 hectares (44% and 56%, respectively), and are also the jurisdictions with the largest proportion of their native forest in patches of less than 10,000 hectares (38% and 32%, respectively). South Australia and Western Australia are also the jurisdictions with the highest area proportions of native forest that is woodland forest (Table 1.33). This again indicates that the highest proportions of fragmented forest are found in regions where woodland forest intergrades into the non-forest vegetation category of sparse woodland (other woody vegetation with a crown cover below 20%).

Forest fragmentation statistics in Victoria

Victoria reported forest fragmentation in Indicator 1.1d of *Victoria's State of the Forests Report 2013* (DEPI 2014d). These data have since been updated in preparation for in *Victoria's State of the Forests Report 2018* (DELWP, unpublished).

The method involved allocating each 30 m x 30 m pixel (cell) in a forest coverage modelled from a composite Landsat image from 2009 to 2013 to one of five categories of increasing fragmentation, and is based on the method of Riitters et al. (2000) that has been applied to forests globally. The categories are named 'interior', 'patch', 'transitional', 'perforated' and 'edge' (Table 1.36), and are defined probabilistically considering the forest status of the eight cells (edge cells plus corner cells) surrounding a central cell, and the proportion of forest in a broader window.

Descriptions of the fragmentation categories and the results of application of this method to Victoria are shown in Table 1.36, and the distribution of the categories across Victoria is shown in Figure 1.22.

Victoria's State of the Forests Report 2013 (DEPI 2014d) also presented these results by region, IBRA bioregion, and tenure, as well as presenting patch-size data for each bioregion. Bioregions in the north-west of the state contain the lowest proportion of forest cover, and also have the smallest average forest patch sizes, a high degree of fragmentation, and the smallest average core forest areas. Eastern Victoria contains the largest areas of continuous forest in the state that is not fragmented.

Forest fragmentation statistics in Tasmania

Forest fragmentation statistics for Tasmania are presented in Indicator 1.1d of *State of the forests Tasmania 2017* (FPA 2017a), and report the proportion of total native forest area that occurs in patches of different size. A total of 45% of Tasmania's forests is in patches larger than 50,000 hectares, and 72% is in patches larger than 10,000 hectares. There was minimal change to these statistics over the period 2005 to 2015.

As for the national analysis, forests in Tasmania are often naturally fragmented where they occur in a matrix of non-forest communities, including in the Tasmanian Wilderness World Heritage Area.

Table 1.35: Native forest patch size distribution, by jurisdiction

Jurisdiction	Total native forest area ('000 ha)	Area proportion of native forest in patches[a] of different size				
		1–1000 ha	>1000–10,000 ha	>10,000–100,000 ha	>100,000–1,000,000 ha	>1,000,000 ha
ACT	130	5%	5%	0%	90%	0%
NSW	19,925	18%	8%	10%	21%	43%
NT	23,686	19%	5%	5%	16%	55%
Qld	51,580	13%	6%	8%	14%	59%
SA	4,856	30%	9%	18%	23%	21%
Tas.	3,342	12%	6%	6%	23%	53%
Vic.	7,645	8%	6%	11%	22%	53%
WA	20,450	24%	8%	12%	14%	42%
Australia	**131,615**	**17%**	**7%**	**9%**	**15%**	**53%**

[a] A patch is defined as an area of native forest in which every cell adjoins (is edge-adjacent to) another forest cell. For each state and territory, patches are confined within the boundary of that state and territory, whereas for Australia patches can cross state and territory boundaries; the number of native forest patches in Australia is therefore less than the sum of the number of native forest patches in the states and territories.

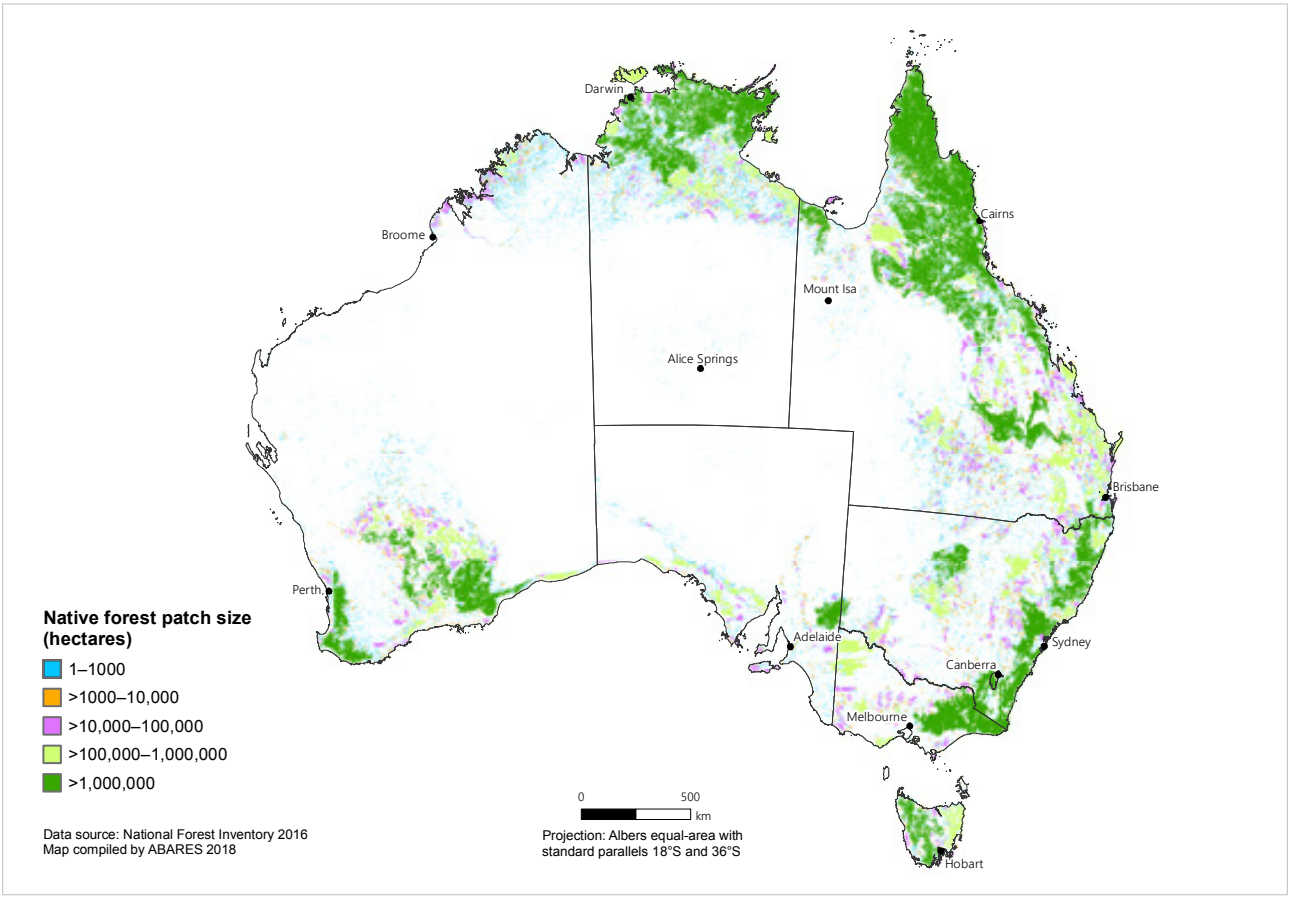
Notes:

The cells for this analysis are the 100 m x 100 m grid cells used by the National Forest Inventory. Forest coverage is from SOFR 2018, Indicator 1.1a.

Totals may not tally due to rounding.

This table, together with other data for Indicator 1.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.21: Native forest patch size distribution across Australia



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

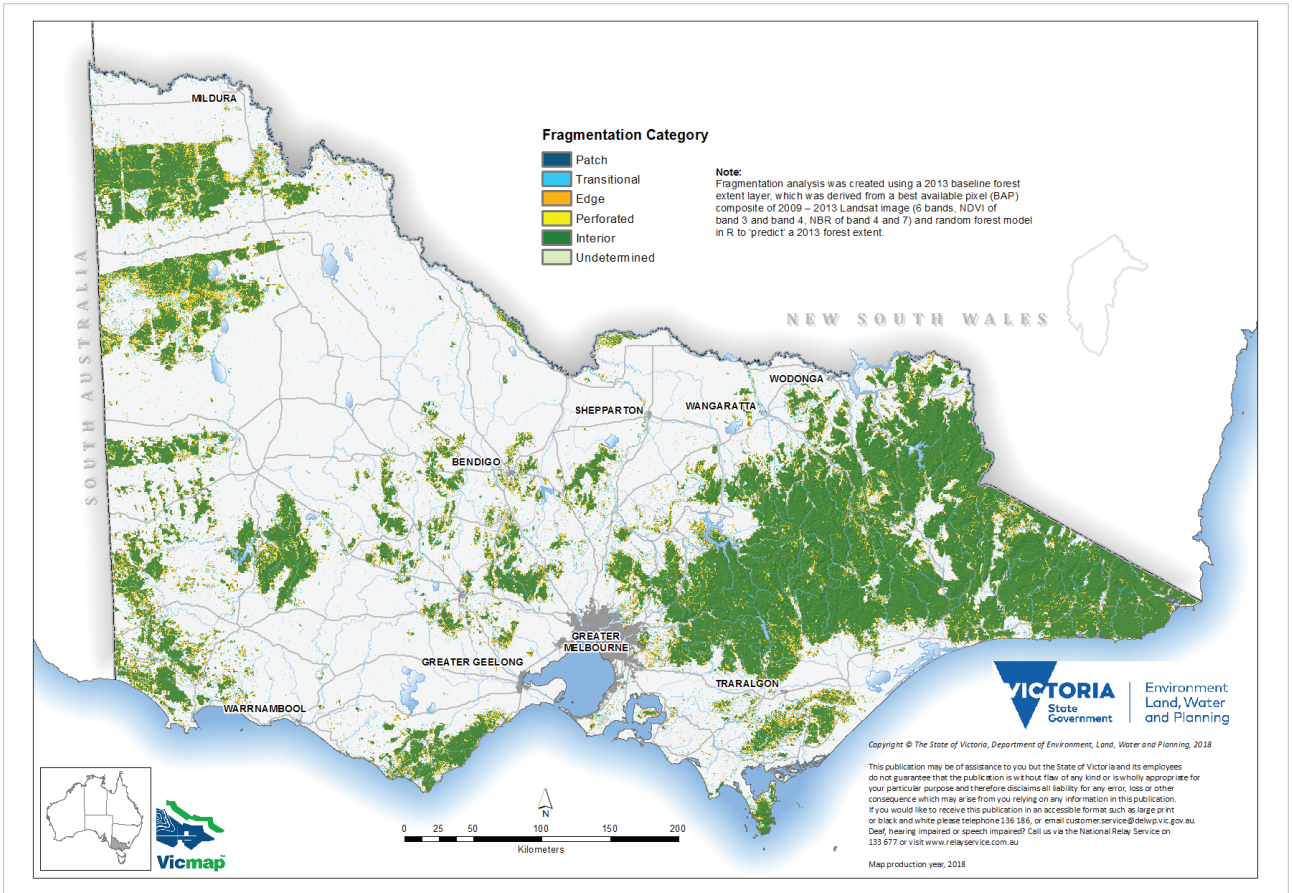
Table 1.36: Fragmentation statistics for Victoria's forests, 2009–13

Fragmentation category	Description	Area proportion
Interior	Forest pixels that are relatively far from the forest-non-forest boundary. Essentially these are forested areas surrounded by more forested areas	75%
Patch	Forest pixels that comprise a small forested area surrounded by non-forested land cover	2.9%
Transitional	Transition areas between connected forest and fragmented forest	3.6%
Perforated	Forest pixels that define the boundary between core forest and relatively small clearings (perforations) within the forested landscape	5.7%
Edge	Forest pixels that define the boundary between core (interior) forest and large non-forested land cover features	13%

Source: DELWP. Data based on a composite Landsat image from 2009 to 2013.

This table, together with other data for Indicator 1.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.22: Forest fragmentation in Victoria, 2013



Note: this is an update of the map that was published in *Victoria's State of the Forests Report 2013* (DEPI 2014d) and that is available at www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0013/29002/ForestFragmentation_map_SFR2013.pdf

Source: DELWP.

Indicator 1.2a

Forest dwelling species for which ecological information is available

Rationale

This indicator reports the level of information available to manage forest dwelling species and tracks changes in this knowledge over time. The amount of habitat, disturbance and life history information available to make management decisions indicates the capacity to assess risk to species and to implement conservation strategies.

Key points

- All states and territories have developed lists of forest-dwelling vertebrate fauna (animal) and vascular flora (plant) species, allowing compilation into national lists.
  - These national lists show that the number of known forest-dwelling species has generally increased in each jurisdiction since the number was first reported in SOFR 1998, reflecting improved information from a variety of survey mechanisms.
- As of July 2016, the national list contained 2,486 forest-dwelling native vertebrate fauna species, with 1,119 of these species being identified as forest-dependent species.
- As of July 2016, the national list also contained 16,836 identified forest-dwelling native vascular flora species. Approximately half of these species occur in Queensland.
- Partial ecological information is available for around 60% of Australia's forest-dwelling vertebrate fauna and vascular flora species. Comprehensive ecological information is available on at least 10% of vertebrate fauna species, mainly mammals, birds and amphibians.
  - Significantly improved information is available for species in regions that have been subject to formal assessment processes, such as those associated with Regional Forest Agreements; and other assessments such as the Kimberley Islands Biological Survey; and for reptiles, frogs, bats and fish.
  - Information on forest-dwelling invertebrates, fungi, algae and lichens for areas other than south-west Western Australia and Tasmania remains very limited.

Knowledge of the species present in a forest, and increases or decreases in their populations, can provide an indication of the extent and condition of forest habitat, and an indication of ecosystem health. This is particularly important in Australia, where knowledge of species diversity is a precondition for the effective management of forest ecosystems. However, the changes in numbers of forest-dwelling and forest-dependent species over time often reflect improvements in the knowledge base from which species lists are compiled, and not actual changes in forest ecosystem diversity.

Davey (2018b) reviews the historical development of Indicators 1.2a–c and 1.3a, the development of databases used to inform indicators, and the reporting of species-level indicators in SOFR 2013.

Forest-dwelling species are species that may use forest habitat for all or part of their lifecycles. This is a broader set of species than forest-dependent species, which are species that must inhabit a forest habitat for all or part of their lifecycles.

The last *Numbers of Living Species in Australia and the World* report (Chapman 2009) reported that, at that date, Australia was home to an estimated 566,398 species, of which 147,579 species had been described. Of the described species in Australia at that date, 92% of flora species, 87% of mammal species, 45% of bird species, 93% of reptile species and 94% of frog species were endemic, that is, were found only in Australia. This high level of endemism increases the importance of conserving the suite of species found in Australia.

Forest-dwelling and forest-dependent vertebrate fauna species

All states and territories have developed lists of extant[65] and extinct forest-dwelling vertebrate fauna (animal) species. These lists have been used as inputs into the development of National Forest Inventory databases for forest-dwelling vertebrate fauna species.

Nationally, in 2016, there were 2,486 native forest-dwelling vertebrate fauna species (Table 1.37). This number of species has increased from that reported in SOFR 2013 as a result of improved information and targeted surveys, even though data accuracy is limited by the absence of data from some states and territories for some reporting periods.

The greatest number of forest-dwelling vertebrate fauna species in each taxonomic group, and in total, is found in Queensland. An improved understanding of fish habitat and fish species distribution has contributed to a doubling of the number of reported forest-dwelling fish species nationally, from 220 species reported in SOFR 2013 to 449 species reported in SOFR 2018. Many of the fish species that were added occupy forested estuarine and mangrove habitats.

Of these vertebrate fauna species, a total of 1,119 are assessed as forest-dependent (Table 1.38). This is an increase from the 1,101 such species reported in SOFR 2013. Approximately half the forest-dwelling vertebrate fauna species are therefore forest-dependent. The greatest number of forest-dependent vertebrate fauna species in each taxonomic group, and in total, is found in Queensland.

These forest-dwelling and forest-dependent vertebrate species are found across a range of habitat types (Table 1.39). Across all forest-dwelling vertebrate species, 30% of habitat usage is of woodland or open eucalypt forest; non-forest habitats represent 37% of habitat types used. There are no substantial differences between taxon groups of forest-dwelling species in the extent to which they use forest versus non-forest habitats. Forest habitats are naturally more highly represented for forest-dependent vertebrate species, comprising 86% of habitats used (Table 1.39). Again, woodland and open eucalypt forest are the most common habitat types used. Fish are the taxon group of forest-dependent species with greatest use of other habitat types.

Table 1.37: Number of native forest-dwelling vertebrate fauna species, by jurisdiction, 2016, and across the five SOFR reporting periods[a]

Taxonomic group[b]	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia[c]
Fish	11	134	196	331	38	35	74	144	449
Amphibians	17	82	55	137	25	11	35	66	229
Reptiles	52	212	273	435	179	18	109	343	786
Birds	207	344	343	491	182	79	247	167	668
Mammals	47	124	119	207	98	40	99	144	354
Total 2016	**334**	**896**	**986**	**1,601**	**522**	**183**	**564**	**864**	**2,486**
Total 1998[d]	–	504	449	582	–	125	485	239	1,227
Total 2001[e]	8	780	439	1,214	462	131	415	646	1,817
Total 2006[e]	–	760	440	–	574[f]	137	513	226	–
Total 2011[e]	334	827	788	1,423	481	165	508	711	2,212
Total 2016	334	896	986	1,601	522	183	564	864	2,486

–, not available

[a] Forest-dwelling species are species that may use forest habitat for all or part of their lifecycles.

[b] As far as possible, subspecies are included separately where they are managed or reported separately, either nationally or by jurisdictions. Non-native species are not included.

[c] Numbers for Australia are less than the sum of numbers for each jurisdiction (i) because many species occur in more than one jurisdiction, and (ii) because numbers for Australia include data from offshore forested islands (such as Torres Strait, Christmas, Lord Howe and Norfolk Islands) not necessarily included in state or territory figures.

[d] As reported in SOFR 1998, and described as a national *minimum* estimate with data from New South Wales, the Northern Territory, Tasmania and parts of Queensland being incomplete.

[e] Data from SOFR 2003, SOFR 2008 and SOFR 2011 respectively.

[f] Potentially incorrectly reported in SOFR 2008.

Note: For this table, lists of fish, amphibian and mammal species were extensively updated using Atlas of Living Australia records, and lists of bird and reptile species lists were partly updated.

Source: National Forest Inventory, ABARES datasets of extant and extinct native vertebrate forest fauna, SOFR 1998, SOFR 2003, SOFR 2008, state and territory agencies and analyses of Atlas of Living Australia records (data download in January–February 2017).

This table, together with other data for Indicator 1.2a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[65] 'Extant' means still living, not extinct.

Table 1.38: Number of native forest-dependent vertebrate fauna species, by jurisdiction, 2016[a]

Taxonomic group[b]	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia[c]
Fish	5	41	23	94	7	7	22	17	116
Amphibians	3	32	3	71	0	0	10	11	96
Reptiles	24	92	90	242	32	9	37	77	350
Birds	122	199	147	280	91	55	147	76	371
Mammals	33	70	49	135	38	27	55	49	186
Total 2016	**187**	**434**	**312**	**822**	**168**	**98**	**271**	**230**	**1,119**

[a] Forest-dependent species are species that must inhabit a forest habitat for all or part of their lifecycles.

[b] Subspecies are included separately where they are managed by jurisdictions or nationally. Non-native species are not included.

[c] Numbers for Australia are less than the sum of numbers for each jurisdiction (i) because many species occur in more than one jurisdiction, and (ii) because numbers for Australia include data from offshore forested islands (such as Torres Strait, Christmas, Lord Howe and Norfolk Islands) not necessarily included in state or territory figures.

Note: For this table, lists of fish, amphibian and mammal species were extensively updated using Atlas of Living Australia records, and lists of bird and reptile species lists were partly updated.

Source: National Forest Inventory, ABARES dataset of extant and extinct native vertebrate forest fauna, state and territory agencies and analyses of Atlas of Living Australia records (data download in January–February 2017).

This table, together with other data for Indicator 1.2a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.39: Habitat use of forest-dwelling and forest-dependent vertebrate species, 2016

	Habitat use as a proportion of total habitat use (%)											
	Forest-dwelling species						Forest-dependent species					
Habitat types	Fish	Amphibians	Reptiles	Birds	Mammals	All species	Fish	Amphibians	Reptiles	Birds	Mammals	All species
Forest habitats												
Rainforest	5	9	6	6	9	6	12	23	17	11	17	15
Closed eucalypt forest	2	8	3	7	5	4	4	20	9	13	10	10
Open eucalypt forest	13	13	11	15	14	13	16	17	21	23	21	21
Woodland eucalypt forest	13	13	21	16	18	17	14	7	24	17	21	18
Forested waterways	19	18	5	10	5	11	19	23	7	9	6	11
Mangrove	8	0	1	5	2	4	4	0	1	7	3	4
Other forest	6	4	12	6	7	8	10	4	6	4	3	6
Plantation	0	0	0	1	1	1	0	0	1	2	2	1
Total forest habitats	**66**	**66**	**60**	**66**	**62**	**63**	**80**	**95**	**87**	**87**	**84**	**86**
Non-forest habitats												
Arid and semi-arid	1	2	8	2	5	4	0	0	1	0	0	0
Marine and coastal	9	1	1	4	1	4	2	1	1	2	1	2
Alpine	0	1	0	0	1	0	0	0	0	0	1	0
Scrubland	4	5	15	11	13	10	3	1	4	5	7	5
Grassland	3	10	10	8	9	7	3	0	2	1	3	2
Other non-forest	16	14	6	10	8	11	13	3	5	5	5	6
Total non-forest habitats	**34**	**34**	**40**	**34**	**38**	**37**	**20**	**5**	**13**	**13**	**16**	**14**

Notes:

Each species was allocated up to six habitat types based on habitat records (see Davey 2018b). For each taxon group, the number of species allocated to each habitat type was then expressed as a percentage of the total number of species habitat-type allocations for that taxon group.

Forest habitats are grouped into rainforest, closed eucalypt forest, open eucalypt forest, woodland eucalypt forest, forested waterways, mangrove, other forest dominated by *Acacia*, *Casuarina*, *Callitris* or other non-eucalypt species, and plantation (see Indicator 1.1a for descriptions and distribution). 'Forested waterways' includes riparian forests and woodlands, swamp forests, fringing forests around water features, and aquatic habitats found within rainforest, forest and woodland ecosystems; examples are creeks, rivers, seepage areas, swamps, wetlands, soaks, small lakes and dams. Non-forest habitats are grouped into arid and semi-arid, marine and coastal (includes marine and wetland environments), alpine, scrubland (other woody vegetation, including heathland, shrubland and open woodland), grassland, and other non-forest (includes non-forest waterways and wetlands, rock outcrops, mudflats, farmland).

For this table, lists of fish, amphibian and mammal species were extensively updated using Atlas of Living Australia records, and lists of bird and reptile species lists were partly updated.

Totals may not tally due to rounding.

Source: National Forest Inventory, ABARES dataset of native vertebrate forest fauna, state and territory agencies and analyses of Atlas of Living Australia records.

This table, together with other data for Indicator 1.2a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

The Regent Bowerbird (*Sericulus chrysocephalus*) lives in rainforests in Queensland and New South Wales.

Forest-dwelling and forest-dependent vascular flora species

Lists of forest-dwelling vascular flora have been compiled by all states and territories, and combined to produce a national list of 16,836 species (Table 1.40). The number of such species and their distribution changes over time, as more surveys are performed and new species are described. As with vertebrate fauna, the changing number of species reported reflects an improved information base rather than changes in the actual numbers of forest-dwelling species. The list of forest-dwelling vascular flora was not updated for SOFR 2018, other than through reporting a more accurate figure for the Australian Capital Territory and an updated figure for Western Australia. Regional surveys in Western Australia, in particular in the Kimberley region, and improved knowledge in the south-west of the state have contributed to the increase in the number of reported Western Australian forest-dwelling vascular flora species.

The number of forest-dependent vascular flora species has not been calculated either by state and territory jurisdictions or nationally.

Table 1.40: Number of forest-dwelling vascular flora species, by jurisdiction, 2016

Reporting date	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia[d]
2016[a]	1,043	7,472	3,854	8,470	2,453	1,034	2,913	3,820[b]	16,836
2011	1,551	7,472	3,854	8,470	2,453	1,034	2,913	3,313[c]	16,836
2006	n.r.	7,461	3,970	n.r.	2,306	1,017	2,853	3,000[c]	n.r.
2001	4	7,448	4,042	8,443	2,346	908	2,872	3,178[c]	16,532
1998	–	–	1,691	7,830	–	1,043	2,959	2,639[c]	13,622

–, not available; n.r., not reported.

[a] Not updated from that reported in SOFR 2013, except for WA and the ACT.

[b] South-west Western Australia and Kimberley region only.

[c] South-west Western Australia only.

[d] Numbers for Australia are less than the sum of numbers for each jurisdiction because many species occur in more than one jurisdiction. The figure for Australia has not been updated with the additional species reported here in south-west Western Australia and the Kimberley region, or with the amended figure for the ACT.

Source: National Forest Inventory, ABARES dataset of forest flora, SOFR 1998, SOFR 2003, SOFR 2008, state and territory agencies.

This table, together with other data for Indicator 1.2a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Level of ecological knowledge

Conservation management processes carried out as part of the development of Regional Forest Agreements (see Indicator 7.1a and Davey 2018a), as well as subsequent specific surveys of rare, threatened or endangered species, have been important in increasing knowledge of forest-dwelling species. Increased knowledge of populations and distributions of some threatened species has resulted in them no longer being classified as threatened and hence being removed from threatened species lists (see Indicator 1.2b). The number of species for which ecological knowledge is considered to be adequate is also increasing as a result of scientific surveys and studies, and of regional planning exercises, especially for species that are considered under threat. As more surveys are undertaken, it is likely that species will be found in areas where they were previously unknown; occasionally, species previously unknown to science will also be discovered. A comprehensive survey of fauna and flora has recently occurred in the Kimberley region of Western Australia (Gibson et al. 2017).

There are no comprehensive lists of the invertebrate fauna, non-vascular flora (including algae, liverworts and mosses, as well as fungi and lichens) or microorganisms that occur in forests, even though these species play key roles in ecological processes. The overall level of knowledge about these species is low, and priority is given to species listed in regulations, schedules or management plans. There are probably well over 100,000 terrestrial invertebrate species in Australia's forests, of which only a small fraction have been described (SOFR 2008).

To date, south-west Western Australia and the Huon region of southern Tasmania are the only forest regions within Australia with comprehensive lists of forest-dwelling invertebrate species and non-vascular flora. Western Australia is collecting comprehensive information on lesser-studied fauna and flora groups in the south-west through Forestcheck (see Case Study 7.7). This should result in the development of a more comprehensive list of forest-dwelling invertebrates and non-vascular flora in the south-west of the state; SOFR 2003 reported an incomplete list of 1,992 forest-dwelling invertebrates occurring in south-west Western Australia alone. In southern Tasmania, the Tasmanian Forest Insect Collection contains more than 216,000 beetle specimens of more than 2,200 species from Tasmanian forests; more than 60% of these species remain to be formally identified, and many are undescribed. The collection specialises in saproxylic (log-dwelling) and ground beetles. Species lists for many other taxa, including lichens, fungi and other non-vascular flora, are also maintained for the Warra Long-term Ecological Research site[66] (see Case study 7.8 in Indicator 7.1e).

Table 1.41 illustrates the level of ecological knowledge about forest-dwelling fauna and flora species. Partial ecological information is available for around 60% of Australia's forest-dwelling vertebrate fauna and vascular flora species. Comprehensive ecological information is available on at least 10% of vertebrate fauna species, mainly mammals, birds and amphibians.

Knowledge varies markedly across taxa. The level of knowledge has generally increased across all vertebrate groups and vascular plants nationally compared with that reported in SOFR 2013. State and territory agencies reported that confidence is greatest in the level of information for species occurring in areas where comprehensive regional assessments have been undertaken. Other than Western Australia, all states and territories reported that confidence was low in the level of knowledge for invertebrates and non-vascular flora. Victoria reported a decline in level of ecological knowledge about forest-dwelling birds, reptiles and mammals since their reporting for SOFR 2008.

For all taxa for which ecological information is minimal or inadequate, risk assessments are necessarily based on information about better studied, closely related taxa in similar ecological niches. Management strategies can also rely on general conservation measures, such as additions to the national reserve system (see Indicator 1.1c), additional environmental protection measures, and measures that provide for the maintenance of ecosystem processes.

[66] www.warra.com

Table 1.41: Assessed level of ecological knowledge on forest-dwelling species, by taxonomic group, 2016

Taxonomic group	Number of forest-dwelling species assessed	Assessed level of knowledge		
		Minimal or inadequate information available to inform management decisions[a]	Partial information available, but some crucial information may be absent or limited[b]	Comprehensive or adequate information available to inform management decisions[c]
		Proportion of species to which knowledge level applies (%)		
Invertebrates				
Insects	–[d]	85	11	4
Other arthropods	–[d]	90	8	3
Non-arthropods	–[d]	90	8	3
Vertebrates				
Fish	459	59	33	8
Amphibians	229	35	46	13
Reptiles	789	33	47	8
Birds	668	26	44	19
Mammals	356	22	61	14
Plants				
Vascular flora	16,836	40	48	8
Non-vascular flora[e]	–[d]	82	15	3

[a] Minimal or inadequate information available to inform management decisions: information limited to species taxonomic identification, with no or very limited knowledge of past and present distribution and population trends.

[b] Partial information available, but some crucial information may be absent or limited: knowledge of at least broad habitat requirements and population trends.

[c] Comprehensive or adequate information available to inform management decisions: knowledge of life history parameters, habitat requirements and distribution, and population status and trends.

[d] The level of knowledge for forest-dwelling species in these taxonomic groups was assessed by jurisdictional agencies for species or taxa listed as threatened either by state and territory legislation or under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

[e] Non-vascular flora are plants without a water-conducting system, including algae, liverworts and mosses; fungi and lichens are also reported under this category.

Notes: Each state and territory was asked to assess the level of knowledge available for species by taxonomic group according to the above descriptions. Figures are the mean of all responses; incomplete, unknown or uncertain responses are included under 'minimal or inadequate information' (except for arthropods, non-arthropods and non-vascular flora where incomplete, unknown or uncertain responses were excluded). Figures are indicative and reflect subjective national understanding of ecological knowledge of taxonomic groups.

Source: Based on state and territory responses to SOFR 2008, SOFR 2013 and SOFR 2018.

This table, together with other data for Indicator 1.2a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Indicator 1.2b

The status of forest dwelling species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment

Rationale

This indicator measures the conservation status of nationally listed threatened forest dwelling species. Documentation of this information over time allows analysis of changes to species' conservation status, indicating the extent to which forest species biodiversity is being maintained.

Key points

- A total of 1,420 forest-dwelling species are on a national list of threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).
  - Of these, 842 species were assessed as forest-dependent.
- The listed threatened forest-dwelling species comprise 307 vertebrate fauna species, 38 invertebrate fauna species, 1,074 vascular flora species and one non-vascular flora species.
  - Of these, 149 vertebrate fauna species are forest-dependent, 28 invertebrate fauna species are forest-dependent, 664 vascular flora species are forest-dependent, and the one non-vascular flora species is forest-dependent.
- A total of 41 forest communities are listed as threatened under the EPBC Act.
- Of the 21 key threatening processes listed under the EPBC Act, 18 apply to forest ecosystems.
- The modelled distribution of listed threatened forest-dwelling and forest-dependent fauna and flora species across Australia's forest area is presented, together with the modelled distribution of listed threatened forest ecological communities.
- During the reporting period 2011–16, 68 forest-dwelling species were added to the national list of threatened species, and 77 were removed from the list.
  - Most additions were based on inherently small population sizes and/or ongoing impacts on habitat extent and quality, including impacts of introduced species and unsuitable fire regimes.
  - Most removals were a result of improved information that indicated that species were no longer considered valid species, or were not threatened.
- Listing statements give information on the nature of the threats to each species.
  - For forest-dwelling fauna species, the most common threat categories are historical land-use change and forest loss caused by clearing for agriculture, grazing, and urban and industrial development, followed by predation from introduced predators (e.g. fox, cat, rat and trout).
  - For threatened forest-dwelling flora, the most common threat categories are small population size and localised distribution, followed by mortality agents (including illegal collection, recreational pressure, pressures from peri-urban development, and genetic or breeding issues) and unsuitable fire regimes.
  - For threatened forest ecological communities, the most common threat categories are weeds, and forest loss due to clearing for agriculture.
  - Forestry operations pose a less significant threat to forest-dwelling fauna and flora species compared with other identified threat categories.
- States and territories have formal threat abatement plans in place to reduce the impacts of key threats and threatening processes on threatened species. A significant amount of research is occurring on key threatened species.

Protecting listed threatened species and ecological communities

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's principal piece of environmental legislation. Among other things, it is designed to protect Australia's native species and ecological communities by providing for:

- identification and listing of threatened[67] species and ecological communities
- development of conservation advice and, where appropriate, recovery plans for listed species and ecological communities
- development of a register of critical habitat
- identification and listing of key threatening processes[68]
- development of threat abatement plans to reduce the impacts of threatening processes where appropriate.

The EPBC Act requires the establishment of national lists of threatened species, threatened ecological communities, and key threatening processes. Listing of species, ecological communities or processes is administered through a scientific assessment process overseen by the Threatened Species Scientific Committee[69]. Once a species or ecological community is listed under the EPBC Act, its recovery is promoted using a published Conservation Advice, or (if developed) a Recovery Plan, under the assessment and approval provisions outlined in the EPBC Act. Recovery plans set out the research and management actions that are necessary to stop the decline of, and support the recovery of, listed threatened species or ecological communities, including the identification of critical habitat. The aim of a recovery plan is to maximise the long-term survival in its natural environment of the species or ecological community. Threat abatement plans are used to ameliorate key threatening processes.

Regional Forest Agreements (RFAs) are alternative (substitute) mechanisms for providing for protection of environmental values and matters of national environmental significance in RFA regions. The four RFA states provide for the protection of listed threatened species and communities in RFA regions through their forest management systems, as recognised in the RFAs.

Key threatening processes

As at end of June 2016, the EPBC Act listed 21 key threatening processes, 18 of which (86%) are direct threats to forest ecosystems (Table 1.42). These listed key threatening processes are separate from the threats identified in individual species listing statements. However, one or more of the forest-related key threatening processes feature in the listing advice for each threatened forest-dwelling fauna and flora[70] species and for each threatened ecological community.

Two new key threatening processes were added to the list during the SOFR 2018 reporting period (Table 1.42), both directly relating to forest ecosystems:

- 'Aggressive exclusion of birds from potential woodland and forest habitat by over-abundant noisy miner (*Manorina melanocephala*)' was listed because of the potential impact of Noisy Miner, a native bird species, on other bird species
- 'Novel biota and their impact on biodiversity' groups together the impacts of competition, predation or herbivory, and habitat degradation by vertebrate and invertebrate pests; competition, habitat loss and degradation by terrestrial and aquatic weeds; and mortality, habitat loss and degradation caused by pathogens.

  'Novel biota' refers to non-native or non-indigenous invasive species that have been introduced and naturalised in a new habitat and have a significant detrimental impact on the environment. It does not include species in domestic, agricultural and commercial forestry situations where these species remain appropriately managed: these species are only included if they escape or are released from managed situations and become invasive, threatening biodiversity. Case study 1.2 discusses an example of 'novel biota' in the form of the sugar glider (*Petaurus breviceps*) that was introduced from Victoria into Tasmania, and its consequent impact on the Swift Parrot (*Lathamus discolor*).

All states and territories maintain legislation to protect native species of flora and fauna, including forest-dwelling and forest-dependent species. Recent changes in forest-related legislation, including those related to the protection of threatened species, are reported in Indicator 7.1a.

Australia's Biodiversity Conservation Strategy 2010–2030 (NRMMC 2010) provides national direction for protection of Australia's biodiversity, including threatened species. A review of the first five years of the strategy has been published (Biodiversity Working Group 2016), with key findings in the areas of improving engagement and communication, considering biodiversity across all landscapes (not just natural terrestrial landscapes), influencing conservation activities, and alignment with international obligations. Australia's first Threatened Species Commissioner[71] was appointed in June 2014.

Australia's Native Vegetation Framework (COAG Standing Council on Environment and Water 2012) guides the ecologically sustainable management of Australia's native vegetation, and provides national goals and targets to improve the extent, connectivity, condition and function of native vegetation.

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67 'Threatened' is a general term covering the formal categories of Extinct, Critically Endangered, Endangered and Vulnerable. Additional formal categories are Conservation-dependent (for forest-dwelling species, currently applies only to seven threatened marine fish) and 'Extinct in the wild' (for forest-dwelling species, currently applies only to the Pedder galaxid, a fish species).

68 Threatening processes to species are natural, human-induced or human-exacerbated factors or processes that increase the risk of population reduction or extinction.

69 www.environment.gov.au/biodiversity/threatened/tssc

70 In this indicator, 'flora' and 'plant' are generally used interchangeably, as are 'fauna' and 'animal'.

71 www.environment.gov.au/biodiversity/threatened/commissioner

Table 1.42: Listed key threatening processes affecting forest-dwelling threatened species

Key threatening process	Effective date[a]
Competition and land degradation by rabbits	16 July 2000
Competition and land degradation by unmanaged goats	16 July 2000
Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*)	16 July 2000
Predation by European red fox	16 July 2000
Predation by feral cats	16 July 2000
Land clearance	4 April 2001
Loss of climatic habitat caused by anthropogenic emissions of greenhouse gases	4 April 2001
Psittacine circoviral (beak-and-feather) disease affecting endangered psittacine species	4 April 2001
Predation, habitat degradation, competition and disease transmission by feral pigs	6 August 2001
Infection of amphibians with chytrid fungus, resulting in chytridiomycosis	23 July 2002
The reduction in the biodiversity of Australian native fauna and flora due to the red imported fire ant, *Solenopsis invicta*	2 April 2003
Loss of biodiversity and ecosystem integrity following invasion by the yellow crazy ant (*Anoplolepis gracilipes*) on Christmas Island, Indian Ocean	12 April 2005
Biological effects, including lethal toxic ingestion, caused by cane toads (*Bufo marinus*[b])	12 April 2005
Predation by exotic rats on Australian offshore islands of less than 1000 km^2 (100,000 hectares)	29 March 2006
Invasion of northern Australia by gamba grass and other introduced grasses	16 September 2009
Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants	8 January 2010
Novel biota and their impact on biodiversity	26 Feb 2013
Aggressive exclusion of birds from potential woodland and forest habitat by over-abundant noisy miners (*Manorina melanocephala*)	9 May 2014

[a] Date from which the threatening process was listed.

[b] Now known as *Rhinella marina*.

Note: Key threatening processes are as listed in the EPBC database.

Source: www.environment.gov.au/cgi-bin/sprat/public/publicgetkeythreats.pl.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Number and distribution of threatened forest-dwelling and forest-dependent species

Forest-dwelling species are species that occur in forest vegetation types, although they may also occur outside forests. As at August 2016, a total of 1,420 forest-dwelling species were listed as threatened under the EPBC Act, comprising 1,347 extant (i.e. living, not extinct) species listed as Critically Endangered, Endangered or Vulnerable, and 73 species (including subspecies) listed as Extinct (Table 1.43).

Of the 1,420 threatened forest-dwelling species listed in the various categories, 307 are vertebrate fauna species, 38 are invertebrate fauna species, 1,074 are vascular flora species and one is a non-vascular flora species.

Based on listings against the EPBC Act in the Species Profile and Threats Database (SPRAT), no forest-dwelling species are known to have become extinct during the last or any SOFR reporting period. Three vascular flora species reported in SOFR 2013 as Extinct, an orchid (*Oberonia attenuata*), a herb (*Ptilotus pyramidatus*) and a shrub (*Prostanthera albohirta*), have been rediscovered. Woinarski et al. (2017) report that a bat (the Christmas Island pipistrelle, *Pipistrellus murrayi*) and a reptile (the Christmas Island forest skink, *Emoia nativitatis*), both forest-dependent species, became extinct between 2009 and 2014, but these species have not yet been formally noted as extinct in SPRAT so are not included as extinct in these tables. A total of 43 forest-dwelling vertebrate fauna species and 30 forest-dwelling flora species are known to have become extinct since European settlement.

Forests comprise 17% of Australia's land base (Table 1.1). The 1,420 listed threatened forest-dwelling taxa (Table 1.43) comprise 79% of Australia's total listed threatened taxa, with the proportion of taxa that are forest-dwelling varying from 72% for Critically Endangered taxa to 83% for Vulnerable taxa (Table 1.44). All threatened amphibians and Critically Endangered mammals are forest-dwelling, as is the one non-vascular plant and the fish species listed as 'Extinct in the wild'. A total of 71% of threatened vertebrate fauna species are forest-dwelling, as are 68% of threatened invertebrate fauna species. Forest-dwelling threatened vascular flora species represent 83% of threatened vascular flora species.

Forest-dependent species are species that require a forest habitat for at least part of their lifecycles. As at August 2016, 149 forest-dependent vertebrate fauna species, 28 forest-dependent invertebrate fauna species, 664 forest-dependent vascular flora species and the one non-vascular flora species, were listed as threatened under the EPBC Act. This totals 842 forest-dependent species.

Figure 1.23A–D shows the modelled number per hectare of listed threatened forest-dwelling and forest-dependent fauna and flora species across Australia (see Davey 2018c for

Table 1.43: Number of listed threatened forest-dwelling species and subspecies, by taxonomic group, 2016

	Threatened							
Taxonomic group	Extinct	Critically Endangered	Endangered	Vulnerable	Total	Non-threatened	Total taxa[a]	Proportion of taxa that are threatened (%)
Fish	1[b]	5	13	11	30	419	449	7
Amphibians	4	5	14	10	33	196	229	14
Reptiles	0	7	11	22	40	749	789	5
Birds	18	8	35	34	95	584	679	14
Mammals	20	6	33	50	109	264	373	29
Total vertebrates	**43**	**31**	**106**	**127**	**307**	**2,212**	**2,519**	**12**
Invertebrates	**0**	**22**	**9**	**7**	**38**	**–[d]**	**–**	**–**
Vascular plants[c]	**30**	**104**	**411**	**529**	**1,074**	**–[d]**	**–**	**–**
Non-vascular plants	**0**	**0**	**1**	**0**	**1**	**–[d]**	**–**	**–**
Total taxa	**73**	**157**	**527**	**663**	**1,420**	**–**	**–**	**–**
Proportion of total threatened forest-dwelling taxa	**5%**	**11%**	**37%**	**47%**	**100%**			

–, not available; n.a., not applicable.

[a] Taxa include species and subspecies. Under the EPBC Act, species are frequently listed at the subspecies level, and the total number of taxa presented here is thus slightly larger than that in Table 1.37, Indicator 1.2a.

[b] Pedder galaxid (*Galaxias pedderensis*) is listed as 'Extinct in the wild' to recognise captive populations and translocated populations outside of its natural range, and is grouped here under 'Extinct'. It was known to occur in the forested waterways of the edges of Lake Pedder and its tributaries before flooding from impoundments occurred in 1972.

[c] Threatened vascular plants include clubmosses, spikemosses, horsetails, ferns, gymnosperms (including conifers) and angiosperms (flowering plants).

[d] The total number of forest-dwelling invertebrate and plant species is unknown.

Notes:

Species are listed as threatened under the EPBC Act.

Species were determined to be 'forest-dwelling' (see Indicator 1.2a) if they were known to occur, were likely to occur or might possibly occur in vegetation types designated as being forest communities in the National Vegetation Information System, or were identified as forest-dwelling in National Forest Inventory datasets.

The application of the 'forest-dwelling' definition has changed slightly from previous SOFRs. Species that occasionally visit forests, or are transient in their visits to forests, are not included as forest-dwelling. For example, migratory listed waders that utilise mudflats fringing mangrove forest are not included. In addition, Lewin's Rail (western) (*Lewinia pectoralis clelandi*), an extinct bird, has continued to be excluded because of uncertainty over whether the wetlands where it was found in Western Australia were in forest.

Listed subspecies or races are reported as separate taxa. Orchidaceae taxonomy is being revised; where the Species Profile and Threats Database (SPRAT, www.environment.gov.au/cgi-bin/sprat/public/sprat.pl) has grouped subspecies/races of orchids, the classification used by the national authority (the Australian Plant Census, www.anbg.gov.au/chah/apc/) has been preferred and these subspecies/races are reported here as separate taxa.

Figures include species found on forested islands (Norfolk and Phillip, Lord Howe, Christmas, Cocos (Keeling), Tiwi and Bathurst (Northern Territory), Kangaroo (South Australia), King and Flinders (Tasmania) and the Torres Strait Island Group (Queensland)).

Source: Environmental Resources Information Network (ERIN) Species of National Environmental Significance database[72] and Species Profile and Threats Database (SPRAT), Australian Government Department of Environment and Energy; National Forest Inventory (NFI), ABARES datasets of extant and extinct native vertebrate forest fauna, vascular and non-vascular forest flora and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.44: Proportion of listed threatened species that are forest-dwelling, by taxonomic group (%), 2016

	Threatened category				
Taxonomic group	Extinct	Critically Endangered	Endangered	Vulnerable	Total
Fish	0	63	81	46	61
Amphibians	100	100	100	100	100
Reptiles	0	78	61	67	67
Birds	82	50	71	50	61
Mammals	74	100	87	78	81
Total vertebrates	**81**	**70**	**79**	**64**	**71**
Invertebrates	**0**	**88**	**47**	**64**	**68**
Vascular plants	**83**	**70**	**78**	**90**	**83**
Non-vascular plants	**0**	**0**	**100**	**0**	**100**
Total threatened taxa	**80**	**72**	**77**	**83**	**79**

Species are listed as threatened under the EPBC Act.

Notes: See notes for Table 1.43. Proportions are based on listed threatened taxa in the SPRAT database accessed at 01 August 2016 (495 fauna species, 1,299 flora species, totalling 1,794 threatened taxa). The database included seven threatened marine fish species classed as 'Conservation-dependent', and these were included in the total taxa numbers for fish, total vertebrates and total threatened taxa.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[72] www.environment.gov.au/science/erin/databases-maps/snes

methodology). The modelled number of listed forest-dwelling fauna species per unit area of forest is highest in the eastern coastal regions of Australia, the Great Dividing Range, and the Kakadu region of Northern Territory, while the modelled number of listed forest-dependent fauna species per unit area of forest is highest in coastal and hinterland areas in north Queensland. The modelled number of listed forest-dependent and forest-dwelling flora species per unit area of forest is highest in wetter coastal and hinterland areas in northern New South Wales and Queensland. These are all areas where species diversity is also high.

Threats and threat categories relating to forest fauna and flora

The individual threats specified in the listing statement for each threatened species were documented (up to six separate threats for each species), then ranked as primary, secondary or tertiary threats based on the emphasis given in the listing advice in regard to their impacts. Threats were then grouped into threat categories based on the methodology of Davey (2018c). The significance of a threat category was assessed on the basis of the number of species for which a threat in that category was specified, and whether that those specified threats were ranked as primary, secondary or tertiary threats.

Table 1.45 provides an assessment of primary, secondary and tertiary threats for all forest-dwelling listed threatened species, based on current listing advice. The proportions of total specified threats in each threat category was similar for both flora and fauna in 2011 (as reported in SOFR 2013) and in 2016 (as reported here).

Land-use change and forest loss caused by clearing for agriculture, grazing, urban and industrial development has been the most significant threat category for forest-dwelling fauna species, followed by predation from introduced predators (e.g. fox, cat, rat and trout). Other significant threat categories are mortality agents, population size and localised distribution, unsuitable fire regimes, and competition from introduced fauna (e.g. rabbits, house mouse, foxes, cats, rats, trout, pigs and goats, and domestic livestock). Disease and pathogens, indirect impacts of invasive species, hydrological changes, forestry operations and identified climatic effects are progressively less significant threat categories for forest-dwelling fauna.

Small population size and localised distribution is the most significant threat category for threatened forest-dwelling flora, followed by mortality agents and unsuitable fire regimes. Land-use change and forest loss, competition from introduced flora (primarily invasive and non-invasive weeds, and escaped pasture grasses), impacts of invasive species (e.g. rabbits, goats, pigs, buffalo and invasive weeds such as lantana and blackberry), and predation and grazing (primarily grazing by domestic livestock, rabbits and macropods) are also significant threat categories. Hydrological changes, disease and pathogens, climatic effects, and forestry operations are progressively less significant threat categories for forest-dwelling flora.

The threat category 'unsuitable fire regimes' includes infrequent fire, too frequent fire, wildfire, lack of management of fire and, for flora, inappropriate intensity of fire. Fire regimes are an intrinsic part of forest management activities and are applied widely across Australia's forests. Where fire is used in forestry operations and is an identified threat to a species, the species has been included under both the 'unsuitable fire regime' and the 'forestry operations' threat categories. However, forestry operations are not a significant threat category for threatened forest flora, compared with other identified threat categories.

Notes to Figures 1.23A–D (on the following pages):

Fauna include both vertebrate and invertebrate taxa. Flora include both vascular and non-vascular plants.

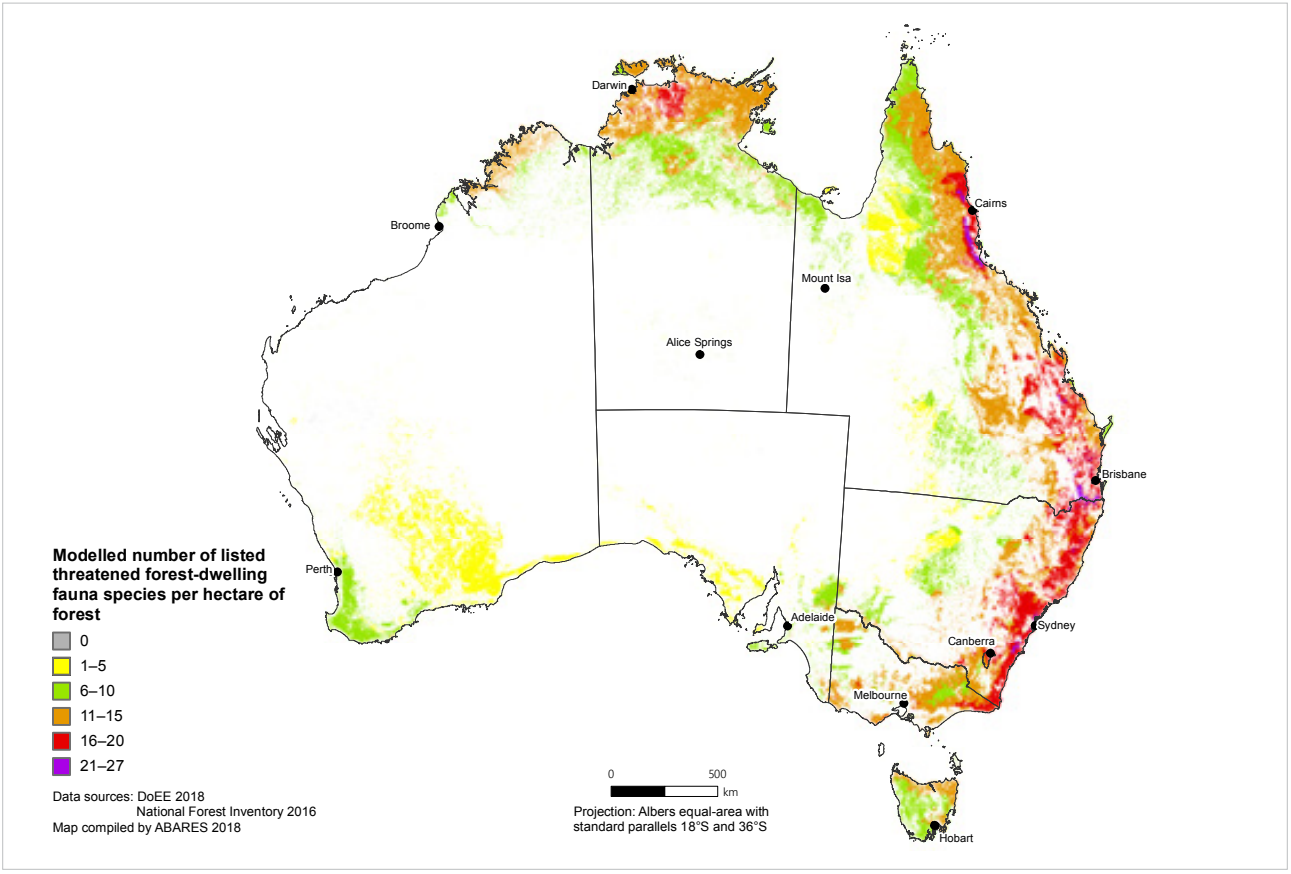
Species were determined to be forest-dependent if they are known to require, are likely to require, vegetation types designated as being forest communities in the National Vegetation Information System, or were reported as forest-dependent by national, state or territory agencies (see Indicator 1.2a).

The maps result from the intersection between the modelled potential extent of extant threatened species listed under the EPBC Act, and the 2016 forest extent (see Indicator 1.1a). The modelling of potential species extent was undertaken by the Environmental Resources Information Network (ERIN) within the Department of the Environment and Energy, and included areas where the species are known to occur, areas where they are likely to occur, and areas where they may occur. The number of species per hectare was calculated by summing the number of listed threatened species (flora or fauna, forest-dwelling or forest-dependent) in each hectare of forest (Davey 2018c). Extinct species were excluded.

Source: ERIN Species of National Environmental Significance Database[73] and National Forest Inventory (NFI).

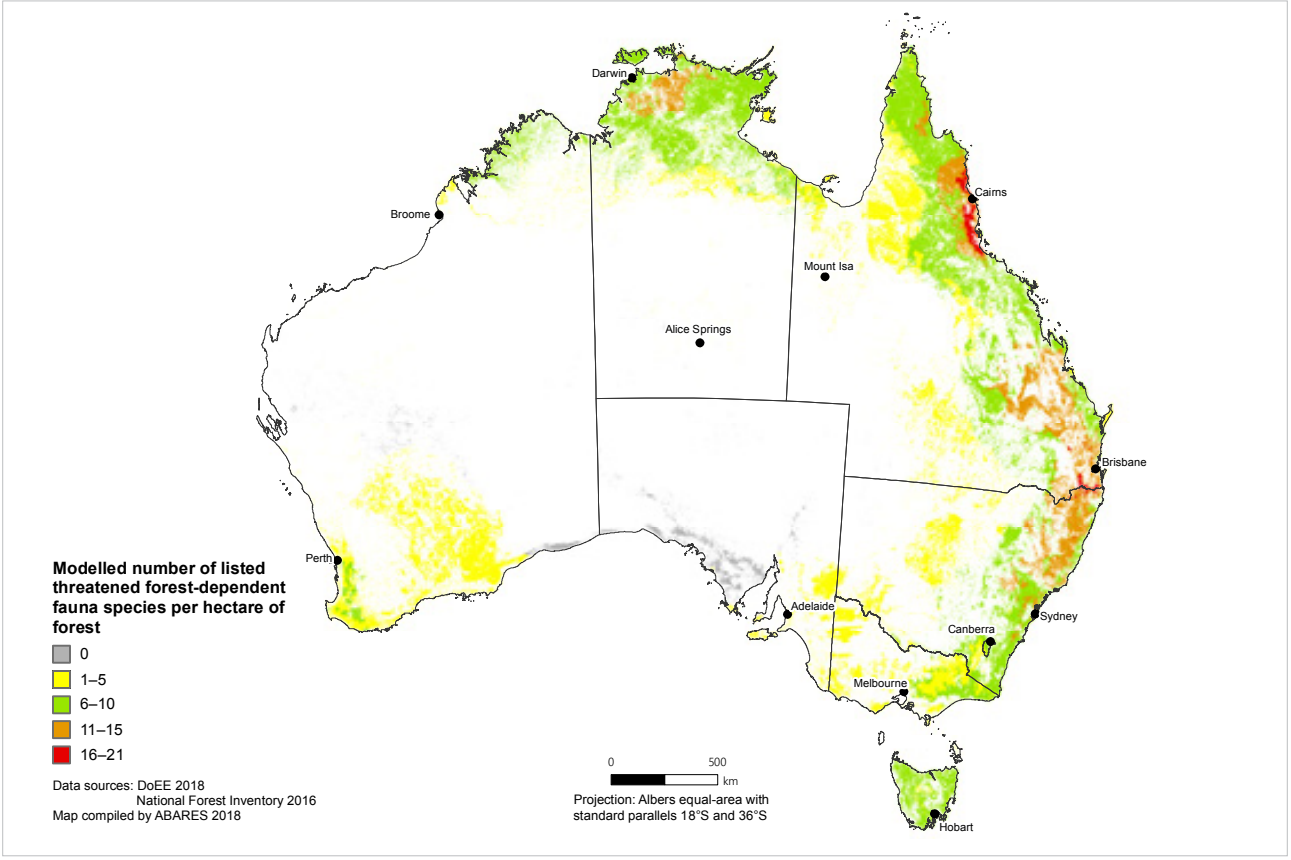
[73] www.environment.gov.au/science/erin/databases-maps/snes

Figure 1.23: Modelled distribution of listed threatened species. A forest-dwelling fauna.



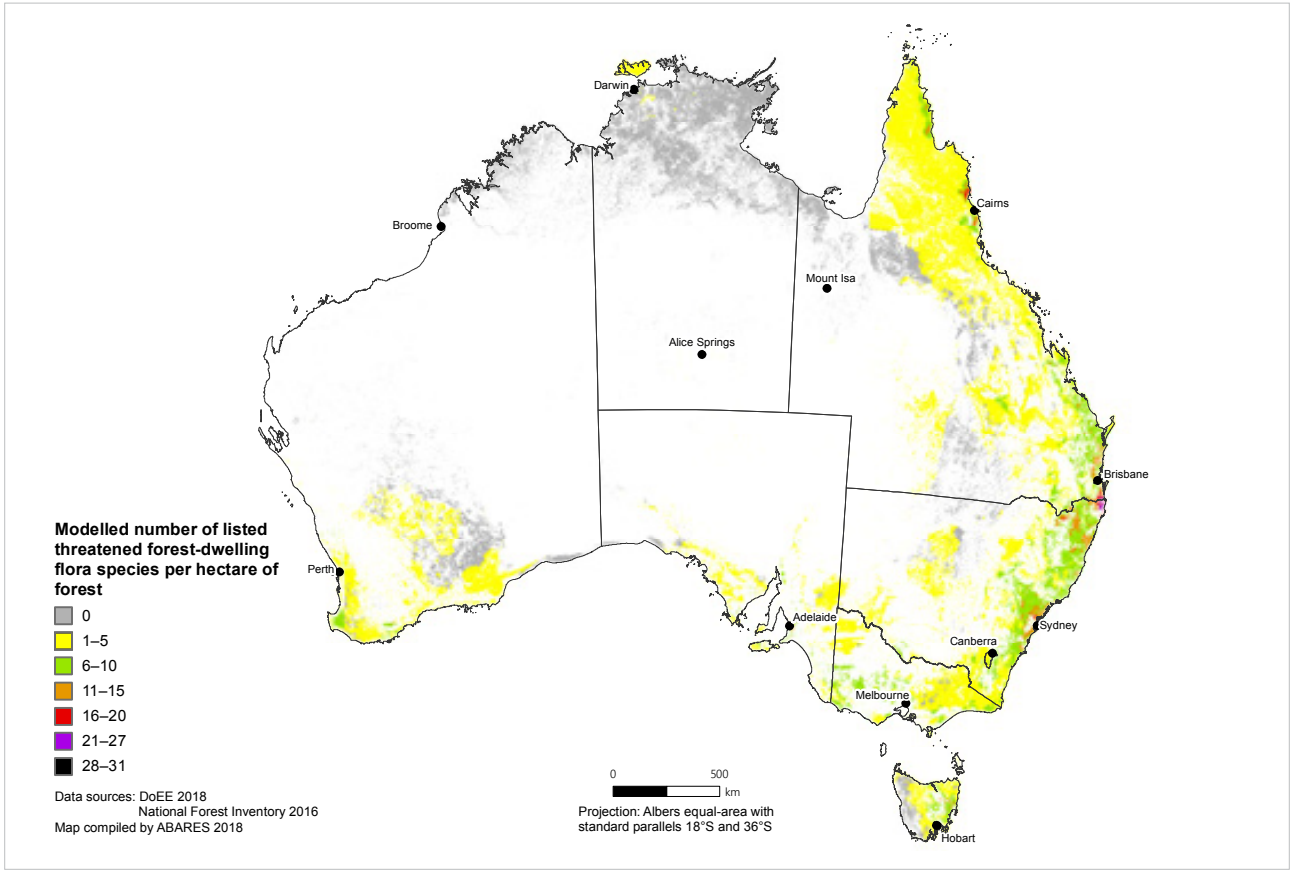
A higher resolution version of this map is available via www.doi.org/10.25814/5be3bc4321162
See notes on page 119.

Figure 1.23: Modelled distribution of listed threatened species. B forest-dependent fauna.



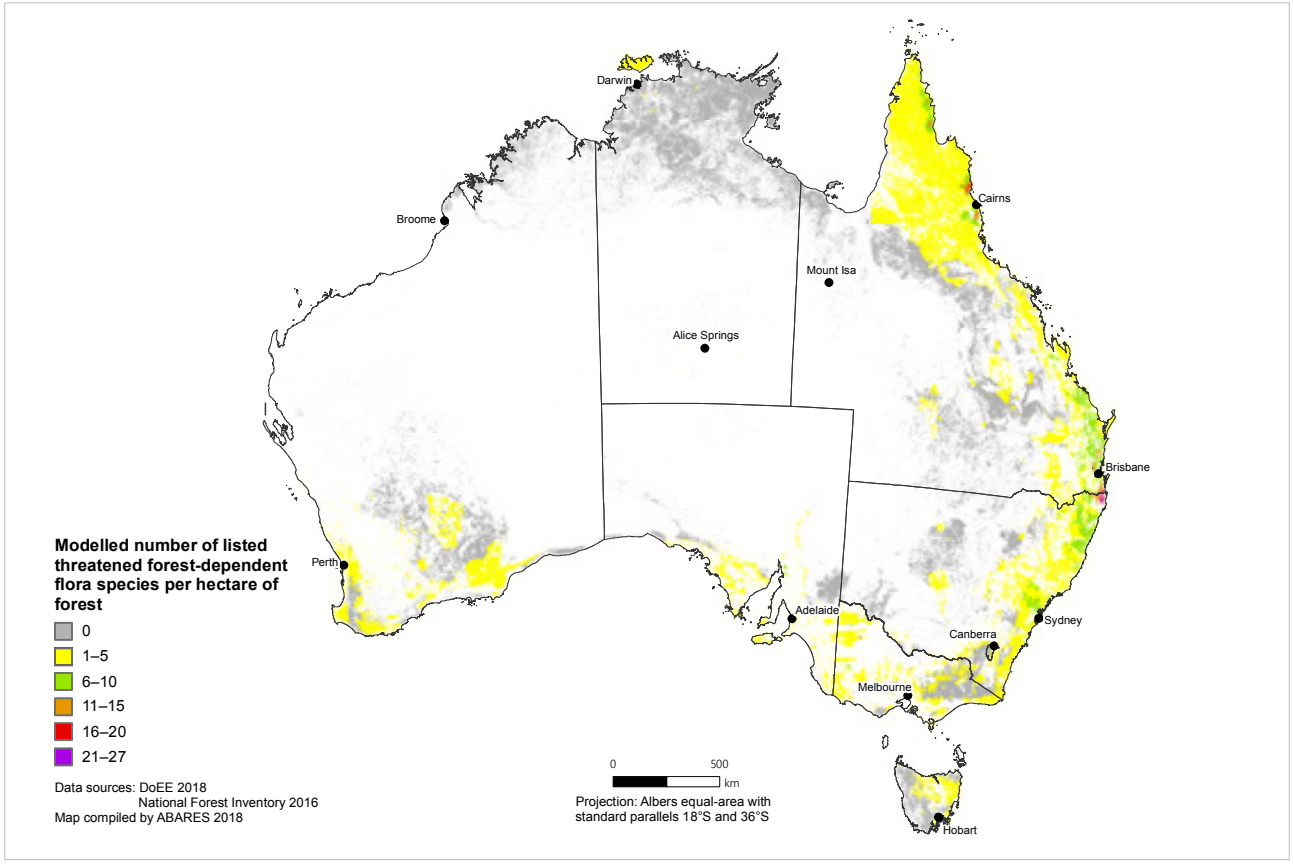
A higher resolution version of this map is available via www.doi.org/10.25814/5be3bc4321162
See notes on page 119.

Figure 1.23: Modelled distribution of listed threatened species. C forest-dwelling flora.



A higher resolution version of this map is available via www.doi.org/10.25814/5be3bc4321162
See notes on page 119.

Figure 1.23: Modelled distribution of listed threatened species. D forest-dependent flora.



A higher resolution version of this map is available via www.doi.org/10.25814/5be3bc4321162
See notes on page 119.

Table 1.45: Threat rating and threat categories for forest-dwelling threatened species, as at 2016

Threat category	Number of species for which a threat in that category was specified				Proportion of total specified threats (%)
	Primary threat	Secondary threat	Tertiary threat	Total	
Fauna (invertebrate and vertebrate)					
Land-use change and/or forest loss[a]	187	45	6	238	17
Predation by introduced fauna	107	58	40	205	15
Mortality agents[b]	71	60	30	161	12
Small or localised population	127	20	10	157	11
Unsuitable fire regime[c]	64	56	20	140	10
Competition from introduced fauna[d]	41	63	15	119	9
Indirect invasive species impacts[e]	32	46	13	91	7
Disease and/or pathogens	31	18	27	76	6
Hydrological change	38	22	10	70	5
Forestry operations[f]	29	24	11	64	5
Climatic effects[g]	13	32	15	60	4
Flora					
Small or localised population	628	193	17	838	15
Mortality agents[h]	493	226	8	727	13
Unsuitable fire regime[c]	410	277	17	704	13
Land-use change and/or forest loss[a]	481	144	1	626	12
Competition from introduced flora[i]	432	173	6	611	11
Invasive species impacts[e]	411	173	3	587	11
Predation and grazing[j]	418	137	5	560	10
Hydrological change	133	125	1	259	5
Disease and/or pathogens	72	142	13	227	4
Climatic effects[g]	60	117	1	178	3
Forestry operations[f]	64	73	11	148	3

[a] 'Land-use change and/or forest loss' includes forest conversion and forest clearing resulting from agriculture, mining operations, and urban and industrial development, but excludes plantation development.

[b] For fauna, 'mortality agents' include hunting, illegal collection, agricultural chemical poisoning, competition and predation from native fauna, road-kill, and genetic or breeding issues.

[c] An 'unsuitable fire regime' can include infrequent fire, too frequent fire, wildfire, lack of management of fire, and (for flora) inappropriate intensity of fire.

[d] 'Competition from introduced fauna' can include competition from Australian fauna introduced to a locality or where their range has extended to new habitats, or where their abundance has increased to a point where they are in unnatural competition (e.g. Noisy Miner).

[e] 'Invasive species impacts' (flora and fauna) include pest fauna and weeds where their invasive nature is emphasised in the listing and the invasive species is listed as a threatening process separately from 'novel biota'. The threat rating is based on the emphasis given to their impact as invasive species in the listing.

[f] 'Forestry operations' are operational forest management activities related to wood production, such as silviculture, harvesting, maintenance of forest roads and fire-trails, fire management relating to wood production, plantation operations and development, and indirect or off-site effects, including impacts of escaped plantation species.

[g] 'Climatic effects' include climate change, climate variability, drought, winds and cyclone impacts.

[h] For flora, 'mortality agents' include illegal collection, agricultural chemical poisoning, road pressures (e.g. mowing, maintenance of forest roads and fire-trails not associated with production forestry, such as reserve management and public roads), human pressures (e.g. dumping, recreational pressure, pressures from development at urban edges), competition from native flora, and genetic or breeding issues.

[i] 'Competition from introduced flora' includes competition from weeds, pasture plants and Australian flora introduced to a locality, but excludes impacts of escaped plantation species.

[j] 'Predation and grazing' includes grazing by introduced and native herbivores, and vertebrate predation of seeds or plants.

Notes:

Classification of threats into primary, secondary and tertiary threats is based on the emphasis given in the listing advice in regard to past and current threat impacts. Up to six separate threats were included for each species; the total number of threats is thus larger than the total number of threatened species.

Flora taxa include vascular plants and one non-vascular plant. Data presented for fauna and flora exclude species removed from the list previously reported in SOFR 2013. Where species listings have been updated during the reporting period, earlier listings of threats are excluded. Data current at 01 August 2016; 1,420 taxa records used grouped into 1,075 flora records and 344 fauna records (307 vertebrate and 38 invertebrate records).

Totals may not tally due to rounding.

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct native vertebrate forest fauna, vascular forest plants and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Changes in conservation status in reporting period

Since SOFR 2013, a number of changes have occurred in the national listing of threatened forest-dwelling species.

The conservation status of 106 listed threatened forest-dwelling species reported in SOFR 2013 (89 vascular flora species, 16 vertebrate fauna species, and one invertebrate fauna species) was amended during the SOFR 2018 reporting period (Table 1.46). Of these species, 17 were moved into a category corresponding to a higher level of threat, six were moved into a category corresponding to a lower level of threat, six were updated but remained in the same category, and 77 were removed from the list (Table 1.46).

All six forest-dwelling species that were moved into a category with a lower level of threat were vascular plants, three of which had previously been classified as Extinct and because of their rediscovery were relisted as Critically Endangered. Eight forest-dwelling vascular plant species were moved up in threat level due to progressive declines in already small populations attributed to mortality agents, pests and weed impacts, and further habitat loss or decline, with five species re-listed as Critically Endangered. Nine forest-dwelling vertebrate species (five birds, two frogs, a mammal and a reptile) were moved up in threat level, with seven of these re-listed as Critically Endangered. Increases in threat level for these nine vertebrates were attributed to continuing land-use change and forest loss, fire impacts, predation by introduced fauna, disease and mortality agents.

Impacts from forest operations were identified as primary threats in the re-listing as Critically Endangered of the Swift Parrot (*Lathamus discolor*), Regent Honeyeater (*Anthochaera phrygia*) and Leadbeater's possum (*Gymnobelideus leadbeateri*). In the case of the Regent Honeyeater, however, it is unclear how 'silviculture practice' (as specified in the listing statement) has resulted in a threat relating to fragmentation of its woodland landscape habitat. Case studies are included below for Swift Parrot (Case study 1.2) and Leadbeater's possum (Case study 1.3).

Of the 77 forest-dwelling species removed from the list, 70 were vascular plant species, six were vertebrate fauna species and one was an invertebrate fauna species (Table 1.47). Two plant and one vertebrate fauna species previously listed as Extinct were removed because of uncertainty about their taxonomic status. Most (59 species, 77% of the total) of the species removed were removed because of better information about their populations, distributions, ecology or threats, because their populations were considered no longer to be in decline, or because they no longer met the eligibility criteria for listing. The remaining 18 species (23% of the total) were removed because they were no longer scientifically recognised as a species as a result of taxonomic revisions (Table 1.48). Of the 77 species removed from the list, forestry operations had been listed as a threatening process for one vertebrate fauna species and seven flora species.

Over the SOFR 2018 reporting period, 68 forest-dwelling species were added to the national list of threatened species, comprising 33 vertebrate fauna species, 28 vascular flora species and seven invertebrate fauna species (Table 1.49). Species classed as Critically Endangered represented 41% (28 species) of the new listings. Other new listings were classed as Endangered (31%) or Vulnerable (28%) (Table 1.49). Newly listed invertebrate fauna and vascular flora species were predominately listed in the Critically Endangered and Endangered categories, including 14 orchids (52% of the new listings of vascular flora). The addition of a species to the national list of threatened species, or movement of a species to a higher risk category (e.g. from Vulnerable to Endangered), may result from a change in the actual threats to a species. However, changes in species ranking should be interpreted with caution, because many listings and de-listings reflect changes in information rather than changes in threat level. Addition of species to the national list of threatened species does give the opportunity to take additional steps to ensure the survival of the species, such as improvements in the management regime, or protection of additional habitat.

Most newly listed forest-dwelling fauna and flora species were added to the list of threatened species because of their small population size and/or restricted range, and threat categories

Table 1.46: Forest-dwelling species on the national list of threatened species with changed rating during the SOFR 2018 reporting period

Change in rating	Invertebrate	Vascular plants[a]	Vertebrate	Total
Transferred up in category	0	8	9	17
Transferred down in category	0	6	0	6
Updated but remained in category	0	5	1	6
Removed from list	1	70	6	77
Total	**1**	**89**	**16**	**106**

[a] Threatened vascular plants include clubmosses, spikemosses, horsetails, ferns, gymnosperms (including conifers) and angiosperms (flowering plants).

Notes:

Refer to notes in Table 1.43 for an explanation of the determination of forest-dwelling species, and for inclusion of data for species found on forested islands. Species added to the national list of threatened forest-dwelling species are given on Tables 1.49 and 1.50.

For these data, the reporting period for SOFR 2018 is January 2013 (when data collection for the corresponding table in SOFR 2013 ceased) to August 2016 (when data collection for this table ceased). The reporting period for SOFR 2013 was December 2007 to December 2012, and the reporting period for SOFR 2008 was January 2001 to December 2007.

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct vertebrate forest fauna, vascular forest plants and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.47: Forest-dwelling species removed from the national list of threatened species during the SOFR 2018 reporting period

Taxa	Extinct	Critically Endangered	Endangered	Vulnerable	Total
Vertebrate fauna	1	0	0	5	6
Invertebrate fauna	0	0	1	0	1
Vascular plants[a]	2	2	11	55	70
Total	**3**	**2**	**12**	**60**	**77**

[a] Threatened vascular plants include clubmosses, spikemosses, horsetails, ferns, gymnosperms (including conifers) and angiosperms (flowering plants).

Notes:

Refer to notes in Table 1.43 for an explanation of the determination of forest-dwelling species, and for inclusion of data for species found on forested islands.

For these data, the reporting period for SOFR 2018 is January 2013 (when data collection for the corresponding table in SOFR 2013 ceased) to August 2016 (when data collection for this table ceased).

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct vertebrate forest fauna, vascular forest plants and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.48: Reasons for the removal of forest-dwelling species from the national list of threatened species during the SOFR 2018 reporting period

Primary reason	Vertebrates	Invertebrates	Vascular Plants	Total	Proportion of total number delisted (%)
Revised taxonomy or no longer considered valid species	3	0	15	18	23
Improved knowledge base to justify change in status	0	0	20	20	26
No longer considered to be in decline	1	1	16	18	23
No identified threat	0	0	2	2	3
No longer meet current eligibility criteria	2	0	17	19	25
Total	**6**	**1**	**70**	**77**	**100**

Notes:

Refer to notes in Table 1.43 for an explanation of the determination of forest-dwelling species, and for inclusion of data for species found on forested islands.

For these data, the reporting period for SOFR 2018 is January 2013 (when data collection for the corresponding table in SOFR 2013 ceased) to August 2016 (when data collection for this table ceased).

For each delisted species, only one primary reason is given for delisting.

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct vertebrate forest fauna, vascular and non-vascular forest plants and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Table 1.49: Forest-dwelling species added to the national list of threatened species during the SOFR 2018 reporting period

Taxa	Extinct	Critically Endangered	Endangered	Vulnerable	Total
Vertebrate fauna	0	8	10	15	33
Invertebrate fauna	0	3	3	1	7
Vascular plants[a]	0	17	8	3	28
Total	**0**	**28**	**21**	**19**	**68**

[a] Threatened plants include clubmosses, spikemosses, horsetails, ferns, gymnosperms (including conifers) and angiosperms (flowering plants).

Notes:

Refer to notes in Table 1.43 for an explanation of the determination of forest-dwelling species, and for inclusion of data for species found on forested islands.

For these data, the reporting period for SOFR 2018 is January 2013 (when data collection for the corresponding table in SOFR 2013 ceased) to August 2016 (when data collection for this table ceased).

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct vertebrate forest fauna, vascular forest plants, and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

relating to land clearing (agricultural and urban), mortality agents, unsuitable fire regimes, predation, grazing and invasive species impacts (Table 1.50). Threats or impacts from land-use change were a primary reason in 78% of new listings of forest-dwelling fauna, related primarily to agricultural and urban development, and land clearing not associated with forestry operations. Predation of fauna by introduced species, and unsuitable fire regimes, were identified as a primary threat category in 53% and 50% of the new fauna listings, respectively. Mortality agents, and small or localised populations, were primary threat categories for 45% and 40% of new listings of forest-dwelling fauna, respectively.

Threats in the categories of small or localised population, and mortality agents, were identified as primary threats for

Table 1.50: Species added to the national list of forest-dwelling threatened species during the SOFR 2018 reporting period, and categories of primary threats given as reasons for listing

Fauna species added to the national list of forest-dwelling threatened species						
Listing category	**Extinct**	**Critically Endangered**	**Endangered**	**Vulnerable**	**Total**	**Proportion of new listings (%)**
Number of added fauna species (vertebrate and invertebrate)	**0**	**11**	**13**	**16**	**40**	**100**
Category of primary threat[a]	**Number of added species for which primary threat in that category was specified[a]**					**Proportion of new listings with primary threat in this category (%)**
Land-use change and/or forest loss	0	9	7	15	31	78
Predation by introduced fauna	0	5	9	7	21	53
Unsuitable fire regime	0	2	8	10	20	50
Mortality agents	0	7	5	6	18	45
Small or localised population	0	7	4	5	16	40
Indirect invasive species impacts	0	3	3	7	13	33
Competition from introduced fauna	0	2	1	8	11	28
Climate effects	0	3	1	5	9	23
Hydrological change	0	4	1	2	7	18
Forest operations[b]	0	1	1	2	4	10
Disease and/or pathogens	0	1	1	1	3	8
Flora species added to the national list of forest-dwelling threatened species						
Listing category	**Extinct**	**Critically Endangered**	**Endangered**	**Vulnerable**	**Total**	**Proportion of new listings (%)**
Number of added flora species (vascular and non-vascular plants)	**0**	**17**	**8**	**3**	**28**	**100**
Category of primary threat[a]	**Number of added species for which primary threat was specified[a]**					**Proportion of new listings with this primary threat (%)**
Small or localised population	0	16	3	2	21	75
Mortality agents	0	13	4	3	20	71
Land-use change and/or forest loss	0	11	5	2	18	64
Invasive species impacts	0	12	2	2	16	57
Predation and grazing	0	11	2	2	15	54
Unsuitable fire regime	0	7	1	0	8	29
Hydrological change	0	5	1	1	7	25
Forest operations[b]	0	4	1	2	7	25
Competition from introduced flora	0	2	1	1	4	14
Disease and/or pathogens	0	0	3	1	4	14
Climate effects	0	0	1	0	1	4

[a] More than one primary threat may affect a species. Primary threats are described in footnotes to Table 1.45.

[b] 'Forestry operations' include silviculture, harvesting, forest roading, fire management and its effect, plantation operations and development, and indirect or off-site effects, including escaped plantation species.

Source: ERIN Species of National Environmental Significance Database and SPRAT database; National Forest Inventory (NFI), ABARES datasets of extant and extinct native vertebrate forest fauna, vascular forest plants and invertebrate forest fauna.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

listing in 75% and 71% of new listings of forest-dwelling flora species, respectively. Mortality agents were predominately human pressures (road maintenance, mowing, illegal collection, recreation, and chemical use) and genetic reasons. Land-use change and habitat loss was a primary reason in 64% of new flora listings; again, this related to agricultural and urban development and land clearing not associated with forestry operations. Threats in the categories invasive species impacts, and predation and grazing, were identified as primary threats in 57% and 54% of new listings of forest-dwelling flora, respectively (Table 1.50).

Forest operations were identified as primary threats in 10% (four species) of new listings of forest-dwelling fauna species, and 25% (seven species) of new listings of forest-dwelling flora species (Table 1.50).

- The four forest-dwelling fauna species were two invertebrates (*Micropathus kiernani* and *Oreixenica ptunarra*), the greater glider (*Petauroides volans*) and the Painted Honeyeater (*Grantiella picta*). In addition, forest operations were identified as a secondary threat in the listing of the mainland subspecies of the broad-toothed rat (*Mastacomys fuscus mordicus*).
- Of the seven newly listed forest-dwelling flora species for which forest operations were identified as a primary threat, four were orchids (*Corunastylis insignis*, *C.* sp. *Charmhaven* (NSW 896673), *Thelymitra adorata* and *T. hygrophila*). The other three species were a tree (*Eucalyptus macarthurii*), a shrub (*Pomaderris pilifera* subsp. *talpicutica*) and a spikemoss (*Selaginella andrewsii*). Three new listings of forest-dwelling flora had forestry operations listed as a secondary threat, namely two orchids (*Prasophyllum innubum* and *P. keltonii*) and a shrub (*Pomaderris vacciniifolia*).

Three case studies on individual threatened species are provided below on:

- the breeding success of the Swift Parrot (*Lathamus discolor*), and predation by the introduced (to Tasmania) sugar glider (*Petaurus breviceps*) (Case study 1.2)
- new approaches to survey and conservation of Leadbeater's possum (*Gymnobelideus leadbeateri*) (Case study 1.3), and
- detecting the presence of the black-footed tree-rat (*Mesembriomys gouldii*) in the Northern Territory (Case study 1.4).

Further case studies on threatened species are provided in Indicator 1.2c (Case study 1.7, reporting on monitoring the koala in New South Wales and Queensland) and in Indicator 1.3a (Case study 1.10, describing the conservation of four listed *Macadamia* species of importance to the horticultural industry).

Threatened ecological communities

At August 2016, the EPBC Act listed 76 threatened ecological communities, of which 41 are forest communities or contain significant proportions of forest. Three threatened ecological communities that are non-forest communities, but contain small proportions of forest, are not included in this total of 41 threatened forest communities. Threatened forest communities thus represent 54% of threatened ecological communities listed under the EPBC Act. This is an increase of 14 ecological communities from the 27 listed threatened ecological communities that contain forest reported in SOFR 2013, and is due to new listings.

Of the 41 listed threatened ecological communities that contain forest, 22 are Critically Endangered, 18 are Endangered and one is Vulnerable (Table 1.51).

Nine newly listed Critically Endangered ecological communities contain forest, as do four newly listed Endangered ecological communities (Table 1.51). In addition, one Endangered ecological community that included only small proportions of forest and that was not included as a threatened forest community in SOFR 2013 was included in SOFR 2018 based on reconsideration of information. These newly listed or newly included forest-containing ecological communities are found in New South Wales, South Australia, Victoria and Western Australia. Clearing resulting from agriculture, urbanisation, peri-urban development and mining, and consequential fragmentation, were the main reasons for all the new listings. Weeds, grazing by domestic stock, native animals and feral herbivores, and changed fire regime impacts including bushfires, were also identified as threats in all new listings.

Twenty-five threatened forest ecological communities occur in New South Wales, 12 in Queensland, eight in Victoria and six in Western Australia; the other states and territories each have five or fewer (Table 1.51). Figure 1.24 presents the

Table 1.51: Number of forest ecological communities listed under the EPBC Act, by jurisdiction

	Critically Endangered		Endangered		Vulnerable		Total	
Jurisdiction	SOFR 2013	SOFR 2018	SOFR 2013	SOFR 2018	SOFR 2013	SOFR 2018	SOFR 2013	SOFR 2018
ACT	1	1	0*	0	0	0	1*	1
NSW	8*	15	9*	10	0	0	17*	25
NT	0	0	1	1	0	0	1	1
Qld	6	6	6*	6	0	0	12*	12
SA	1*	2	2*	3	0	0	3*	5
Tas.	0	0	0	0	1	1	1	1
Vic.	4*	5	3	3	0	0	7*	8
WA	0	1	3	5	0	0	3	6
Australia	**13**	**22**	**14***	**18**	**1**	**1**	**28***	**41**

* Correction to numbers misreported in SOFR 2013.

Notes:

Data are current as at 01 August 2016, and are based on distribution information in the listing advice for each ecological community. Individual listed ecological communities can occur in one or more state or territory, so the figures for Australia are not the sum of the figures for individual jurisdictions.

Source: ERIN Communities of National Environmental Significance Database and listing data, www.environment.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl; National Forest Inventory (NFI), ABARES datasets of threatened ecosystems.

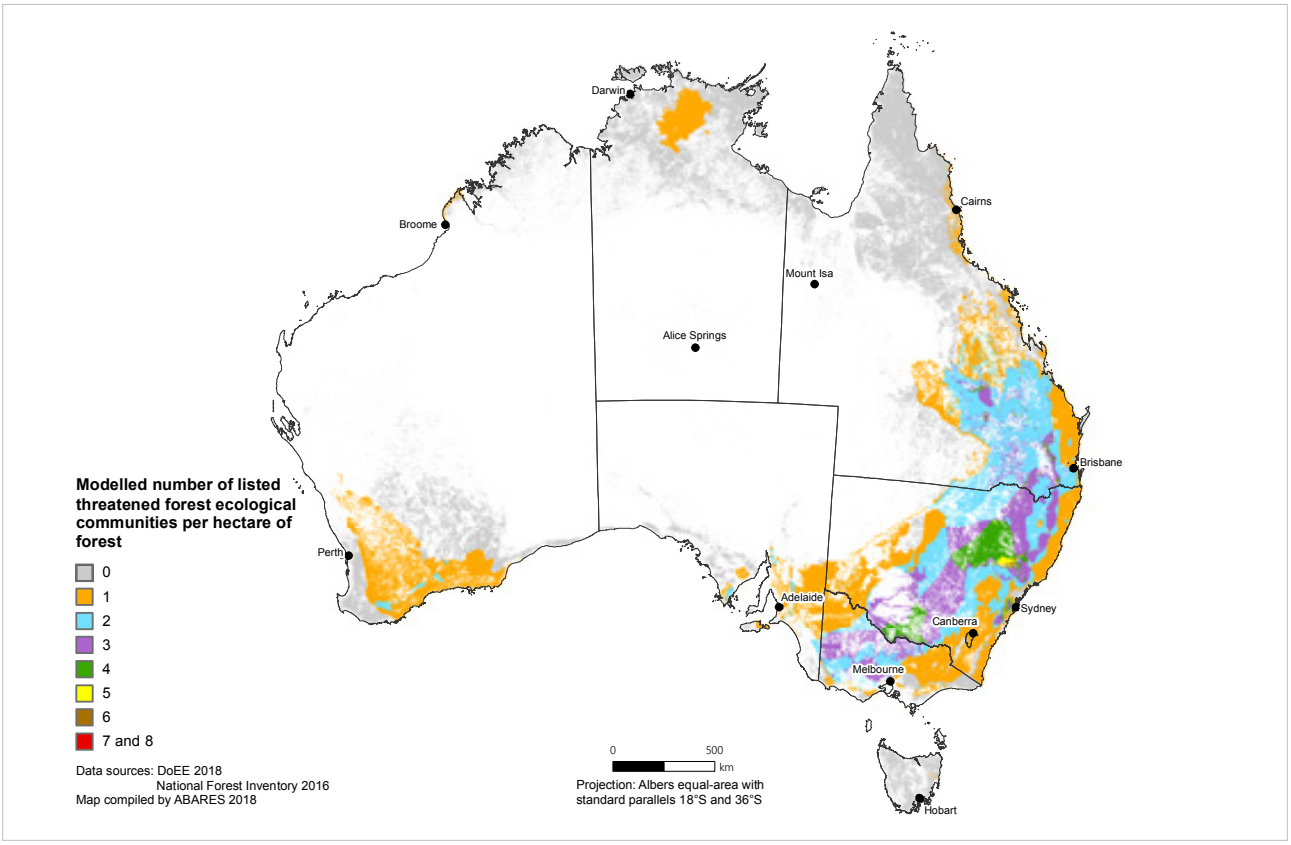
This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

modelled potential distribution of threatened forest ecological communities, shown as the number of listed threatened forest ecological communities that could occur in each unit area[74].

The threat categories for the historical and current threats listed for these 41 threatened forest ecological communities, based on listing and policy statements, are summarised in Table 1.52. Weeds, forest loss through agricultural clearance, grazing pressure (primarily by stock and macropods), fire (inappropriate fire management or inappropriate fire regimes) and fragmentation are each given as threats (reasons for listing) for 76% or more of the threatened forest ecological communities listed. Feral animal pressures, impacts of hydrological change, climatic impacts (drought and climate change) and forest loss through urbanisation are identified in more than half of the listings. Human pressures, including urban fringe impacts (rubbish, recreation pressure, roading impacts and poor management) and pollutants each appear in 51% or more of the listings. Diseases including dieback syndromes are identified in 41% of listings. Forestry operations appear in 32% of the listings (13 listings), with eight of the 13 referring to historical wood production operations in native forests, five referring to current forestry activities, two referring to plantation establishment, and one (the 'Brigalow (*Acacia harpophylla*) dominant and co-dominant ecological community'; Commonwealth of Australia 2013a) identifying current forest practice as a less significant threat primarily on private land[76].

States and territories have commenced regional studies on assessing strategies to manage cumulative impacts of threats, and on how best to implement strategies to manage these impacts on forest-dwelling threatened species and threatened forest ecological communities. An example is the study of threatened species and ecological communities in Queensland's brigalow forests, of which only 9% of its original 7 million hectares remain as small isolated remnants as a result of agricultural clearing and development since European settlement (Ponce Reyes et al. 2016).

Figure 1.24: Modelled distribution of listed threatened forest ecological communities



Note: the map results from the intersection between the modelled potential extent of threatened ecological communities listed under the EPBC Act and the 2016 forest extent (see Indicator 1.1a). The modelling of the extent of potential communities was undertaken by ERIN (Australian Government Department of the Environment and Energy) and included areas where the communities are known to occur, areas where they are likely to occur, and areas where they may occur. The number of communities per hectare was calculated by summing the number of listed threatened communities in each hectare of forest. Some threatened ecological communities are restricted in extent and cannot readily be visualised at the scale of this map. This map has been compiled from datasets with a range of scales and quality, and is therefore indicative only and not meant for local assessment.

This modelled distribution of listed communities may differ from state and territory reporting based on more detailed regional ecosystem maps and community surveys.

Source: ERIN Communities of National Environmental Significance Database[75], National Forest Inventory (NFI).

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

[74] Caveats are associated with maps of listed threatened ecological communities (see www.environment.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl).

[75] www.environment.gov.au/science/erin/databases-maps/ecnes

[76] Ecological communities may have more than one type of forestry activity listed as a threat.

Table 1.52: Threats to threatened forest ecological communities listed under the EPBC Act

Category of threat (historical and current)[a]	Number of listed communities for which a threat in that category was specified	Proportion of threatened forest ecological communities with a threat in that category (%)
Weeds[b]	38	93
Forest loss – agriculture[c]	37	90
Grazing pressures[d]	33	80
Fire pressures[e]	33	80
Fragmentation[f]	31	76
Feral animals[b]	28	68
Hydrological change[g]	25	61
Climatic impacts[h]	24	59
Forest loss – urbanisation[c]	21	51
Human pressures[i]	19	46
Disease[j]	17	41
Forestry operations[k]	13	32
Loss of ecological function[l]	9	22
Isolation – disconnection[f]	6	15
Small remnants[f]	6	15
Forest loss – mining[c]	6	15

[a] Threats to ecological communities were grouped into threat categories based on thematic grouping or key words found in threat descriptions. Descriptions of threatened forest communities reported in SOFR 2013 have been updated to accord with this approach. More than one threat may be given for an ecological community. The analysis was performed on the 41 forest ecological communities identified on Table 1.51.

[b] Threats due to pests and weeds were identified on 38 occasions, and are here listed in two categories, 'weeds' and 'feral animals'.

[c] Threats due to forest loss (forest conversion and forest clearing) were identified for 39 threatened ecological communities, and have been listed in three categories: 'agriculture', 'urbanisation' (urban and industrial development) and 'mining' based on the use of these key words. Plantation conversion and development is included in the threat category 'forest operations'.

[d] The threat category 'Grazing pressures' includes grazing by native animals, domestic stock, rabbits and feral stock.

[e] The threat category 'fire pressures' includes wildfire, deliberate fire (arson), hazard reduction burning, lack of fire and altered fire regimes associated with intensity, frequency, seasonality and patchiness of historical fire regimes.

[f] Threats relating to very small or fragmented ecosystems were identified for 34 threatened ecological communities; 'fragmentation', 'isolation-disconnection' and 'small remnants' were identified as categories using key words. Fragmentation is associated with the loss of spatial connectivity between forest areas. Isolation-disconnection groups threats to ecosystems where fragmentation or configuration of remnants was affecting the viability of the ecosystem. The threat category 'small remnants' identifies ecosystems where only small proportions of the ecosystem remain as remnants.

[g] The threat category 'Hydrological change' includes threats to ecosystems that cover salinity, flooding, changed drainage, acidification, reduced stream flow, and changes in water table and aquifers.

[h] The threat category 'Climatic impacts' includes threats due to climate change impacts, increases in incidence, duration or intensity of droughts, and storm or cyclonic damage.

[i] The threat category 'Human pressures' includes threats from inappropriate use of chemicals and machinery, road maintenance, recreation impacts, firewood collection, frequent human disturbance and rubbish dumping.

[j] The threat category 'Disease' covers threats such as disease agents, risks and syndromes including identified and unidentified disease, dieback (rural, insect derived, Bell Miner, and phytophthora dieback syndromes), and risk of disease from phytophthora and myrtle rust.

[k] The threat category 'Forestry operations' includes threats associated with the forest industry such as silviculture, harvesting, forest roading, fire management and its effect, plantation operations and development, and indirect or off-site effects, including escaped plantation species. Harvesting, thinning or logging on private forest land is included as a forestry operation. It does not include forest management and operations not associated with the forest industry, such as firewood collection, park management and maintenance of public road networks (such threats are included in 'human pressures').

[l] The threat category 'Loss of ecological function' includes degradation resulting in changing fauna and flora composition affecting the integrity of the ecosystem, and identified loss in ecosystem processes and functions.

Source: ERIN Species of National Environmental Significance Database, www.environment.gov.au/science/erin/databases-maps/snes; National Forest Inventory (NFI), ABARES datasets of threatened ecosystems. Data current at 01 August 2016.

This table, together with other data for Indicator 1.2b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Case study 1.2: Breeding success of the Swift Parrot (*Lathamus discolor*) and effects of predation by sugar gliders (*Petaurus breviceps*)

The Swift Parrot (*Lathamus discolor*, Figure 1.25) is a small, largely nectar-feeding, fast-flying parrot which spends its winter in south-eastern mainland Australia before migrating to Tasmania in late winter/early spring to breed. This species was listed as Vulnerable under the Commonwealth *Endangered Species Protection Act 1992* and the Tasmanian *Threatened Species Protection Act 1995*, and was up-listed to Endangered at the commencement of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and under the Tasmanian *Threatened Species Protection Act 1995* in 2000 due to small population size and loss of habitat. In 2016 the species was up-listed to Critically Endangered under the EPBC Act, following evidence of significant population declines as a result of nest predation, primarily by sugar gliders (*Petaurus breviceps*) which were introduced into Tasmania from Victoria at some point after 1835 (Campbell et al. 2018).

Nectar from Tasmanian blue gum (*Eucalyptus globulus*) and black gum (*E. ovata*) flowers is the primary food source for the Swift Parrot during its breeding season. Flowering is variable in space and time, and at any one locality it may be more than five years between significant flowering events (Stojanovic et al. 2015). Swift Parrots breed primarily in eastern Tasmania but breeding has also been recorded in isolated areas in northern Tasmania (Figure 1.26). Swift Parrots breed in tree hollows in mature eucalypts up to about 5 km from their foraging areas. They typically nest in large groups (e.g. up to 40 to 50 nests) covering large areas (~100 ha). Research by the Australian National University (ANU) has found that Swift Parrots prefer tree hollows with characteristics (e.g. a small entrance diameter and a deep cavity) that help to exclude predators by physically preventing access to the nest chamber (Stojanovic et al. 2012).

Early attempts to assess the population of breeding birds in Tasmania estimated 1,320 pairs (Brown 1989). Another survey, carried out during the 1995–96 breeding season following initial listing of the species, estimated 940 pairs. During the breeding seasons from 1999 to 2004, fixed-stationary observer techniques were used at 55 sites to estimate the density of Swift Parrots across the range of dry, grassy blue gum forest in eastern Tasmania (Saunders et al. 2010). More comprehensive breeding season surveys from 2004 to 2014 provided information on the annual variation in the spatial characteristics of breeding events. These surveys also confirmed the importance of wet forest habitats for breeding (Webb 2008). Surveys continued over the 2014–15, 2016–17 and 2017–18 seasons by researchers from the ANU as part of a project funded by the Australian

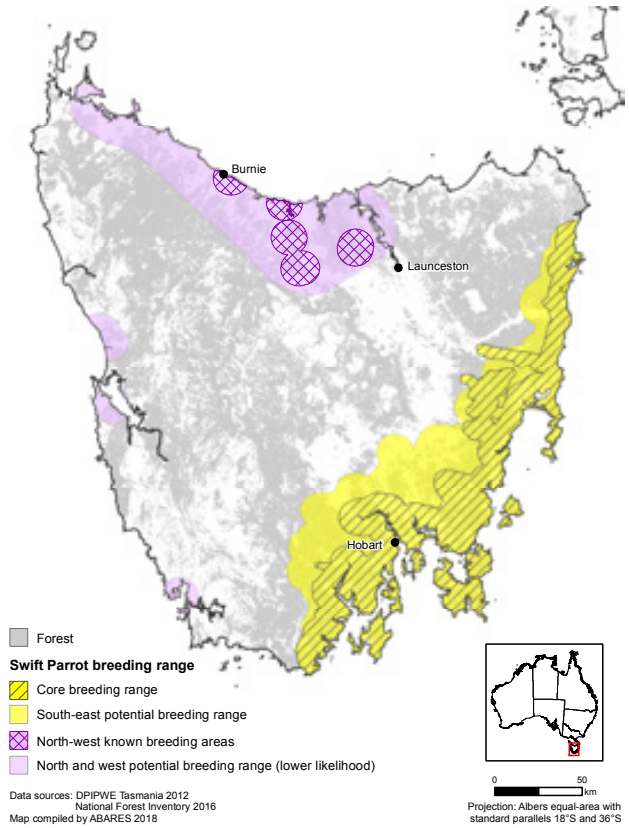
Figure 1.25: Male Swift Parrot (*Lathamus discolor*)

Dejan Stojanovic

Continued

Continues

Figure 1.26: Swift Parrot breeding range



Note: Map shows the potential breeding range of the Swift Parrot in Tasmania, based on current information. The breeding range is divided into the core breeding range (the area, within the south-east potential breeding range, thought to be of highest importance for the maintenance of breeding populations), the south-east potential breeding range (areas in the south-east of Tasmania where breeding could occur based on the occurrence of breeding habitat and foraging habitat), north-west known breeding areas (sites in the north-west of Tasmania where nest sites are known to occur), and the north and west potential breeding range (areas in the north-west of Tasmania where breeding could occur based on the occurrence of small breeding habitat and foraging habitat, but is less likely to occur than areas in the south-east).

Source: SOFR 2013, National Forest Inventory (NFI), Tasmania Department of Primary Industries, Parks, Water and Environment; adapted from FPA and Threatened Species Section (DPIPWE) (2012).

Research Council. The results confirm clustering of breeding birds in discrete parts of their overall range driven by flowering patterns in a particular season (Webb et al. 2014; Stojanovic et al. 2015; Webb et al. 2017). In some years the area available for breeding was limited due to poor and localised flowering (Webb et al. 2017).

Historically, loss and alteration of habitat as a result of land clearing, forestry activities and wildfire was recognised as the main threat to the species. However, recently ANU researchers found that nest predation by the introduced sugar glider is also a major threat to the Swift Parrot (Stojanovic et al. 2014; Heinsohn et al. 2015), and that predation rates increase with increasing habitat loss and fragmentation (Stojanovic et al. 2014). Predation risk varies dramatically across the breeding range of Swift Parrots, depending on the presence of sugar gliders, and may have contributed to significant declines in the Swift Parrot population in recent years. Population Viability Analysis modelling suggests declines of >80% within a three-generation period (12–18 years) (Commonwealth of Australia 2016a).

Conservation efforts for Swift Parrots in forests outside of Tasmania's formal reserve system have evolved over the past 20 years with the increasing knowledge of the habitat requirements of the species. Conservation actions taken to mitigate impacts of forestry activities on the Swift Parrot vary according to the location (e.g. whether in an area known to be important for breeding), the type of forestry operation, and the local availability of breeding habitat for the species. Conservation actions include protection of known nest sites, pre-harvest surveys for breeding habitat, and exclusion from harvesting plans of nesting and foraging habitat in areas important for breeding. Forest planners also undertake training in the ecology, identification and management of Swift Parrots and their habitat. There has been increasing recognition of the need to account for the spatiotemporal variation in the availability of breeding habitat, and that there may be several years between use of a particular site by the species. Strategic conservation planning at the landscape level aims to ensure that adequate nesting habitat and foraging habitat is available to support the breeding population of Swift Parrots in any one year.

Recent conservation work has also focused on efforts to reduce predation by the sugar glider at nesting locations. The ANU research team is testing a range of nest protection approaches. Swift Parrots readily utilise nest boxes, and a network of nest boxes has been set up across the breeding range of the species, with devices designed to

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exclude or repel sugar gliders attached to some of these nest boxes. Such devices include mechanical doors affixed to the entrance, with a motor operated by an ambient light switch set to open during daylight hours and close at night. Preliminary results show that the resident nesting birds are not affected by such devices.

A Recovery Plan for the species has been in place since 1997. The current National Recovery Plan for the Swift Parrot was adopted in 2011 (Saunders and Tzaros 2011).

A new Swift Parrot recovery plan is being developed that will include conservation actions to reverse the trajectory of decline for this species, and address the recently recognised threat from sugar gliders. The primary actions will be to protect, as much as possible, existing breeding habitat and foraging habitat in high-risk areas, and to develop and implement strategies to reduce predation from sugar gliders.

Case study 1.3: Targeted surveys to improve conservation of Leadbeater's possum (*Gymnobelideus leadbeateri*)

Leadbeater's possum (*Gymnobelideus leadbeateri*, Figure 1.27) is a small arboreal possum found only in Victoria, where it is largely confined to the montane ash forests of the Central Highlands Regional Forest Agreement region, north-east of Melbourne. It was thought to be extinct after it disappeared from the few locations where it had been initially recorded, mostly around Western Port Bay, between 1867 and 1915. However, the species was rediscovered near Marysville in 1961, and has since attracted considerable community interest, being one of Victoria's faunal emblems. Leadbeater's possum is listed as Critically Endangered under the EPBC Act.

Key habitat requirements for Leadbeater's possum include large trees with hollows that are used as den sites, and a dense understorey or midstorey that provides both food and movement pathways. There are a range of threats to the species and its habitat. Extensive bushfires over the last century have changed the age structure of the montane ash forest, as ash trees are frequently killed by high-intensity fires, resulting in even-age regrowth forests. Fire-killed trees provide den sites, however those remaining from the 1939 bushfires are collapsing, leading to a shortage of suitable hollows in many areas (Lindenmayer et al. 2012). In addition to changing the forest structure, bushfires can cause mortality directly. Approximately one-third of the range of the species burnt during extensive bushfires in 2009, with subsequent surveys revealing that Leadbeater's possum had disappeared from most burnt areas, irrespective of fire intensity (Lindenmayer et al. 2013; Lumsden et al. 2013). Loss of critical habitat resources as a result of wood harvesting is also a threat to Leadbeater's possum, and about one-third of its potential habitat across the Central Highlands RFA region is available for wood harvesting (LPAG 2014a).

In 2014, in response to these threats to the species, the Leadbeater's Possum Advisory Group (LPAG) made 13 recommendations to support the recovery of the species, while maintaining a sustainable forest industry (LPAG 2014b). One of the key recommendations was to establish a timber harvesting exclusion zone of 200 m radius around all verified records of the species from 1998 onwards, to protect colonies and surrounding habitat. LPAG also recommended extensive targeted surveys be undertaken to rapidly locate more colonies for protection from timber harvesting. This required the development of an efficient, reliable and effective survey method to sample across the range of the species.

Automated cameras had been extensively used for ground-based surveys; however, they had rarely been used to survey arboreal mammals. The Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning[77], Victoria (ARI) designed surveys for Leadbeater's possum using cameras, and worked with arborists to install the cameras in trees, using creamed honey as a lure. Cameras were set on tree trunks at varying heights up to 47 m, targeting areas of well-connected vegetation where Leadbeater's possum were most likely to be moving or foraging. This approach was highly effective, and it was calculated that the method had a greater than 85% chance of detecting the species if it was were present at a site (Nelson et al. 2017).

ARI surveyed 438 sites between 2014 and 2017 using this method. In the first two years, surveys were very targeted, focusing on areas of State forest predicted to be more likely to contain Leadbeater's possum. These surveys were very successful, with Leadbeater's possum detected at 149 sites (52% of the sites surveyed; Nelson et al. 2017; Figure 1.28). While this approach maximised the likelihood of detecting the possums, due to the spatially targeted nature of the sampling it limited extrapolation of the occurrence of the species to other areas. In the third year, an alternative

[77] Until January 2015, the Department of Environment and Primary Industries.

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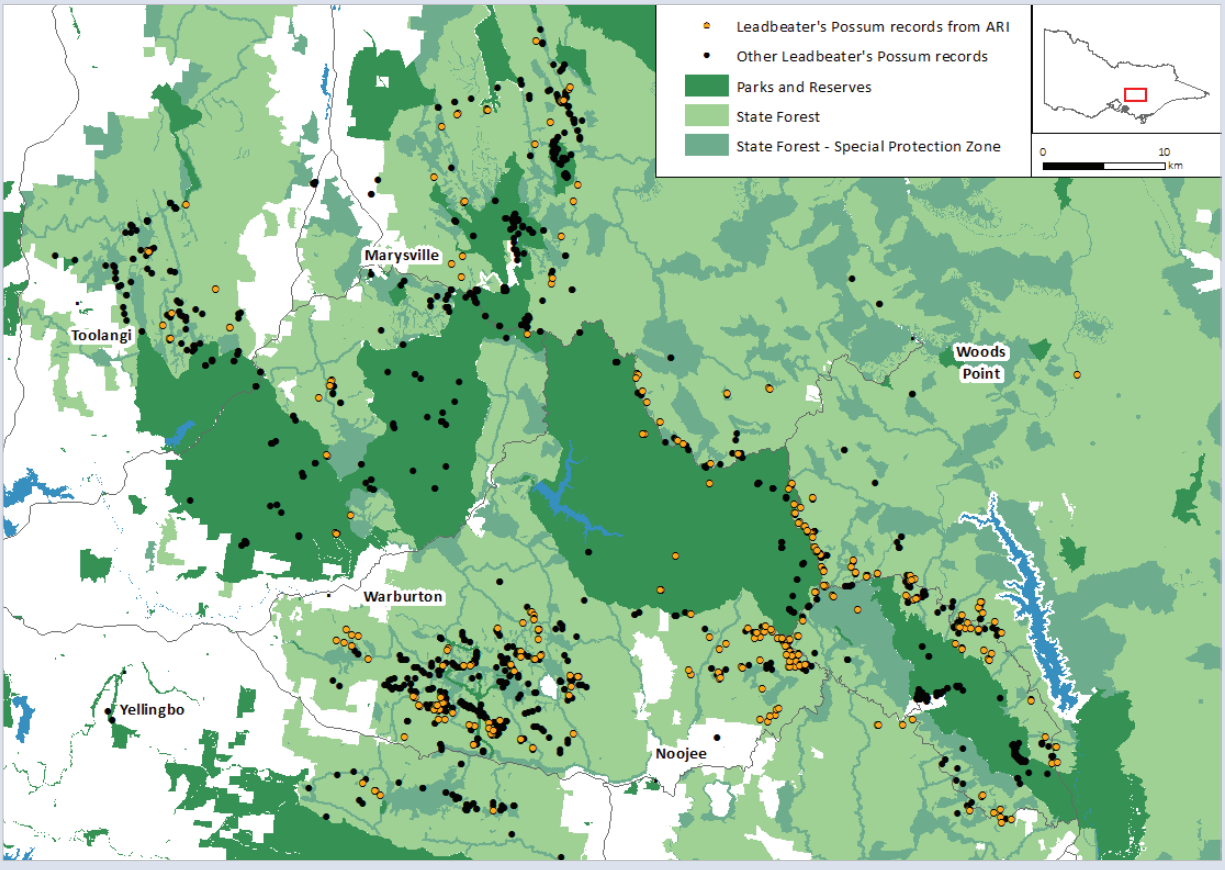
Figure 1.27: Leadbeater's possum (*Gymnobelideus leadbeateri*), which occurs in the montane ash wet forests of Victoria

Figure 1.28: Location of Leadbeater's possum records in Victoria, including recent records from Arthur Rylah Institute's targeted surveys



Source: Arthur Rylah Institute (ARI), showing site records to May 2017 in the Victorian Biodiversity Atlas.

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approach was taken, selecting sites randomly across the range of the species, including in parks and reserves in addition to State forest, and also sampling areas burnt during the 2009 bushfires. An additional 149 sites were surveyed in this way, with Leadbeater's possum located at 55 (37%) of these randomly selected sites. The species was recorded in forest of a wide range of age classes and disturbance histories, including both 1939 regrowth and younger stands of regrowth from fire or from timber harvesting.

This survey technique primarily records animals where they are foraging, and for colonies to use young regrowth forest there needs to also be suitable hollow-bearing trees nearby to provide denning sites. Some animals were recorded in forest stands burnt during the 2009 fires, encouragingly showing some level of recolonisation of these areas within eight years of the fires.

Timber harvesting exclusion zones have been established around all the ARI records of Leadbeater's possum, providing increased protection for 204 newly detected colonies and their habitat. Data from these extensive surveys have improved knowledge of the distribution of Leadbeater's possum and its use of habitat across its range, and are being used to update species distribution models to inform future conservation and management.

Source: Lindy Lumsden, Arthur Rylah Institute

Case study 1.4: Use of camera traps for assessing the presence of the black-footed tree-rat (*Mesembriomys gouldii*)

Black-footed tree-rats (*Mesembriomys gouldii*) are a forest-dependent species that occupy open and woodland forest of northern Australia tropical savannas, where they den in tree hollows or pandanus during the day and forage on the ground and in trees at night (Pittman 2003; Rankmore 2006). They are one of Australia's largest native rats, and eat fruits, supplemented by flowers (of *Grevillea* and *Eucalyptus*), insects and freshwater mussels (Morton 1992).

Three disjunct subspecies are recognised: *M. g. gouldii* inhabits the north-west Kimberley (Western Australia) and mainland Northern Territory, *M. g. melvillensis* is found on Melville Island (Northern Territory), and *M. g. rattoides* inhabits Cape York Peninsula (Queensland). Because of the decline of these subspecies across their range, coupled with on-going threats (habitat loss and fragmentation; habitat loss due to invasive exotic grasses; inappropriate fire regimes; and feral cat predation), all three subspecies were listed under the EPBC Act in 2015. The Kimberley and Northern Territory subspecies *M. g. gouldii* is listed as Endangered, and the other two subspecies are listed as Vulnerable. While black-footed tree-rats are considered uncommon to rare in the Kimberley and Queensland, they are still common but patchily distributed across the Top End of the Northern Territory (Figure 1.29).

It is essential to determine the presence of threatened species reliably prior to potential impacts of habitat loss or development, and wildlife surveys designed to detect these species can ensure adequate protection measures are in place. A consideration of the trade-offs between expense, survey effort and the needed accuracy and precision of survey results can optimise the value of wildlife surveys for monitoring and environmental management. Of particular importance is the concept of imperfect detection, where a species remains undetected in surveys even though it is present in the landscape. The probability of detecting a species with different sampling designs can be assessed using occupancy modelling. This approach is particularly useful when target species are rare or elusive, and there are competing priorities for threatened species management funding and resources.

Camera trapping has become the most widely used, cost-effective and low-impact means of reliably detecting terrestrial mammal species, because it can provide systematic and accurate data over prolonged survey periods without the requirement for live trapping (Gálvez et al. 2016). The advantages of camera trapping over conventional methods for species inventory, ecological and monitoring studies are well recognised (Meek et al. 2014; Smith et al. 2016). Camera traps are particularly suited to surveying forest mammals, and can provide systematic and accurate data over prolonged survey periods. Analysis of camera trap data across eight regions in the open and woodland forests of the Northern Territory (Figures 1.29–1.31) has allowed the determination of optimal number of cameras and deployment time required to reliably detect the presence of black-footed tree-rats (Risler 2017).

The outcomes of camera trap detectability research can incorporated into impact assessment guidelines to improve detectability and provide definitive and achievable methods for detecting the black-footed tree-rat. Such research is applicable across species and habitats and will serve to standardise survey design and methods, providing a greater knowledge base for natural resource management and species conservation and reduced the likelihood of imperfect detection.

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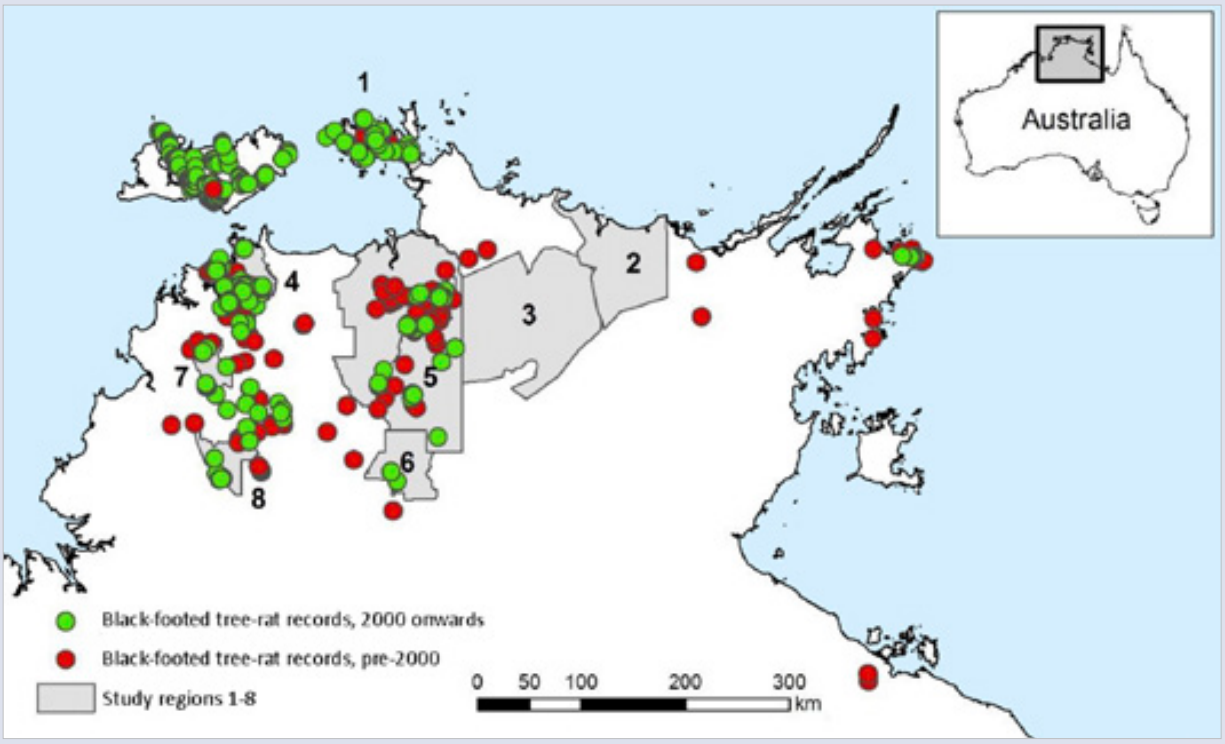
Figure 1.29: Distribution of black-footed tree-rat in the Northern Territory



Source: Northern Territory Government fauna atlas records overlaid on eight study regions (Risler 2017).

Figure 1.30: Setting up a camera trap, Northern Territory

Figure 1.31: Black-footed tree-rat photographed by the camera trap in Figure 1.30

Indicator 1.2c

Representative species from a range of habitats monitored at scales relevant to regional forest management

Rationale

This indicator provides broad habitat, population, and range information for representative forest dwelling flora and fauna. Evidence of changing ranges or densities of forest dwelling species can be used to guide forest management activities so that they are consistent with maintenance of forest biodiversity.

Key points

- There continues to be a lack of comprehensive knowledge and monitoring of the occurrence of representative species across land tenures and forest types, which limits the conclusions that can be drawn from available data.
  - Efforts to monitor forest-dwelling species vary across state and territory jurisdictions, and in some jurisdictions have diminished or been discontinued for certain taxa.
  - States and territories undertake separate monitoring for their own regulatory and research requirements, and their priorities may differ from national priorities.
- Birds are the taxonomic group with the largest number of programs in place to track population trends over time. Monitoring efforts of state and territory agencies for birds are supplemented by a large-scale investment by non-government organisations. A number of case-studies on monitoring programs are presented.
- Long-term monitoring programs such as Forestcheck in Western Australia and the Warra Long-term Ecological Research site in Tasmania contribute monitoring information supportive of continuous improvement of sustainable forest management in those states.

Forest-dwelling species are monitored under programs implemented by a range of different bodies, including state and territory forest management agencies, state and territory conservation agencies, the Terrestrial Ecosystem Research Network (TERN), universities, non-government organisations and private individuals. These programs have been established for a variety of reasons and at various scales; for example, university programs are often designed to address particular research questions, usually at a localised scale. The states and territories monitor forest-dwelling species to meet requirements specified by relevant legislation and/or sustainable forest management policies; priorities at the state and territory level may differ from those set at the national level. There are few examples of long-term monitoring programs across the full range of a forest-dwelling species.

Recognising the value of a structured, broad-based monitoring program in assisting long-term management, Western Australia established Forestcheck, a comprehensive approach to monitoring species in the state's south-western forests (McCaw et al. 2011; SOFR 2013 see Case study 1.3). Forestcheck is one of only a few programs in the world collecting regional-scale information on mosses, lichens, fungi and invertebrates, as well as the better known components of forest biodiversity (vertebrates and vascular plants) and Case study 7.7 reports current findings from Forestcheck. The work at the Warra Long-term Ecological Research (LTER) site in Tasmania is another example (see Case study 7.8).

Sustainable forest management requires an understanding of ecological trends over long time-scales. Long-term monitoring programs such as Forestcheck in Western Australia and the work at the Warra LTER site in Tasmania deliver some of that information and thereby contribute to continuous improvement of sustainable forest management in those states. Burns and Lindenmayer (2014, p.23) noted that "Long-term monitoring of birds, fungi, beetles and vascular plants in harvested and unharvested forest plots in southern Tasmania and south-western Australia showed that the recolonisation of harvested areas by different groups of flora

and fauna varies markedly and depends, in part, on retained forest elements within the post-harvest area (e.g. habitat trees, logs and patches of intact forest)". This is an example of monitoring information on biodiversity and species that has been used to influence forest management practices. In general, there is more monitoring of species and their habitats on multiple-use public native forests than on other tenures.

Indicator 1.2c of SOFR 2013 provided several case studies as examples of outcomes of monitoring forest-dwelling species:

- the relocation of the threatened northern quoll (*Dasyurus hallucatus*) affected by the spread of cane toads (*Rhinella marina*) in the Northern Territory as part of the Island Ark program (SOFR 2013, p.100, Case study 1.5)
- breeding sites and populations of the threatened Swift Parrot (*Lathamus discolor*) (SOFR 2013, pp.101–2, Case study 1.6)
- incidence of a disease agent in the population of the threatened Tasmanian devil (*Sarcophilus harrisii*; SOFR 2013, pp.103–4, Case study 1.7), and
- plants and beetles along an altitudinal transect at the Warra LTER site in southern Tasmania (SOFR 2013, pp.105–6, Case study 1.8).

The Swift Parrot is included in SOFR 2018 as an example of monitoring of breeding success and the effects of predation (Case study 1.2 in Indicator 1.2b). In this Indicator, Case study 1.6 reports the monitoring of bat species in New South Wales, while monitoring the koala (*Phascolarctos cinereus*) in Queensland is reported in Case study 1.7, and in New South Wales with new methodologies in Case study 1.8. Case study 1.9 illustrates a cooperative monitoring program on the northern bettong (*Bettongia tropica*) by government, academic and non-government institutions in Queensland.

Species that are commercially harvested for non-wood forest products are also monitored. Harvesting of tree ferns (*Dicksonia antarctica*), common brushtail possum (*Trichosurus vulpecula*), Bennett's wallaby (*Macropus rufogriseus*) and Tasmanian pademelon (*Thylogale billardierii*) in Tasmania are examples (see Indicator 2.1d and FPA 2017a).

Stocks of commercial fisheries species that occur in forested waterways (freshwater, estuarine and/or mangroves), or use forested waterways as nursery habitat, are also monitored: examples are barramundi (*Lates calcarifer*) in Queensland (DAF 2017a), giant mud crab *Scylla serrata* and orange mud crab *S. olivacea* in the Northern Territory (DPIR 2017), and white banana prawn (*Fenneropenaeus merguiensis*) across coastal Northern Australia (Larcombe and Bath 2017).

Monitoring at state and territory level

Table 1.53 indicates the extent to which monitoring programs are in place for representative species in various taxonomic groups, by state and territory, and how the monitoring effort compares with that reported in SOFR 2013. This table is based on reporting by individual Commonwealth, state and territory agencies and therefore might not include all existing programs – in particular, programs carried out by tertiary institutions may not be recorded. Monitoring programs for forest-dwelling species are increasingly being coordinated through non-government organisations and universities in conjunction with government departments. For some particular taxonomic groups in some states and territories, effort and capacity has diminished over time or is non-existent, and some programs monitoring groups of taxa have discontinued (Table 1.53).

Since SOFR 2013, monitoring of representative species has increased significantly in the Australian Capital Territory, Northern Territory and Western Australia, particularly in parks and reserves. Monitoring of representative mammal, bird, invertebrates and vascular plants in Tasmania remained at similar levels to those reported in SOFR 2013, with no monitoring of reptiles, amphibians, fish and non-vascular plants, while effort has increased in monitoring threatened bird species. The Australian Capital Territory, Western Australia (including Forestcheck) and Tasmania (including the Warra LTER site) each have programs monitoring more than 500 representative forest-dwelling and forest-dependent species, including many invertebrate species. Figures 1.32 and 1.33 illustrate the monitoring results for beetles and birds from Warra. The other states and the Northern Territory each monitor less than 100 representative forest-dwelling and forest-dependent species in their jurisdictions.

A new monitoring program, the Western Australian North Kimberley Landscape Conservation Initiative monitoring and evaluation program, was established in 2011 to inform adaptive management of fire and feral cattle on conservation reserves in the North Kimberley region of Western Australia. The network of monitoring sites includes more than 90 sites on conservation lands, including in the Mitchell River, Drysdale River and Prince Regent national parks. Indicators of condition are mammal fauna composition and abundance, vegetation condition, and fire regimes (the latter characterised from satellite imagery). Rainforest patches are being monitored to assess changes in extent associated with fire and grazing impacts. Traditional owners are engaged in the monitoring, and work is integrated with complementary work being undertaken by traditional owners on adjoining lands. Monitoring results are collated and reported every two years; Corey and Radford (2017) is an example.

Monitoring effort continued in New South Wales, including increased monitoring of fauna through the WildCount program[78]. WildCount commenced in 2012 as a 10-year fauna monitoring program that uses motion-sensitive digital cameras at 200 sites across 146 parks and reserves in eastern New South Wales, and is expected to be able to detect changes in the occurrence of at least 12 birds and mammals. Some site-specific monitoring programs for threatened rainforest

[78] www.environment.nsw.gov.au/animals/wildcount.htm

Table 1.53: Taxonomic groups for which representative native species are being monitored, by jurisdiction

Jurisdiction	Level of monitoring, and change in effort and capacity from that reported in *Australia's State of the Forests Report 2013*[a]															
	Mammals		Birds		Reptiles		Amphibians		Fish		Invertebrates		Vascular plants		Non-vascular plants	
ACT	++	>	++	>	+	=	++	>	+	>	++	n	++	>	0	0
NSW[b]	++	>	++	=	0	0	+	<	++	>	+	=	++	=	+	=
NT	++	>	+	=	+	>	+	>	+	>	+[d]	>	+	>	0	0
Qld	++	>	+	=	+	=	+	<	+	<	+[d]	=	+	=	0	0
SA	+	<	++	=	+	<	+	<	+	=	0	0	++	<	0	0
Tas.	++	=	++	>	0	0	0	0	0	0	++	=	++	=	0	0
Vic.	++	>	++	>	0	D	+	=	+	<	+	=	++	>	0	D
WA	++	>	++	>	++	=	++	=	0	0	++	=	++	>	++	=
Australia[c]	+	=	++	=	++	=	++	=	++	<	+[e]	=	0	0	0	0

Level of monitoring	
0	No species in the taxonomic group is being monitored, or no data available on monitoring effort
+	At least one species of the taxonomic group is being monitored to detect changes in population size at a scale relevant to forest management
++	More than 10 species are being monitored to detect changes in population size at a scale relevant to forest management
Change in monitoring effort and capacity since SOFR 2013	
n	New program
>	Increased level
=	Stable level
<	Decreased level
D	Monitoring discontinued
0	No species in the taxonomic group is being monitored, or no data available on monitoring effort.

[a] MIG and NFISC (2013).

[b] Data incomplete for conservation estate in NSW.

[c] Includes species monitored across jurisdictions, and includes non-government mechanisms through BirdLife Australia (Birdata, birdata.birdlife.org.au/), FrogWatch and ReptileWatch (www.frogwatch.org.au and www.frogwatch.org.au/index.cfm?action=cms.page&section=2).

[d] Includes only the white banana prawn (*Fenneropenaeus merguiensis*) and/or mud crab (giant mud crab *Scylla serrata*, and orange mud crab *S. olivacea*), and no terrestrial invertebrates.

[e] Includes only the Murray crayfish (*Euastacus armatus*) monitored in the Murray–Darling Basin, and the mud crab fishery monitored in northern Australia, and no terrestrial invertebrates.

Notes:

Monitoring of introduced and invasive species are not included.

Studies of monitoring of forest ecosystems are not included.

Monitoring of fish includes Murray–Darling Basin and coastal freshwater waterways; forested estuarine waterways and mangrove ecosystems are included only for the Northern Territory and Queensland. Monitoring of waterbirds in the five forested "The Living Murray Icon Sites" in the Murray–Darling Basin is not included.

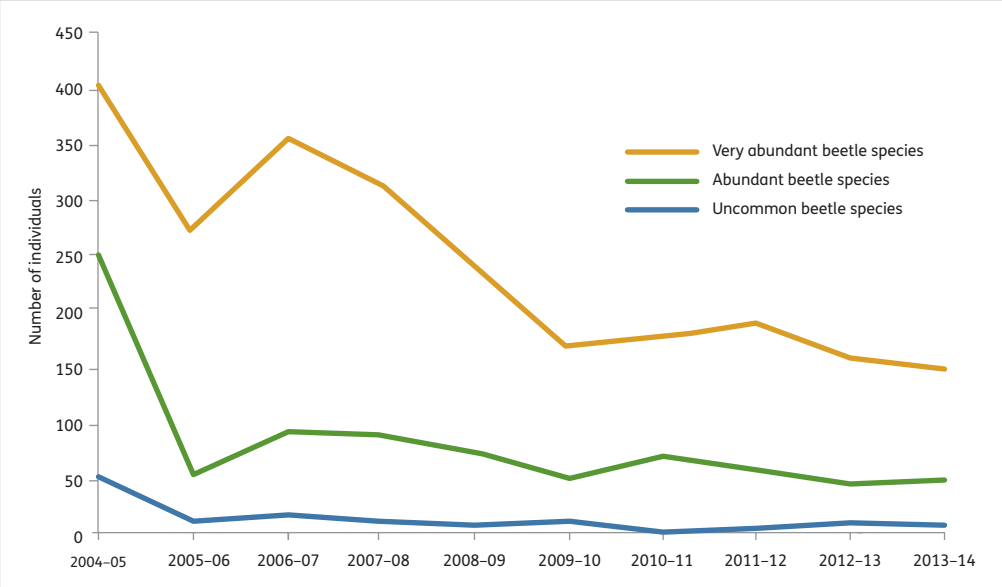
Source: Australian Government, state and territory agencies, and MIG and NFISC (2013).

This table, together with other data for Indicator 1.2c, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

species (covering two amphibians, two mammals and a bird species) ceased in 2014 in specific locations in the New South Wales reserve system, due to the cessation of funding support from the Caring for Our Country (Commonwealth) program. Continuation of one long-term monitoring program monitoring the impacts of fire on cool temperate rainforest in north-eastern New South Wales (including vascular and non-vascular plants, birds and other fauna), which commenced in 1930, is uncertain as the program is now run on a volunteer basis. Targeted monitoring of fish species in forests has continued. A new monitoring program commenced in the reserve system in the far south-east corner of New South Wales, monitoring impacts of fox control programs and ecological burning on target species, including the threatened southern brown bandicoot (*Isoodon obesulus*) and long-nosed potoroo (*Potorous tridactylus*). In the Pilliga region of north-eastern New South Wales, a new bird monitoring program commenced in 2013, while examples of ongoing programs include monitoring the recovery of diurnal birds from intensive forest harvesting, and tracking bird diversity in response to eucalypt plantation establishment. Monitoring of representative species on New South Wales state forests (see for example Case study 1.6 on bat populations) remained stable during the SOFR 2018 reporting period.

Monitoring of representative species in the Northern Territory occurs across all taxonomic groups other than non-vascular plants. Since 1994, detailed vegetation and fauna sampling has been undertaken every five years using 220 permanent plots in Litchfield, Kakadu and Nitmiluk national parks; monitoring representative forest species is part of this sampling. Monitoring of small mammals and feral animals using Indigenous rangers in collaboration with government

Figure 1.32: Beetle abundance at Warra site WR008J[a]



Very abundant, >95th percentile of abundance; abundant, 75–95th percentile of abundance; uncommon, <75th percentile of abundance.

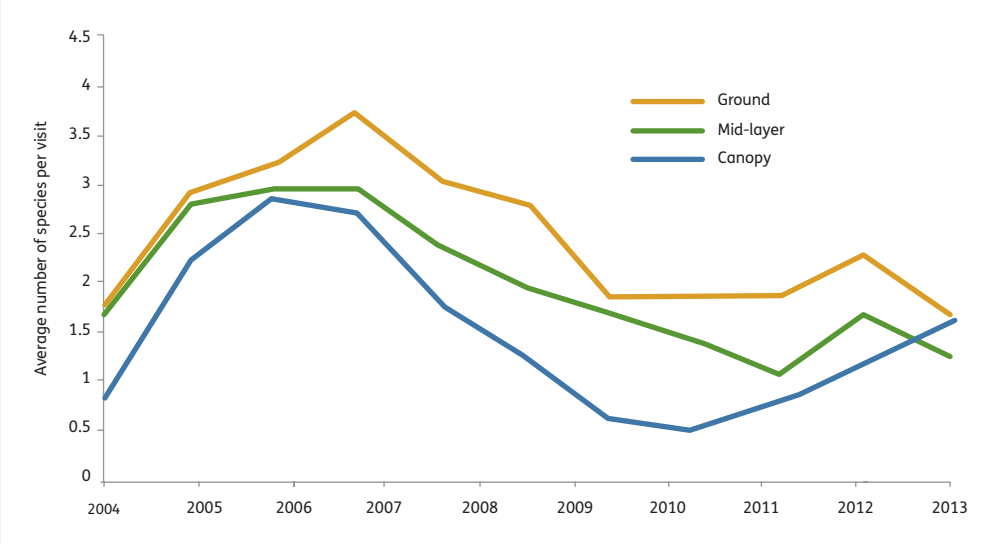
[a] WR008J is a control site.

Note: Data from monthly pitfall trap sampling done in coupe WR008J by Forestry Tasmania (now Sustainable Timber Tasmania) as part of ongoing monitoring of the Silvicultural Systems Trial (Baker et al. 2009). WR008J is one of the unharvested control sites of the Silvicultural Systems Trial.

Source: Sustainable Timber Tasmania.

The data used to create this figure, together with other data for Indicator 1.2c, are available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Figure 1.33: Average bird species per survey site visit at Warra site WR008J[a]



[a] WR008J is a control site.

Note: Data from annual birds surveys done in coupe WR008J by Forestry Tasmania (now Sustainable Timber Tasmania) as part of ongoing monitoring of the Silvicultural Systems Trial (Lefort and Grove 2009). WR008J is one of the unharvested control sites of the Silvicultural Systems Trial.

Source: Sustainable Timber Tasmania.

The data used to create this figure, together with other data for Indicator 1.2c, are available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

and academic specialists is occurring in native forests on Indigenous lands.

Whilst monitoring of representative species of birds and fish in South Australia remained stable, South Australia reported that monitoring effort of representative species of amphibians, mammals, reptiles and vascular plants had declined during the SOFR 2018 reporting period. The number of forest-dwelling vascular plants being monitored reduced from >30 species in the SOFR 2013 reporting period to 25 in the SOFR 2018 reporting period; all 25 species are listed under the national EPBC Act. Similarly, monitoring of representative species of terrestrial forest-dwelling fauna in South Australia is now confined to a selection of threatened species listed under the EPBC Act: one amphibian, 11 birds, five mammals and two reptiles. Continuation of the monitoring of birds is increasingly reliant upon volunteers and community groups (the example of the Red-tailed Black-cockatoo is described below: Case Study 1.5). Monitoring of populations of listed and non-listed native fish species under the EPBC Act continued in the eastern forested environments of the Murray River in South Australia. As well, populations of the forest-dwelling threatened Yarra pygmy perch (*Nannoperca obscura*) continue to be monitored as a requirement of its recovery plan (Saddlier and Hammer 2010).

The majority of monitoring of representative species in Queensland occurs in protected areas of the reserve system. Since the SOFR 2013 reporting period, Queensland reports that monitoring of mammals has increased to >10 species, monitoring of birds, reptiles and vascular plants has remained stable at <10 species, while monitoring of amphibians and fish has declined. Monitoring has ceased of native fish populations in the Murray–Darling Basin in Queensland.

Victoria reported increased monitoring of mammals, birds and vascular plants, and discontinuation of monitoring of reptiles, non-vascular plants and *Galaxias* fish species. The monitoring of several amphibians continued at the level reported in SOFR 2013.

At the national level, the most comprehensive monitoring is in place for birds, driven by a national volunteer program coordinated by the non-government organisation Birdlife Australia, and supplemented by state and territory agency-specific programs. Birds are usually reasonably visible and hence amenable to direct monitoring, but this is not the case for all bird species, so innovative monitoring approaches are also required. In addition, a community partnership program in association with the non-government organisations FrogWatch and ReptileWatch[79] is active in Northern Australia (Kimberley region Western Australia, Northern Territory and North Queensland), and provides digital information on amphibian and reptile species through a biodiversity portal. FrogWatch programs also are carried out in southern Australia. Fauna-monitoring approaches involving non-government organisations generally involve work in collaboration with state and territory government agencies to develop comprehensive monitoring programs using public participation. Information material and supporting databases, such as the Atlas of Living Australia[80] and Australian Reptiles Online Database[81], support these monitoring activities.

Monitoring of native fish in the Murray–Darling Basin (covering four states and one territory) is continuing, and is coordinated by the Murray–Darling Basin Authority (an Australian government authority). However, it is occurring at a decreased level compared to that reported in SOFR 2013. During the SOFR 2008 and SOFR 2013 reporting periods, monitoring of fish populations in the basin was guided by the *Native Fish Strategy for the Murray–Darling Basin 2003–2013*[82], and its goal "to rehabilitate native fish communities in the Murray–Darling Basin back to 60 per cent of their estimated pre-European settlement levels after 50 years of implementation" (Murray–Darling Basin Ministerial Council 2003). Koehn et al. (2014b) and Lintermans et al. (2014) discuss the foundations and implementation of the strategy in the basin. However, the funding for strategy programs ceased after its initial 10-year period (Koehn et al. 2014a).

Monitoring of vegetation condition, fish and waterbirds, and intervention monitoring associated with environmental watering events in the Murray–Darling Basin, is now largely confined to the monitoring of "The Living Murray Icon Sites" (TLM Sites) along the Murray River. There are six icon sites, five of which are forested: Barmah–Millewa Forest and Gunbower–Koondrook–Perricoota Forest on the Victorian and New South Wales border on the Murray River, Hattah Lakes and Lindsay–Mulcra–Wallpolla Islands in northwest Victoria in the Murray River floodplain, and the Chowilla and Lindsay–Wallpolla Islands icon site located on the Murray River at the border of South Australia, New South Wales and Victoria (Hughes et al. 2016). Fish populations in these forested icon sites are reported to have improved or remained stable since the SOFR 2013 reporting period (Hughes et al. 2016). Monitoring sites in the Murray–Darling Basin outside of these icon sites have generally been discontinued, other than those located in the Australian Capital Territory. Monitoring of fish populations in forests in the headwaters of the Basin (in New South Wales, Queensland and Victoria) and along the Darling River and its tributaries (in New South Wales and Queensland) ceased after 10 years of implementation of the *Native Fish Strategy for the Murray–Darling Basin 2003–2013*.

[79] www.frogwatch.org.au

[80] The Atlas of Living Australia is Australia's national biodiversity database, receives support from the Australian Government through the National Collaborative Research Infrastructure Strategy (NCRIS), and is hosted by CSIRO. It is a node of the Global Biodiversity Infrastructure Facility (GBIF). It is used for research, environmental monitoring, conservation planning and management, reporting, education, and citizen science activities; see www.ala.org.au/

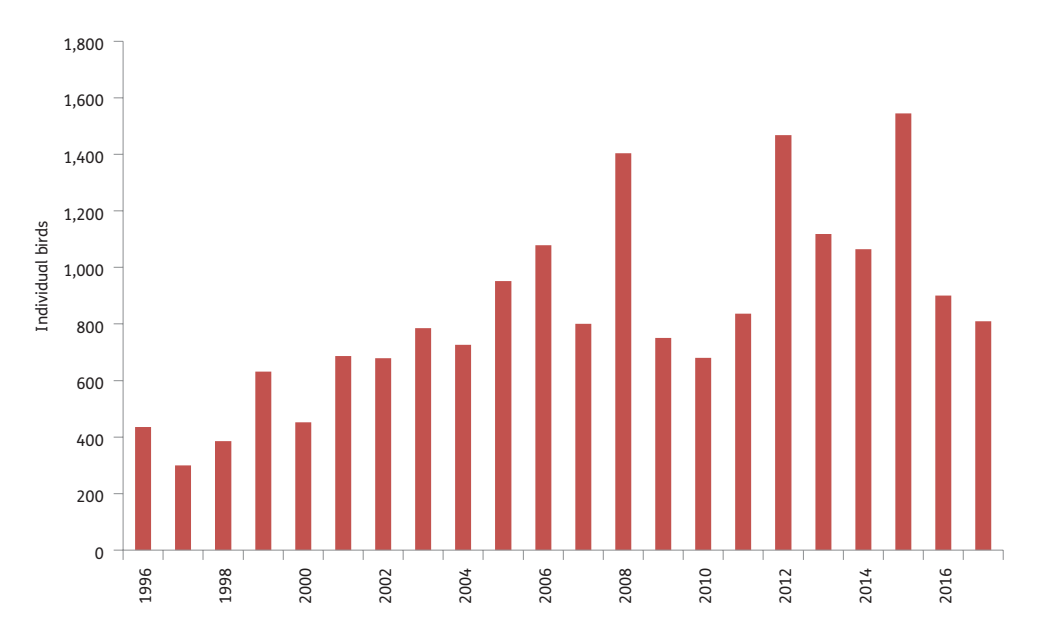
[81] www.arod.com.au/arod

[82] www.mdba.gov.au/sites/default/files/pubs/NFS-for-MDB-2003-2013.pdf

Case study 1.5: South-eastern Red-tailed Black-cockatoo

An example of a non-governmental monitoring program is the annual population count of the endangered south-eastern Red-tailed Black-cockatoo (*Calyptorhynchus banksii graptogyne*) that has taken place since 1996 across approximately 18,000 square kilometres of western Victoria and south-east South Australia. Counts have reported between 300 and 1,545 birds in the period to 2017 (Figure 1.34). Such counts provide a minimum number of birds in the population, determine patterns of habitat use and the location of large flocks, as well as indications of previous year's breeding success, and allow determination of trends over time in the population. This subspecies inhabits desert stringybark (*Eucalyptus arenacea*) and brown stringybark (*E. baxteri*) woodlands on the Glenelg, Wimmera and Naracoorte Plains, and adjacent woodlands of river red gum (*E. camaldulensis*), yellow gum (*E. leucoxylon*) and buloke (*Allocasuarina luehmannii*), and has a specialised diet, feeding primarily on stringybark and buloke seed. As a result of historical clearing, only 43% of the original suitable habitat in the region remains. The degraded condition of the remaining stringybark habitat, its patchy recovery, limited nesting hollows, fire impacts, and periodic scarcity of their preferred food supply are the main current threats to this subspecies. The small numbers of breeding pairs, continuing loss of dead hollow-bearing trees, lack of regeneration or retention of future hollow-forming trees, and declining health of scattered trees on private land are serious medium-term to long-term threats (SOFR 2013, Case Study 1.4).

Figure 1.34: Annual population counts (1996–2017) of the south-eastern Red-tailed Black-cockatoo (*Calyptorhynchus banksii graptogyne*)



Notes: The annual count covers stringybark forest in south-eastern South Australia and western Victoria, and is undertaken by volunteers on a single day in early May, on behalf of the Red-tail Recovery team and BirdLife Australia. Variation in counts between years can depend upon how dispersed individual birds and flocks are across the region on the counting day, which relates in turn to the fruiting pattern and seed crop of stringybark trees.

Source: SOFR 2013 Case study 1.4 updated with data from www.redtail.com.au/results.html.

Case study 1.6: Comparing bat populations between unlogged and regrowth forests

Bats are a diverse and ecologically important group of mammals. Most insect-eating bats ('microbats') are hollow-dependent, with females congregating in hollows of large trees to raise their young each spring. Annual banding of a small suite of bat species roosting in tree hollows at a study area in Chichester State Forest, northern New South Wales over 14 years (1999–2012) gave mark-recapture data that could be used to estimate survival, abundance and body condition (Law et al. 2018). Bats were captured in harp traps (Figure 1.35) in replicated catchments with different wood harvesting regimes, as well as over El Niño and La Niña weather cycles.

The study area comprises small catchments of unharvested forest and regrowth forest regenerating from Australian Group Selection harvesting in 1983. Riparian buffers were retained on creeks, and scattered old, hollow trees and unharvested rainforest were also retained in areas harvested. These and other environmental protections are now a standard requirement in wood production forests of NSW on public and private lands.

In total, 3,043 bats were banded, with a 32% re-trap rate, and a maximum time-to-recapture of nine years. A large portion of the bat population was resident in the area. The effect of logging history (unlogged forest compared to regrowth forest 16–30 years after logging) on apparent survival was minor and species-specific, with no detectable effect on survival for two species (chocolate wattled bat, *Chalinolobus morio*; large forest bat, *Vespadelus darlingtoni*), a small positive effect for one species (eastern forest bat, *V. pumilus*), and a small negative effect for one species (southern forest bat, *V. regulus)* (Figure 1.36). There was also no effect of logging history on the abundance or body condition of any of these species. Despite annual variation in abundance and body condition across the 14 years of the study, no relationship with logging or extreme weather was evident. Apparent survival of resident bats was not strongly influenced by weather patterns except for the smallest species (eastern forest bat). Annual banding continues, and the 2018 sample represents 20 years of monitoring in this project.

The study area is located in a high-elevation, wet sclerophyll forest that appears to be a climate refuge, which may have buffered bat population dynamics from weather extremes. The study supports the value of climate refuges in mitigating projected impacts of climate change, and demonstrates that carefully planned native forest harvesting with appropriate environmental protections can be compatible with managing sensitive taxa. Such long-term research is necessary to underpin and fine-tune sustainable forest management practices.

Figure 1.35: Harp trapping for bats in an unlogged catchment of Chichester State Forest, NSW

Continued

Continues

Figure 1.36: Bat species monitored at Chichester State Forest, New South Wales, and response of annual survival to logging and climate extremes

A Chocolate wattled bat, *Chalinolobus morio*. No effect of logging history on survival detected, no effect of climate on survival detected.

B Large forest bat, *Vespadelus darlingtoni*. No effect of logging history on survival detected, no effect of climate on survival detected.

C Southern forest bat, *V. regulus*. Small negative effect of logging history on survival, no effect of climate on survival detected.

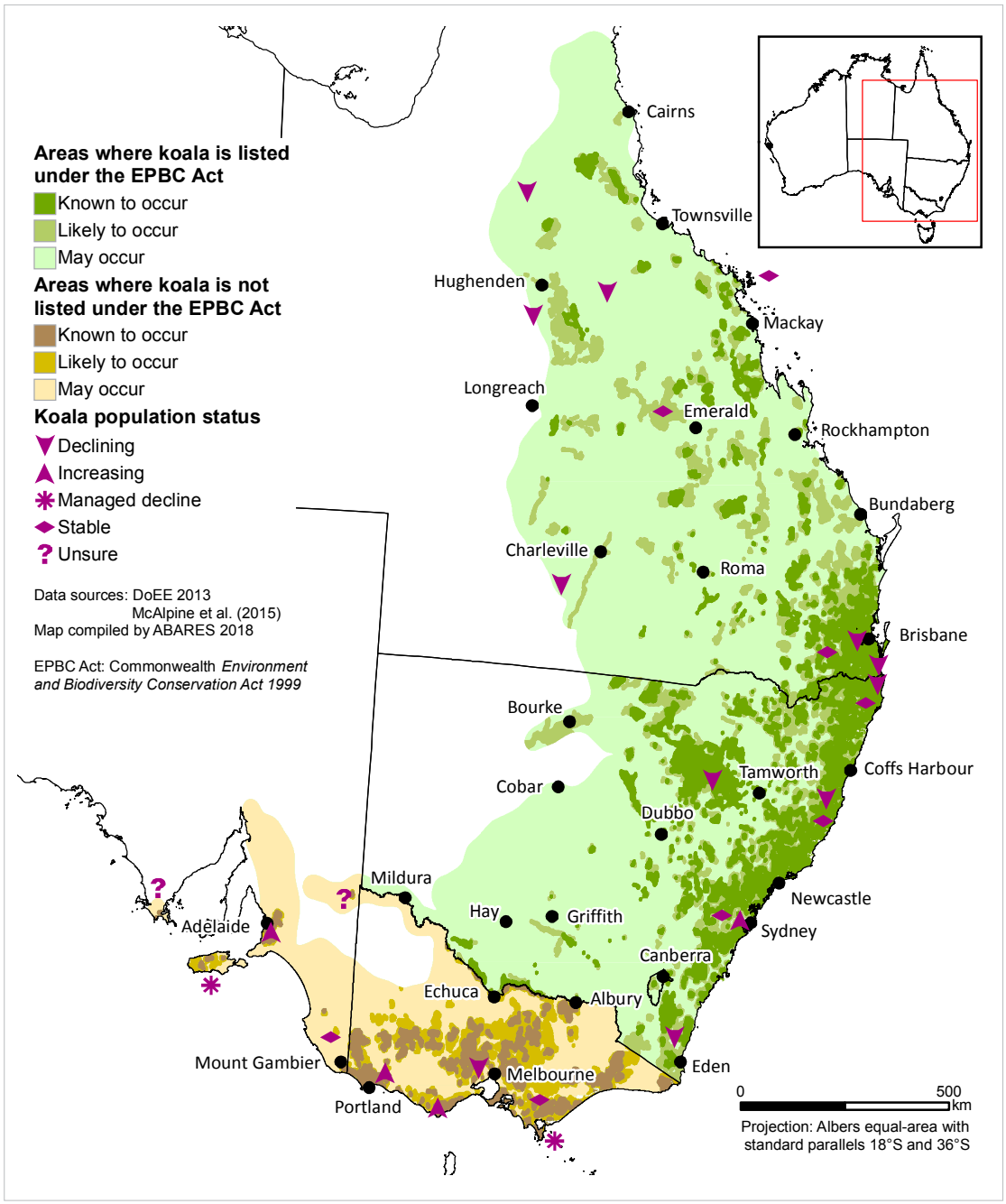
D Eastern forest bat, *V. pumilus*. Small positive effect of logging history on survival, negative effect of climate on survival detected in hot summers.

Koala

The koala (*Phascolarctos cinereus*) is one of the most distinctive and iconic wildlife species in Australia. Koalas occur in the Australian Capital Territory, New South Wales, Queensland, South Australia and Victoria. They inhabit a range of open and woodland forest and other woody non-forest vegetation communities containing their preferred food species from the genus Eucalyptus. Case Study 1.9 in SOFR 2013 provides a discussion of why koala populations in the Australian Capital Territory, New South Wales and Queensland (northern populations; Figure 1.37) were listed in May 2012 as Vulnerable under the EPBC Act. McAlpine et al. (2015) reports the regional population status and trends of koalas across the range of the species (see Figure 1.37).

Two case studies on the koala present current data on monitoring the species: Case study 1.7 in Queensland and Case study 1.8 in New South Wales.

Figure 1.37: Indicative distribution of the koala in Australia



Note: Koala distribution data are compiled using a range of datasets of varying quality and should only be used as a guide. The presence of the species or its habitat should be confirmed by using local information.

Source: Distribution data from ERIN, DoEE 2013; regional population status and trend data from McAlpine et al. (2015). Map compiled by ABARES 2018.

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

Case study 1.7: Monitoring koala populations in Queensland

Koalas and their habitat have been monitored on St Bees Island National Park off the coast of Mackay in Central Queensland since 1998 (Melzer et al. 2012). At that time, the tenure of the island was leasehold, but most of the island became national park in 2002. The monitoring program included 10 years of radio-tracking and 24-hour observations of individual animals. Data collected include population size, reproductive seasonality and success, social dynamics, day/night tree utilisation, ranging, tree and ecosystem use, and the relative contribution of different tree species to the diet. Habitat and population monitoring continues, with a census undertaken in most years, and fire and pest plant control trials are being established to inform future habitat management. The eradication of goats from the island commenced in 2007, to conserve significant ecosystems including koala habitat. Vegetation monitoring plots were established by the Queensland Parks and Wildlife Service (QPWS) prior to the commencement of the goat culling program, and have been monitored for approximately 10 years.

The koala population on St Bees Island has declined over the last 15 years from around 300 animals to less than 100 animals, with the greatest declines associated with the increased intensity and duration of dry seasons over recent El Niño events. Island vegetation is changing, with a general loss of grassy eucalypt woodlands and open forest. Rainforest elements (shrubs, small trees and lianes) and/or a dense *Lantana camara* shrub layer now dominate the midstorey, resulting in a loss of the herbaceous ground stratum. In places, rainforest community boundaries have expanded, stranding mature *Eucalyptus* trees. Burning has been successfully undertaken in grasslands, but there have been no successful ecological burns in the eucalypt communities. Despite the almost complete removal of goats from the island (over 3,000 removed to date), there is little or no successful establishment of *Eucalyptus*, *Corymbia* or *Allocasuarina* seedlings or recruitment of the eucalypt species (Queensland bluegum, *E. tereticornis*; poplar gum, *E. platyphylla*) that the koala feed upon on St Bees Island. Census data suggests that numbers of the introduced swamp wallaby (*Wallabia bicolor*) have increased following the removal of feral goats. Trials to develop landscape-scale management to redress lantana dominance commenced in 2017. A strategy for control of wallaby impacts is also being considered.

Koala monitoring in Minerva Hills National Park, south of Emerald in central Queensland, commenced in 1990 (Melzer 2005), and included radio-tracking and collecting similar data to those collected on St Bees Island. Koala populations and arboreal mammals continue to be monitored in Minerva Hills National Park.

In the region around Minerva Hills, koala abundance has declined dramatically, with local extinctions following droughts in the 2000s. The Minerva Hills National Park population persists at a low level (around 1 koala / 50 hectare). However, habitat quality has declined with extensive death of *E. tereticornis* in stream-fringing forest, as well as declines in canopy condition of other species. There is no evidence of natural regeneration of *E. tereticornis* or recovery of the stream-fringing forest. Repeat spotlight surveys along fixed transects have revealed an arboreal mammal community of abundant brushtail possum (*Trichosurus vulpecula*), some greater gliders (*Petauroides volans*), and occasional koala. The spotlighting data form a five-year baseline for future assessment. Some tree planting (inside and outside the park) has been undertaken to help redress the loss of koala fodder species; the success of the plantings is being monitored.

Case study 1.8: Researching the response of koalas to wood harvesting in New South Wales

Koalas are a cryptic species that are difficult to survey, especially in remote, tall forests. This has led to a poor knowledge-base about their status in forested areas away from peri-urban forests surrounding population centres.

The key threats to koalas have been identified as permanent tree cover loss by land clearing, increased housing near bushland, road traffic, dog attack, prolonged drought, and disease (McAlpine et al. 2015). However, the impact of native forest management and wood harvesting on koalas has been a frequent focus of community discussions about forestry practices. In 2015, a joint research project between the New South Wales Department of Primary Industries (DPI) and the Environment Protection Authority (EPA) produced a new habitat map to assist with better identifying important koala habitat in areas proposed for wood harvesting in north-east NSW (Law et al. 2017).

As part of the field validation of this habitat map, an innovative acoustic method for surveying koalas was trialled. Acoustic devices (SongMeters) are set at sites for one week to record male bellows during the breeding seasons. Recordings are scanned by Ecosounds software at the Queensland University of Technology (QUT) to identify koala bellows amongst other nocturnal sounds. Acoustic detection is proving to be a highly successful and efficient technique for recording koalas in forested areas where traditional surveys (visual counts, faecal pellet counts, community surveys and reported sightings) have had limited effectiveness. The success of trials of this new survey method led to an ongoing project involving systematic assessment and research into the status of koalas in forests and their response to wood harvesting.

A key aim of this research project is to determine if koala occupancy varies with harvest intensity and time since harvest. Acoustic surveys were undertaken during 2015–2017, targeting modelled high-quality habitat (Law et al. 2017) over an extensive area representing 1.6 million hectares of forested habitat for koalas in northern New South Wales. Sites were stratified by known harvest history, and included unharvested sites. A total of 170 sites were surveyed, making this one of the most comprehensive regional surveys for koalas in New South Wales. Preliminary results indicate unexpectedly high occupancy rates (an average of 65%) across a broad range of forests and amongst all successional ages and harvest intensities. Analysis is proceeding to allow a more comprehensive assessment of the response of koalas to wood harvesting. In addition, the three years of data collection will form the basis of an ongoing forest landscape monitoring program for koalas.

Koala and her joey in a eucalypt tree, New South Wales.

Case study 1.9: Monitoring the northern bettong *Bettongia tropica* in the Queensland Wet Tropics bioregion

The northern bettong (*Bettongia tropica*) has long been recognised as endangered, and considered as a species undergoing on-going decline. Through the Northern Bettong Recovery Group, and in partnership and cooperation with the Australian Wildlife Conservancy, James Cook University (JCU), the World Wide Fund for Nature (WWF) and the Threatened Species branch of Department of Environment and Science, Queensland Parks and Wildlife Service (QPWS) has been undertaking baseline data collection and monitoring to fill some of the key gaps in the knowledge necessary for the species recovery. Knowledge of the status of these northern bettong populations will assist in assessing the health of the tall open forest communities of the Wet Tropics bioregion.

Bettongia tropica (northern bettong).

A long-term population monitoring program (mark/recapture) in the Lamb Range (Davies Creek National Park, Dinden National Park and Danbulla State Forest), initiated by the QPWS in 2000 and continued by JCU and the WWF, suggests the local bettong population is stable. The status of the geographically isolated populations to the north (Windsor/Spurgeon Tablelands) and south (Koombooloomba and Paluma–Taravale/Mt Zero) is less certain, with no sightings recorded in the last 10–30 years despite reasonably extensive cage and camera trapping survey efforts. An intensive effort is being made to assess the presence or absence of northern bettongs in these areas as well as in potential habitat that has never been surveyed. These efforts recently led to the rediscovery of a population at Mt Spurgeon in the north of their known range, and plans are underway to assess its status. Unsuitable fire regimes (particularly fire exclusion, and irregular hot wildfires late in the dry season) are thought to be a significant contributing factor in the decline of this species.

A field guide for managing fire in northern bettong habitat was published in 2017 as part of the Caring for Country project (DEHP 2017). The guide was a joint effort by the Department of Environment and Heritage Protection[83], QPWS, JCU and WWF.

[83] From December 2017, the Department of Environment and Science.

Indicator 1.3a

Forest associated species at risk from isolation and the loss of genetic variation, and conservation efforts for those species

Rationale

This indicator assesses the risks to loss of forest genetic variation and describes the formal measures designed to mitigate this risk. A loss of genetic diversity in species can result in a decreased ability to adapt to future environmental change, and thus a higher risk of extinction.

Key points

- The number of forest-dwelling native fauna and flora for which data on genetic variation are available is still very small, although understanding of these species is increasing.
- Isolation and forest fragmentation have resulted in significant risks of loss of genetic variation in some species.
  - Genetic-related issues are identified in the listing statements for 173 (50%) of the 345 threatened forest-dwelling fauna (vertebrate and invertebrate animals) and for 747 (69%) of the 1,075 threatened forest-dwelling flora (vascular and non-vascular plants).
  - A total of 57% of Australia's threatened forest-dwelling fauna and flora species listed under the EPBC Act have small populations identified as a genetic risk factor. This comprises 43% of threatened fauna species, and 62% of threatened flora species.
- Formal efforts are being made to improve long-term genetic conservation outcomes by placing seed of threatened flora species into seed banks, and by increasing connectivity among patches of native vegetation.

The distributions of many Australian native species before European settlement are not well known. Historical records, expert opinion and analysis, evidence of major changes in species distributions, and incidental observations have been used to compile maps of, or to model, the former distributions of species. For example, the Comprehensive Regional Assessments (CRAs) used in Regional Forest Agreement (RFA) processes provided pre-1750 estimates of the extent of forest ecosystems across the 12 CRA regions. Estimates of the historical distribution of species are required to determine whether subsequent reductions in distribution could increase the risk of loss of genetic variation.

Risk to forest genetic variation

Species with a lower level of genetic variation are less able to respond to gradual or immediate threats, and so face a higher risk of extinction (see discussion in Saunders et al. 1998) although many other factors are relevant in individual species. In practice, it is difficult to determine how much of the genetic variation within a species has been lost historically. However, it is possible to identify whether certain species are becoming endangered by the increased isolation of specific populations due to habitat depletion and fragmentation, and by threatening biotic factors such as those discussed in Indicators 1.2b and 3.1a.

The process of forest fragmentation (see Indicator 1.1d), mainly caused by clearing for agricultural land use and urban expansion, is a significant contributor to a reduction in genetic variation of certain species. New or updated conservation advice and recovery plans for threatened plant populations that have become fragmented increasingly identify genetic inbreeding and reduced fecundity[84] as risks. This is because loss of genetic diversity can reduce the ability of species to adapt to change, and inbreeding depression can cause loss of fitness. Native populations at greatest risk and of greatest concern are those that are already small or fragmented and with high conservation value. Isolated remnant populations and island populations are also at greater risk of developing

[84] Fertility is the ability of an individual, population or species to reproduce sexually. Fecundity is a measure of the number of viable, fertile offspring produced that survive to reproductive age. Fecundity can increase or decrease in a population according to factors such as age distribution, availability of food or nutrients, or availability of mates or pollinators.

genetic inbreeding and risks of reduced fecundity over time (Furlan et al. 2012). Climate change, such as that predicted to result from an increasing atmospheric concentration of greenhouse gases, is also likely to contribute to a reduction in forest genetic variation (Doley 2010; Keenan 2017).

Changes over time in the genetic diversity of forest-associated flora have not been extensively measured, although a range of studies have documented genetic variation and the distribution of this variation within existing populations of species at a single point in time (see Broadhurst et al. 2017).

- These studies suggest that a reduction in range is less likely to cause significant loss of genetic variation in species with a high level of diversity within populations and a low level of diversity between populations. This type of population genetic structure has been found for most of the limited number of tree species that have been measured to date.
- A reduction in range is more likely to reduce genetic variation in species that exhibit low genetic diversity within populations and high variability between populations, such as that typically encountered in species with naturally restricted ranges (e.g. narrow-leaved mallee, *Eucalyptus angustissima*).

Knowledge of genetic variation in Australia's native species, and conservation measures to maintain that variation, are greatest in non-threatened species of economic importance for wood production in Australia and/or internationally (see Indicator 1.3b). Examples include shining gum (*E. nitens*, Hamilton et al. 2008; Southerton et al. 2010), southern or Tasmanian blue gum (*E. globulus*, Thavamanikumar et al. 2011; Carrillo et al. 2017; FPA 2017a) and blackbutt (*E. pilularis*, Sexton et al. 2010). Other than for native tree species of economic importance (Indicator 1.3b), the number of forest-dwelling species for which data on genetic variation are available has increased slowly since SOFR 2008 (see Broadhurst et al. 2017). Genetic variation and diversity of *Macadamia*, a tree genus of international importance as a food crop and with all four species listed as threatened, has been well researched (see Hardner et al. 2009 and Case study 1.10).

State and territory data

Tasmania has continued assessing the forest-dwelling species potentially at risk from isolation and loss of genetic variation as a result of past human-induced or natural events. Minimal data are available for the other states and territories.

As at 2016, a total of 392 forest-dwelling threatened and priority species in Tasmania were rated as potentially at risk from isolation and loss of genetic variation; 92% were vascular plants at potentially moderate and high risk (Table 1.54). This compares to the total of 277 forest-dwelling threatened and priority species in Tasmania that were rated as potentially at risk from isolation and loss of genetic variation in SOFR 2013.

Threatened species

The states and territories and the Australian Government maintain lists of threatened species; the Australian Government list is at the national level under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (see Indicator 1.2b).

Species with populations that are low in numbers, small in geographic extent or fragmented, that have low genetic variability, or that have hybridisation and fecundity issues,

Table 1.54: Number of forest-dwelling threatened and priority species in Tasmania potentially at risk from isolation and loss of genetic variation, 2016

	Risk category			
Taxonomic group	Potential high and moderate risk	Potential low risk	Unknown risk	Total
Fish	5	5	0	10
Amphibians	2	0	0	2
Reptiles	0	0	2	2
Birds	7	5	0	12
Mammals	2	1	1	4
Total vertebrate fauna	**16**	**11**	**3**	**30**
Dicotyledons	242	23	0	265
Monocotyledons	71	4	0	75
Pteridophytes	20	0	0	20
Gymnosperms	2	0	0	2
Total vascular flora	**335**	**27**	**0**	**362**
Total all groups	**351**	**38**	**3**	**392**

Note: Level of risk was estimated qualitatively for vertebrate fauna and vascular plant groups (excluding orchids) that are listed as threatened in Tasmania, or are identified as Regional Forest Agreement priority species. Explanation of risks and a list of species is given in Appendix 1.3.a of FPA (2017a).

Source: Amended from FPA (2017a).

This table, together with other data for Indicator 1.3a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

have genetic-related reasons contributing to the listing of species as 'threatened'. Table 1.55 summarises the genetic-related reasons associated with listing forest-dwelling species on the national threatened species list under the EPBC Act. Genetic-related issues are identified for 173 (50%) of the 345 threatened forest-dwelling fauna, and for 747 (69%) of the 1075 of threatened forest-dwelling flora (vascular and non-vascular plants).

In 57% of Australia's threatened forest-dwelling fauna and flora species (43% of the threatened fauna species and 62% of the threatened flora species; Table 1.55), small populations were identified as being a genetic risk. Hybridisation, while a natural process, represents a genetic risk to 1% of Australia's forest-dwelling threatened fauna and flora.

For listed threatened forest-dwelling flora, genetic-related risks associated with fecundity were identified in 31% of listings, fragmented populations were identified as a risk in 26% of listings, and low genetic diversity was identified directly in 24% of listings.

Orchids and cycads have the highest rate of genetic-related risks. There are 198 threatened forest-dwelling orchid species, of which 73% have risks associated with small populations, 56% have fecundity issues, and 33% have genetic risks separately associated with fragmentation and low genetic diversity. Of the 14 threatened forest-dwelling cycad species, 93% had fecundity-related issues identified as genetic risks in their listing statements; of these, 86% identified illegal collection (which can reduce gene pool, availability of mates, and reproduction), 64% reported pollination-related issues and 29% recorded inbreeding issues.

For listed threatened forest-dwelling fauna, 10% or less of listings identified risk factors associated with fragmentation, low genetic diversity or fecundity. Of the threatened forest-dwelling invertebrates, 66% (25 listed species) had small

Table 1.55: Threatened forest-dwelling species in Australia with conservation concerns about isolation or genetic capacity

	Number of listed threatened species with genetic-related reasons associated with listing[a]						
Taxonomic group[b]	Small population[c]	Fragmented population	Low genetic diversity	Hybridisation	Fecundity issues	Total	Total number of species
Fresh-water algae	0	0	0	0	0		1
Cycads	5	1	5	0	13	13	14
Clubmosses and spikemosses	2	1	1	0	1	2	9
Flowering plants[d]	643	269	246	9	316	715	1,017
Conifers	2	1	1	0	2	2	4
Ferns	14	3	3	0	2	14	28
Whisk-ferns	1	0	0	0	0	1	2
Total flora	**667**	**275**	**256**	**9**	**334**	**747**	**1,075**
Proportion of total number of listed threatened flora species (%)	**62**	**26**	**24**	**1**	**31**	**69**	**100**
Mammals	36	15	10	0	13	48	109
Birds	51	8	7	2	13	61	95
Reptiles	20	6	0	1	3	21	40
Amphibians	15	1	0	0	2	15	33
Fish	2	0	0	0	1	3	30
Invertebrates	25	2	2	0	3	25	38
Total fauna	**149**	**32**	**19**	**3**	**35**	**173**	**345**
Proportion of total number of listed threatened fauna species (%)	**43**	**9**	**6**	**1**	**10**	**51**	**100**
All groups	**816**	**307**	**275**	**12**	**369**	**921**	**1,419**
Proportion of total number of listed threatened species (%)	**57**	**22**	**19**	**1**	**26**	**65**	**100**

[a] Includes species that have become extinct where a genetic reason was identified. Listed subspecies or races are reported as separate taxa.

[b] Fresh-water algae are Charophyta; clubmosses and spikemosses are Lycopodiophyta; whisk-ferns are Psilophyta.

[c] Includes populations low in numbers, small in geographic extent, or comprising only a few subpopulations (e.g. island species). Only populations with an identified genetic-related risk are included; that is, listed threatened species with small populations with no identified genetic risk associated with its small population are excluded.

[d] Orchidaceae taxonomy is being revised. Where SPRAT data has grouped subspecies/races of orchids for the purpose of a taxon identifier, the classification used by the national authority (the Australian Plant Census) has been retained and these subspecies/races are reported as separate taxa. Where the listing of a species has been updated, the updated information has been used.

Source: National Forest Inventory; listing statements on the Australian Government Department of the Environment and Energy database (www.environment.gov.au/biodiversity/threatened/index.html).

This table, together with other data for Indicator 1.3a, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

populations listed as a genetic risk, with two recently listed species having fragmentation, low genetic diversity and fecundity reasons identified as additional genetic risks. A third, recently listed invertebrate (a butterfly) had illegal collection of adults identified as affecting the population's fecundity (reproductive success).

The Tasmanian devil (*Sarcophilus harrisii*) is listed as Endangered because of the threat posed by devil facial tumour disease, which also relates in part to the low level of genetic variation in the species (refer SOFR 2013 Case study 1.7). The koala (*Phascolarctos cinereus*) is listed as Vulnerable because of recent population decline and population fragmentation, resulting in population isolation and reduced genetic variation (refer SOFR 2013 Case study 1.9). Case study 1.10 discusses the genetic threats to the four threatened *Macadamia* species and their importance to the macadamia nut industry.

Formal measures to mitigate risk

Australia's Biodiversity Conservation Strategy 2010–2030 (NRMMC 2010) is a guiding policy framework for conserving the country's biodiversity, which includes genetic diversity. This framework uses a diverse mix of Australian, state, territory and local government approaches to biodiversity conservation, combined with private sector approaches. Formal measures are in place across state and territory jurisdictions to address the risk of loss of genetic variation in threatened species. These measures include recovery plans for threatened species, habitat restoration, wildlife corridors, engineered animal movement mechanisms (e.g. possum bridges), seed-collecting programs, management of habitat and populations under forest management systems (e.g. forest management plans and code of practice systems), and the national reserve system. The overall status of Australia's forest genetic resources is described in Indicator 1.3b.

Many species at risk are conserved ex situ by sample specimens found in botanic gardens and the National Arboretum. The National Macadamia Germplasm Collection, which was planted in three locations, provides ex situ conservation for representatives of three of the four threatened species of *Macadamia* (Hardner et al. 2004, 2009).

The Council of Heads of Australian Botanic Gardens (2008) identified seed banks as part of Australia's biodiversity risk mitigation strategy, and as having a key practical role in assisting with on-ground biodiversity recovery and management. The Australian Seed Bank Partnership was formed as a consequence of this, to mitigate risks to Australia's flora in the face of changing climates and other threats, with collaboration from Australia's leading botanical institutions, seed scientists and conservation and restoration experts[85]. The Partnership undertakes the collecting and banking of native seed for conservation, as well as developing enabling technologies and sharing the body of knowledge required to strengthen Australia's capacity to restore and connect landscapes and ecosystems through seed-based restoration. The work of the Partnership makes significant contributions to Australia's support of the Convention on Biological Diversity and *Australia's Biodiversity Conservation Strategy 2010–2030* (ASBP 2011) and contributes to genetic conservation of Australia's forest species (Indicator 1.3b).

Possum bridge to allow animals to move between forest fragments and maintain connectivity of populations.

[85] See asbp.ala.org.au/

Case study 1.10: Genetic conservation of *Macadamia* and its importance to the macadamia nut industry

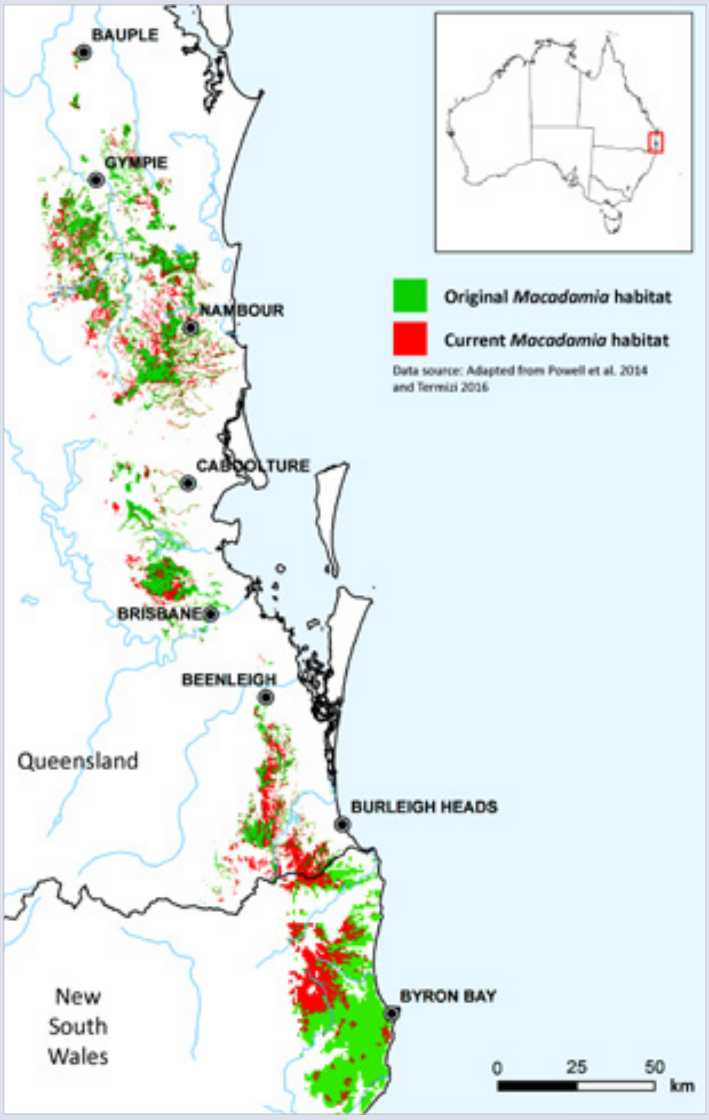
All four species in the genus *Macadamia*, family Proteaceae, are listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999*. Since 2009, a recovery plan has been operating for the four species (Costello et al. 2009) and a revised recovery plan is being drafted.

The four macadamia species are native to Australia and endemic to the coastal ranges and foothill forests of north-east New South Wales and south-east Queensland, within subtropical rainforest and sclerophyll forest containing subdominant subtropical rainforest. The natural distributions of the three vulnerable species, *Macadamia integrifolia*, *M. ternifolia* and *M. tetraphylla*, overlap.

The endangered *M. jansenii* is only known to occur in Bulburin National Park, Queensland, 150 km north of the nearest populations of the other species.

It is estimated that over 80% of wild macadamia trees have been lost since European settlement (Macadamia Conservation Trust[86]). Clearing of rainforest has also led to the fragmentation and isolation of rainforest remnants (Figure 1.38). This has decreased genetic diversity within remnants, especially in south-east Queensland, and decreased gene flow between remnants, although relatively high levels of genetic diversity still remain in *Macadamia* (Hardner et al. 2009). Sub-populations within each *Macadamia* species have differentiated genetically as

Figure 1.38: Current and historic distribution of *Macadamia* habitat



Note: 'Original *Macadamia* habitat' is modelled, 'Current *Macadamia*' habitat is a result of field surveys. The habitat of *M. jansenii* is not shown; this species occurs in a small area north of the illustrated map.

Source: adapted from Powell et al. 2014 and Ahmad Termizi et al. 2016.

[86] www.wildmacadamias.org.au

Continued

Continues

a result of past climate change, site adaptation and limited gene flow between populations (Hardner et al. 2009). Threats to the four *Macadamia* species include further habitat loss and fragmentation through vegetation clearing, inappropriate fire regimes, and weed invasion. Potential genetic threats are inbreeding among populations, loss of fertility as a result of isolation and habitat fragmentation (Powell et al. 2014), and introgression hybridisation of horticulture cultivars into wild population genetic stocks (O'Connor et al. 2015).

Macadamia nuts are traditionally a valuable food and cultural resource for Indigenous peoples. Early European settlers also recognised their food value, and commenced planting *M. integrifolia* and *M. tetraphylla* on farmland as single trees grown from seeds of local wild stock in the 1860s (Costello et al. 2009). Through tree breeding and genetic improvement, macadamia nuts have become a highly valued international commercial food crop. Macadamia nuts are commercially grown in Brazil, Colombia, Costa Rica, Guatemala, Israel, Kenya, Malawi, New Zealand, South Africa, Swaziland, Thailand, United States and Zimbabwe (South Africa DAFF 2014). Macadamia industries in developing countries are contributing to poverty reduction and sustainable development of these countries. *Macadamia* spp. are forest genetic resources contributing to food security domestically and globally, and are listed under the International Treaty on Plant Genetic Resources for Food and Agriculture (Singh et al. 2013).

Hardner et al. (2009) reviewed the domestication of macadamia, and the genetic linkages to wild populations. Macadamia were first commercialised in Hawaii from Australian genetic material. The Hawaiian cultivars underpin the genetic stock grown as an international food crop (Peace et al. 2008). However, the diversity of this germplasm is low compared to that of wild populations of the species.

Macadamia integrifolia and *M. tetraphylla* and their hybrids are also grown commercially in Australia, with 98% of trees being *M. integrifolia* (Keogh et al. 2010). Australia is the world's leading producer of macadamia nuts, providing 35% of the world supply, with Australia's industry worth $200 million per year (Horticulture Innovation Australia 2016). The area planted to macadamia orchards (which are not reported as forest) has increased from 17,000 hectares in 2010 (Keogh et al. 2010) to 28,000 hectares in 2017, with 53% of the area of orchards in New South Wales, 47% in Queensland and a small area in Western Australia[87]. Hawaiian cultivars are estimated to represent 80% of the growing stock planted in Australian commercial orchards (Ahmad Termizi et al. 2016).

The in situ conservation of wild populations of the four *Macadamia* species is important for biodiversity conservation of the species, as well as an important source of genetic traits to improve the genetic stock of orchard material used in the domestic and global macadamia nut industry. Current work by the Macadamia Conservation Trust[88] is capturing the genetic material found in natural and planted trees. Further domestic and international breeding of commercial macadamia nut that aims to broaden the genetic base will rely on access to genetic material found in the Australian native populations of *Macadamia*.

The National Macadamia Germplasm Collection established in 2001 is an ex situ conservation collection that contains a large sample of the genetic variation of the three vulnerable species, planted as orchards. The collection will also provide source material for introduction of new genetic material into future breeding programs (Peace et al. 2001; Hardner et al. 2009).

[87] Australian Tree Crop Response Map, Horticulture Innovation Australia. Data downloaded from www.arcgis.com/home/webmap/viewer.html?webmap=17213a10236f465590fe80d4298e5256

[88] www.wildmacadamias.org.au

Indicator 1.3b

Native forest and plantations of indigenous timber species which have genetic resource conservation mechanisms in place

Rationale

This indicator uses the coverage and implementation of formal genetic resource conservation mechanisms as a measure of the degree to which timber species' genetic resources are managed and conserved.

Key points

- The genetic resources for all Australian native forest species are conserved in situ in Australia's native forests. Genetic resources for some tree species are also conserved in arboreta, seed banks, seed orchards and plantations.
  - Most states and territories have guidelines and management plans for conservation of the genetic diversity of species in native forests, often as part of broader programs for biodiversity conservation.
  - The Australian, state and territory governments, research organisations, seed banks, arboreta, seed orchards and the private forestry sector, together with their tree-breeding and genetic improvement programs, all contribute to the conservation and sustainable management of forest genetic resources.
- Tree-breeding and genetic conservation and/or improvement programs exist for at least 48 native (indigenous) wood-producing and oil-producing species and varieties.
  - Between 2011 and 2016, there was a reduced investment in breeding of native tree species, with some programs closed, and some previously established provenance/progeny trials and seed orchards retained but no longer monitored.
  - A small number of non-commercial endangered species are conserved ex situ through infrastructure (arboreta and seed orchards) associated with tree breeding and improvement programs.
- Restoration plantings are also contributing to the conservation of the genetic resources for forest tree species.
- New research on forest species genetics has included the sequencing of the eucalypt genome, and the testing of provenances of species suitable for climate adaptation and ecological restoration.
- Some native forest species from Australia are a dominant part of the hardwood plantation industry in many other countries, and a component of the genetic resources for these species is located overseas.

Native forests in Australia contain a diverse range of tree, shrub and groundcover species, with the forest composition and dominant species varying with geographic location and climate. This indicator considers conservation of native forest genetic resources broadly, then considers conservation and breeding of native wood production species used in plantations.

Conservation of native forest genetic resources

In situ conservation

In situ conservation of forest biodiversity, both in multiple-use public native forests and in protected areas such as nature conservation reserves and national parks, is the primary mechanism for conservation of forest genetic resources in Australia.

Conservation of a representative sample of forest communities is expected to conserve both the component species, and a representative sample of genetic variation across the range of each species. Therefore, the level of conservation of forest genetic resources is linked to the level of conservation of forest biodiversity. State governments have developed a set of criteria that include broad benchmarks for the in situ conservation of forest biodiversity (see Indicator 1.1c). The Commonwealth and state and territory governments also monitor the National Reserve System with regard to agreed targets, and register species and ecological communities that are at threat. The *National Reserve System Strategy 2009–2030*[89] includes the following national targets:

- core areas established for the long-term survival of threatened ecosystems and threatened species habitats in each of Australia's bioregions by 2030.
- critical areas for climate change resilience, such as refugia, to act as core lands of broader whole-of-landscape-scale approaches to biodiversity conservation by 2030.

Most states and territories have guidelines and management plans for conserving the genetic diversity of native forest species of commercial significance during wood harvesting. In the regeneration of native forest after wood harvesting, the aim is to maintain local gene pools and the approximate composition and spatial distribution of all species present before harvesting. For example, codes of forest practice in Victoria and Tasmania require harvested native forest to be re-sown or regenerated with a species mix that approximates the natural mix of canopy trees present before harvest, with seed to be sourced either from the stand to be harvested or from the nearest similar ecological zone ('seed zone') (DEPI 2014b; FPA 2015b). Management plans may also include specifications for selection of seed, elite or plus trees of good form and health. In Western Australia, silvicultural guidelines specify the seed sources to be used in the rehabilitation of log landings within all harvested coupes and areas cleared for bauxite mining in jarrah (*Eucalyptus marginata*) forest.

Ex situ conservation

In addition to forest reservation, a range of organisations, including the Australian Tree Seed Centre (ATSC), Forestry Corporation of NSW, Sustainable Timber Tasmania and the Queensland Government, have established ex situ seed orchards and undertaken conservation plantings for several rare and endangered tree species. Species in these conservation seed orchards include Queensland western gum (*E. argophloia*), Barber's gum (*E. barberi*), Camden white gum (*E. benthamii*), Brooker's gum (*E. brookeriana*), Morrisby's gum (*E. morrisbyi*), spinning gum (*E. perriniana*), Risdon peppermint (*E. risdonii*), varnished gum (*E. vernicosa*) (Singh et al. 2013), blackwood (*Acacia melanoxylon*), Wally's wattle (*A. pataczekii*) and lemon myrtle (*Backhousia citriodora*). Case study 1.12 describes conservation work on the rare New South Wales species Camden white gum.

During the reporting period, a conservation planting of Miena cider gum (*E. gunnii* ssp. *divaricata*) in Tasmania was destroyed by possums, and the main wild population of the rare Tasmanian endemic *E. morrisbyi* underwent a dramatic decline. Conservation strategies for *E. morrisbyi* are now being coordinated by a recovery group consisting of DPIPWE, University of Tasmania, NRM South[90], the Royal Tasmanian Botanic Gardens, and volunteers. The University of Tasmania has established conservation plantings of this species.

In Australia, native forest genetic resources are also conserved in seed banks, grafted plantings, plantations and biodiversity plantings. Australian forest genetic resources are generally highly accessible, and a very large amount of material has been collected, stored and dispersed throughout Australia and the world (Singh et al. 2013).

Seed banks

Seed banks are an important tool for safe and efficient storage of wild and improved plant genetic material, but require a sound understanding of seed harvest, storage and germination requirements (ASBP 2016). For those species for which seed can be dried and stored, seed banks prolong seed viability and maximise its availability for future research and planting. The ATSC, based in Canberra, maintains a national collection of seeds of more than 800 tree and shrub species in some 77 genera, including more than 240 *Acacia*, 19 *Allocasuarina*, 10 *Casuarina*, 21 *Corymbia*, 280 *Eucalyptus* and 35 *Melaleuca* species. It provides a high-quality, ex situ sample of Australia's tree and shrub genetic diversity. Initially, the ATSC collected and stored seed mostly on a population or provenance basis, but more of its seed is now collected from individual parent trees. These genetically distinct acquisitions are important for ex situ genetic resource conservation.

State, regional and private organisations also maintain seed collections, including state and Australian government botanic gardens, and the Australian PlantBank which was opened

[89] www.environment.gov.au/land/nrs/publications/strategy-national-reserve-system

[90] www.nrmsouth.org.au/

in 2013 at the Australian Botanic Garden, Mount Annan, NSW. The Australian Seed Bank Partnership is a national collaboration between nine seed banks within botanic gardens across Australia, plus three flora-focused organisations. Seed collections in the Partnership include some timber tree species and a wide range of threatened and endangered species. For the majority of the species, the seed bank is the only ex situ conservation mechanism. The Partnership has projects to increase banking of seed from threatened species and from those species susceptible to myrtle rust (see Indicators 1.3a and 3.1a). The seed collections may be used in the future to strengthen or re-establish populations at threat or where localised extinction has occurred (ASBP 2016). Translocation to locations less conducive to myrtle rust may be considered for some species (DoEE 2016a).

Greening Australia also maintains seed collections of species to be used for revegetation purposes[91]: there is a country-wide collection (Nindethana Australian Seeds) which offers over 3,000 species, and 5–6 regional collections (about 40–50 species each), including forest tree and understorey species. Greening Australia and some private organisations also manage seed production areas (SPAs) to produce seed for biodiversity plantings. Greening Australia's largest SPA provides up to 150 understorey species used for restoration of grassy woodlands, largely on cleared agricultural land.

Many Australian organisations, including botanic gardens, continue to contribute to global collections of Australian native forest genetic materials. Since the early 1960s, the ATSC has supplied more than 200,000 certified seed lots from more than 1,000 tree or shrub species to researchers in more than 100 countries. Australia is also a partner in the Millennium Seed Bank Partnership, the largest ex situ conservation project in the world, which is run by the United Kingdom's Royal Botanic Gardens, Kew[92]. At the end of 2015, seed from 35,386 species had been collected as part of the Millennium Seed Bank Partnership goal of banking 25% of the world's flora. Australian partners in Australia's Seed Bank Partnership contributed around 18% of these collections.

Biodiversity plantings

Genetic conservation is also achieved by ensuring that good quality seed from known and appropriate locations and parentage is used in conservation plantings. Several guidelines exist to encourage best practice in seed collection, handling and storage[93], tissue culture, cryopreservation and restoration plantings, including the choice of material that anticipates climate change (Offord and Meagher 2009; SERA 2017; Hancock et al. 2016). Restoration plantings (those where the original source of the planted material is known with certainty) are increasingly contributing to the conservation of forest genetic resources. Greening Australia is currently working with university researchers on provenance selection suited to future climate change scenarios, to inform seed collection for biodiversity plantings. For example, the University of Tasmania and Greening Australia have planted provenance trials of cabbage gum or snowgum (*E. pauciflora*) and black gum or swamp gum (*E. ovata*) in Tasmania in order to test suitability for future climate change scenarios (see Prober et al. 2016).

Genetic diversity research

Information on the genetic diversity and genetic structure of species can be used to inform species management, tree improvement programs, conservation policy, and conservation activities. More than 80 Australian forest flora species have been examined over the past four decades for population genetic variation using molecular or non-molecular techniques. The genetic diversity of several native forest and plantation timber species has been analysed for traits such as variability in wood characters and disease susceptibility, to inform tree breeding strategies. Only a small number of threatened species have been investigated (see for example, Broadhurst et al. 2017).

The reference genome sequence for eucalypts was released during the reporting period by an international consortium, including Australians, working on flooded gum (*E. grandis*) (Myburg et al. 2014). An understanding of the eucalypt genome is expected to improve studies of comparative and evolutionary biology, as well as eucalypt adaptation, and accelerate breeding for productivity and wood quality. The subtropical eucalypt *E. grandis* and the temperate eucalypt southern (Tasmanian) blue gum (*E. globulus*) are key species for tree breeding effort worldwide.

Conservation and use of plantation genetic resources

A substantial proportion of the genetic base of Australian native forest trees used in commercial plantations is conserved in forest in reserves. Much of the genetic base has also been brought into seed collections, tree improvement and breeding programs and seed orchards (plantations specifically planted and managed for seed production).

Table 1.56 lists the key indigenous plantation species (timber and essential oils) in Australia for which seed collections are available for research and commercial purposes (wild-collected seed or improved through tree breeding). These seed collections ensure that the provenance (locality) or parentage of the seed is recorded.

Some collections of plantation genetic resources are held by forest industry agencies and companies, and some by industry cooperatives and research organisations. Most of these organisations are listed in Table 1.57.

Australia's forest genetic resources play an important role in maintaining and improving plantation forest productivity by conserving the original genetic variation in species, and

[91] www.greeningaustralia.org.au/services-native-seed/

[92] www.kew.org/science/collections/seed-collection/about-millennium-seed-bank; brahmsonline.kew.org/msbp/Where/Australia

[93] See www.greeningaustralia.org.au/florabank for example

Table 1.56: Plantation species with reproductive material available in seed collections in Australia[a]

Species	Type of seed material[b]
Acacia auriculiformis	improved
A. crassicarpa	improved
A. mangium	improved
A. melanoxylon	improved
Acacia other species	wild
Araucaria cunninghamii	improved
Casuarina cunninghamiana	wild
C. obesa	wild
Casuarina various species	wild and improved
Corymbia citriodora ssp. *citriodora*	improved
C. citriodora ssp. *variegata*	improved
C. henryi	improved
C. maculata	improved
C. torelliana	cultivated
Eucalyptus argophloia	improved
E. astringens	wild
E. benthamii	improved
E. biturbinata	wild
E. botryoides	improved
E. camaldulensis ssp. *simulata*	improved
E. camaldulensis var. *camaldulensis*	improved
E. camaldulensis var. *obtusa*	improved
E. cladocalyx	improved
E. cloeziana	improved
E. dunnii	improved
E. globulus	improved
E. grandis	improved
E. kochii	wild
E. leucoxylon	wild
E. longirostrata	wild
E. loxophleba ssp. *lissophloia*	improved
E. moluccana	wild
E. nitens	improved
E. occidentalis	improved
E. pellita	improved
E. pilularis	improved
E. polybractea	improved
E. saligna	improved
E. sieberi	improved
E. sideroxylon	improved
E. smithii	improved
E. tereticornis ssp. *tereticornis*	improved
E. tricarpa	improved
E. viminalis	wild
Eucalyptus other species	wild
Grevillea robusta	improved
Santalum album	improved
S. lanceolatum	improved
S. spicatum	wild and cultivated

through providing source material from which desirable traits can be observed and selected. This can occur through selection of tree genotypes of higher growth rate and improved wood quality; selection of genotypes that are better adapted to projected warmer and drier conditions (Byrne et al. 2013); or selection of genotypes that are resistant or tolerant to existing pests and diseases, or that may be resistant or tolerant to future pests and diseases and changing climatic conditions.

Tree improvement and breeding

Tree-breeding and/or improvement programs exist for at least 48 native (indigenous) wood-producing and oil-producing species and varieties (summed across Tables 1.56–1.59).

A range of private companies and state research organisations in Australia manage tree improvement and breeding programs for native wood-supply species grown in plantations (Table 1.57), including through industry cooperatives such as the Southern Tree Breeding Association (STBA). Although breeding populations are maintained mainly for improving commercial wood production, they have an important role in conserving species genetic resources. Plant breeding strategies require a base population with wide-ranging genetic diversity. In Australia, seed for this base population is normally collected from native forest in a range of locations (known as provenances).

The Southern Tree Breeding Association (STBA), formed in 1983, runs a cooperative national tree improvement program for southern (Tasmanian) blue gum (*Eucalyptus globulus*), and provides a database and quantitative analytical services for shining gum (*E. nitens*) and other plantation species. The program for *E. globulus* has been running since the amalgamation in 1994 of genetic material and data from eight selection and breeding programs previously managed by individual organisations. Grafted trees of *E. globulus* have been planted in the National Genetic Resource Centre for plantation forestry at Mount Gambier, South Australia, which was launched in August 2005 with support from the Australian and South Australian governments. Control-pollinated *E. globulus* seed is collected and stored in refrigerators, and diversity is maintained in numerous field trials spread across temperate Australia. The TREEPLAN® genetic evaluation system[94] is being used to update genetic values for *E. globulus* and *E. nitens*.

Table 1.56: Notes

[a] Formal seed collections as listed here are collections made from representative or high-quality trees from known provenances or parents, and are stored in facilities under controlled conditions to maximise seed longevity. This table presents key plantation species and does not include many other species collected for genetic conservation, research, revegetation or international purposes, or seed collected for prompt use by some forestry and revegetation organisations without long-term storage.

[b] For species with improved seed, collections of wild seed from selected provenances are also available.

Source: organisations listed in Table 1.57 as well as the Australian Government Department of the Environment and Energy (Australian Seed Bank Partnership); Northern Territory Department of Primary Industries and Resources; Victorian Department of Environment, Land, Water and Planning; and Western Australian Department of Biodiversity, Conservation and Attractions.

[94] www.stba.com.au/page/treeplan

Table 1.57: Plantation species in tree improvement or breeding programs in Australia

Species	Agency
Acacia melanoxylon	CSIRO, PIRSA, Sustainable Timber Tasmania
Araucaria cunninghamii	HQPlantations Pty Ltd
Corymbia citriodora subsp. *citriodora*	CSIRO, Queensland DAF
C. citriodora subsp. *variegata*	Queensland DAF[a], Seed Energy
C. henryi	CSIRO, Queensland DAF
C. maculata	CSIRO, Australian Low Rainfall Tree Improvement Group[b], PIRSA, Seed Energy
C. torelliana	Queensland DAF
Eucalyptus argophloia	Queensland DAF, CSIRO, Forestry Corporation of NSW[c]
E. astringens	PIRSA
E. benthamii	CSIRO
E. biturbinata	Queensland DAF
E. botryoides	PIRSA
E. camaldulensis	Australian Low Rainfall Tree Improvement Group, CSIRO, PIRSA, Queensland DAF
E. cladocalyx	Australian Low Rainfall Tree Improvement Group, PIRSA, Seed Energy
E. cloeziana	Queensland DAF
E. dunnii	CSIRO/Forestry Corporation of NSW (jointly), SeedEnergy, Queensland DAF
E. globulus	Southern Tree Breeding Association, Australian Bluegum Plantations, HV Plantations, PIRSA, Sustainable Timber Tasmania, WA Plantation Resources (WAPRES)
E. grandis	Queensland DAF
E. leucoxylon	PIRSA
E. longirostrata	Queensland DAF
E. nitens	Private industry, Sustainable Timber Tasmania, HV Plantations
E. occidentalis	CSIRO, Australian Low Rainfall Tree Improvement Group, PIRSA
E. pilularis	Queensland DAF
E. polybractea	Private industry
E. regnans	Sustainable Timber Tasmania
E. saligna	CSIRO, Seed Energy
E. sieberi	CSIRO
E. sideroxylon	CSIRO, Australian Low Rainfall Tree Improvement Group
E. smithii	CSIRO, Australian Bluegum Plantations, WA Plantation Resources
E. tereticornis	Queensland DAF
E. tricarpa	CSIRO, Australian Low Rainfall Tree Improvement Group
Grevillea robusta	CSIRO/Queensland DAF (jointly)
Melaleuca uncinata	PIRSA
Santalum album	Quintis (not Australian provenances)
S. lanceolatum	University of the Sunshine Coast
S. spicatum	Forest Products Commission (WA)

CSIRO, Commonwealth Scientific and Industrial Research Organisation; PIRSA, Primary Industries and Regions South Australia

[a] Until 2012, the Queensland Department of Agriculture, Fisheries and Forestry (DAFF).

[b] The Australian Low Rainfall Tree Improvement Group was formed in 1999 as a partnership between CSIRO and several industry and state forestry organisations in southern Australia. Although external funding ceased in 2009, a range of trials established under this group remain managed by the host organisations.

[c] Until January 2013, Forests NSW.

Source: Information was sourced from replies to data requests sent to plantation owners and managers listed in this table as well as the STBA; Northern Territory Department of Primary Industries and Resources; Victorian Department of Environment, Land, Water and Planning; and Western Australian Department of Biodiversity Conservation and Attractions.

Various state forestry management agencies also maintain tree improvement programs (Table 1.57). With the exception of *E. globulus*, *E. nitens*, *Corymbia* species, selected eucalypts and *Santalum spicatum*, investment in native species tree breeding decreased between 2011 and 2016. Some programs were closed, with plus trees, seed orchards and/or provenance/progeny trials retained but no longer monitored. The numbers of active trials for key species are shown in Table 1.58. A wider range of species is held in seed orchards (Table 1.59) than represented in current tree improvement programs.

The Queensland Department of Agriculture and Fisheries (DAF)[95] manages a range of seed orchards for producing improved seeds of *Eucalyptus* and *Corymbia*. Current tree breeding and improvement research is focused on Gympie messmate (*Eucalyptus cloeziana*) and spotted gums (*Corymbia citriodora* subsp. *citriodora*, *Corymbia citriodora* subsp. *variegata*, *C. henryi* and *C. torelliana*) as well as lemon myrtle (*Backhousia citriodora*), and on determining species susceptibility to myrtle rust (see Indicator 3.1a). Seed orchards of brown salwood (*Acacia mangium*), thick-podded salwood (*A. crassicarpa*) and large-fruited red mahogany (*Eucalyptus pellita*) in Queensland were lost due to cumulative damage from cyclones Larry (2006) and Yasi (2011). Also in Queensland, tree breeding undertaken by HQ Plantations focuses on hoop pine (*Araucaria cunninghamii*, with full and half-sib crosses from existing seed orchards) and a small number of eucalypt species.

Forestry Corporation of NSW[96] manages two seed orchards of blackbutt (*E. pilularis*) that have been retained from a previous tree improvement and breeding program. Hardwood tree improvement is now limited to seed collection from historic blackbutt seed orchards, and maintaining a register of plus trees.

Sustainable Timber Tasmania[97] and its predecessors have maintained a shining gum (*E. nitens*) breeding program for 40 years (Hamilton et al. 2008), producing seed and seedlings for sawlog plantations. They also maintain an active southern (Tasmanian) blue gum (*E. globulus*) breeding program. In Western Australia, the Forest Products Commission has an active breeding program for native sandalwood, *Santalum spicatum*.

Table 1.58: Tree improvement trials for main species in Australia (trials under active management)

		Provenance trials		Progeny trials		Clonal testing and development	
Species	Plus trees[a]	No. of trials	No. of provenances	No. of trials	No. of families	No. of tests	No. of clones tested
Araucaria cunninghamii	876 first-generation	20	50	~100	~900	–	–
Corymbia hybrids	0	–	–	20	500	15	30
C. citriodora	n.a.	3*	~15	3*	~80	–	–
C. maculata	n.a.	~7*	~15	~7*	~150	-	-
Eucalyptus cloeziana	25	–	–	1	–	1	–
E. dunnii	449	–	–	3	260	–	–
E. globulus	n.a.	102	>29	148	>5,903	656	120
E. grandis	115	–	–	–	–	–	–
E. nitens	n.a.	2	–	8	13	600	–
E. pilularis	352	–	–	–	–	–	–
E. polybractea	–	>1	>10	2	89	1	12
E. smithii	–	3	–	5	349	0	0
Eucalyptus hybrids	n.a.	4	–	–	–	~10	~100
Santalum album	115	2	–	6	115	–	–
S. lanceolatum	–	2	–	–	–	–	–
S. spicatum	–	1	6	1	100	–	–
Cathormion umbellatum (host to sandalwood in WA)	4	1	6	–	–	–	–

–, not available; n.a., not applicable; *, combined provenance-progeny trial listed under both headings

This table shows the main species in tree improvement programs as at June 2016 for which trial data are available.

[a] Number of plus trees (superior trees) listed if program is beginning and only first-generation seed orchards have been established, or if the program is ending and only plus trees are retained.

Source: Status as at June 2016, based on consultation with organisations listed in Table 1.57 as well as the STBA and the Western Australian Department of Biodiversity, Conservation and Attractions; data for *Araucaria cunninghamii* are from SOFR 2013.

This table, together with other data for Indicator 1.3b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

[95] Until February 2015, Department of Agriculture, Fisheries, and Forestry.

[96] Until January 2013, Forests NSW.

[97] Until July 2017, Forestry Tasmania.

Table 1.59: Plantation species in seed orchards in Australia

	Seed orchards		
Species	**Number**	**Generation[a]**	**Area (hectares)**
Araucaria cunninghamii	9	1, 1.5, 2, 3	25
Corymbia citriodora subsp. *citriodora*	1	1	2.3
C. citriodora subsp. *variegata*	12	1 and 1.5	>27
C. henryi	2	1	2
C. maculata	9 (including 1 CSO)	1 or 2	15.06
C. torelliana	2	1	3
Eucalyptus argophloia	3 SSO	1,2	4
E. biturbinata	1	1	0.5
E. benthamii	5	1,2	~10
E. botryoides	3	1	2.76
E. camaldulensis	3	1	>1.81
E. cladocalyx	10	1	9.38
E. cloeziana	2	1	7
E. dunnii	13 (including 1 CSO)	1,1.5, 2	>21.0
E. globulus	23 (including at least 1 CSO)	1, 1.5, 2, 3 and 4	>43.2
E. grandis	6	1, 1.5	>9.04
E. kochii	22	1	–
E. loxophleba ssp *lissophloia*	15	1	>2.25
E. loxophleba ssp *gratiae*	1	1	–
E. marginata	2	1	3.17
E. moluccana	1 CSO	n.a.	–
E. nitens	7	1	>12
E. occidentalis	10	1	5.58
E. pilularis	9 (including 1 CSO)	1	15
E. polybractea	21 (including 1 CSO)	1	>3.42
E. saligna	7	1	12.85
E. sideroxylon	1	1	0.44
E. smithii	2	1	6
E. tricarpa	3	1	1.13
Grevillea robusta	2	1,1.5	1.25
Santalum album[b]	5	1	26
S. lanceolatum	2	1	0.4
S. spicatum	5	1	8.77

–, no data; CSO, clonal seed orchard; SSO, seedling seed orchard; n.a., not applicable

[a] Generation refers to first, second, third, etc. breeding cycle in the seed orchard. An entry of 1.5 indicates the orchard is a mix of first-generation seed (wild seed) and improved seed from a first-generation seed orchard.

[b] *S. album* is native to northern Australia, Timor and India. The seed orchards in Australia are unlikely to contain any local provenances.

Source: Status as at June 2016, based on consultation with organisations listed in Table 1.57.

This table, together with other data for Indicator 1.3b, is available in Microsoft Excel via www.doi.org/10.25814/5bda82c8d76d4

Other genetic conservation mechanisms

Aside from currently active tree breeding programs, timber species are conserved in arboreta, plantations, and some species trials and seed orchards that have been retained from earlier tree breeding research. Arboreta and private collections focus on species that are widely cultivated, including species of *Eucalyptus*, *Corymbia* and *Acacia*.

The ATSC has a number of provenance progeny tests (many in partnership with state governments and private growers) that serve as repositories of genetic material for species including thick-podded salwood (*Acacia crassicarpa*), brown salwood (*A. mangium*), the spotted gums (*Corymbia citriodora* ssp. *variegata*, *C. henryi* and *C. maculata*), river red gum (*E. camaldulensis*), sugar gum (*E. cladocalyx*), Dunn's white gum (*E. dunnii*), swamp yate (*E. occidentalis*), large-fruited red mahogany (*E. pellita*), Sydney blue gum (*E. saligna*) and red ironbark (*E. sideroxylon* and *E. tricarpa*) (Singh et al. 2013).

Various forestry agencies have retained some species trials and seed orchards although the formal breeding program has been closed. For example, Western Australia has a rich history of testing many native species for timber and eucalypt oil production, including the eucalypts powderbark wandoo (*Eucalyptus accedens*), narrow-leaved mallee (*E. angustissima*), southern mahogany (*E. botryoides*), river red gum (*E. camaldulensis*), sugar gum (*E. cladocalyx*), karri (*E. diversicolor*), southern (Tasmanian) blue gum (*E. globulus*), pointed-bud mallee (*E. horistes*), York gum (*E. loxophleba*), mottlecah (*E. macrocarpa*), jarrah (*E. marginata*), yellow stringybark (*E. muelleriana*), swamp yate (*E. occidentalis*), blackbutt (*E. pilularis)*, blue-leaved mallee (*E. polybractea*), red mahogany (*E. resinifera*), Sydney blue gum (*E. saligna*), salmon gum (*E. salmonophloia)*, red ironbark (*E. sideroxyloni* and *E. tricarpa*), manna gum (*E. viminalis*), wandoo (*E. wandoo*), river red gum hybrids (*E. camaldulensis* x *E. globulus* and *E. camaldulensis* x *E. grandis*) and spotted gums (*Corymbia maculata* and *C. calophylla*), as well as swamp sheoak (*Casuarina obesa*). Some trials and seed orchards still exist although they are no longer actively managed.

Mallee eucalypt species have been widely planted in Western Australia and inland New South Wales for carbon abatement, salinity management and oil production. The Western Australian Department of Environment and Conservation (DEC)[98] owns seed orchards for blue-leaved mallee (*E. polybractea*) and York gum (*E. loxophleba* subsp. *lissophloia*), although the breeding programs for these species have been closed. Work on blue-leaved mallee selections for improved oil production (e.g. Doran et al. 2016; Tables 1.58 and 1.59) is being carried out by private industry.

Sandalwood plantations in Australia comprise Indian sandalwood (*Santalum album*, using introduced provenances from India, Timor and Indonesia) and, more recently, the native species Australian sandalwood (*S. spicatum*). Seed of *S. spicatum* is harvested from native stands and increasingly from cultivated stands in the Western Australian wheatbelt[99] (see also Table 1.56). Tree breeding work by private industry and the Forest Products Commission WA is aiming to improve selections of *S. album* and *S. spicatum*, respectively, for productivity and oil yield. The University of the Sunshine Coast has established an initial trial of the Queensland native species northern or Cape York sandalwood (*S. lanceolatum*) (Case study 1.11).

Normally, seeds are collected from native forest whenever new genetic material is needed for tree breeding programs. However, seed from several provenances of some eucalypts is no longer available in situ due to a combination of forest loss and protection of populations within conservation reserves (with associated restrictions on commercial seed collection). Some important parts of the genetic material for southern (Tasmanian) blue gum (*E. globulus*) and shining gum (*E. nitens*) are now held only in existing Australian plantations and special-purpose field trials.

Gene flow from plantations

Gene flow from plantations of non-local trees into surrounding native forest could change the genetic make-up of local populations of native trees through a phenomenon called 'introgression'. This involves infiltration of genes from one species or provenance into another through hybridisation (Potts et al. 2001). A number of species in their native habitat have been identified as susceptible to hybridisation with nearby plantations, including swamp peppermint (*Eucalyptus rodwayi*), alpine cider gum (*E. archeri*), and spinning gum (*E. perriniana*) (with shining gum *E. nitens*); black gum or swamp gum (*E. ovata*) (with southern (Tasmanian) blue gum, *E. globulus*; FPA 2011b); spotted gum (*Corymbia citriodora* ssp. *variegata*) (with cadaghi, *C. torelliana*; Wallace and Leonhardt 2015; Shepherd and Lee 2016); and Queensland western white gum (*E. argophloia*) (with a variety of species; Randall et al. 2016). In the case of *Corymbia*, there are some first generation (F1) crosses in the native stands, but not many second generation crosses occur (Wallace and Leonhardt 2015; Shepherd and Lee 2016).

Tasmania has guidelines to reduce the risk of genetic contamination of native stands, particularly where the susceptible species are of high conservation value, through risk assessment, regular monitoring for flowering and hybrid seedlings, and careful decisions regarding replanting of plantations. Other strategies used by the forest industry include careful selection of species and provenances; manipulation of flowering times and flower abundance; and silvicultural practices such as isolation distances, the use of buffer zones of non-interbreeding species, and closer planting to reduce the area of crowns able to produce flowers.

[98] The Department of Environment and Conservation (DEC) was formed on 1 July 2006 by the amalgamation of the Department of Environment and the Department of Conservation and Land Management (CALM). CALM conducted a breeding program on several mallee species for some years. Components of the Department of Environment and Conservation (existed 1 July 2006–30 June 2013) subsequently became the Department of Parks and Wildlife (2013–2017), which has now been absorbed into the Department of Biodiversity, Conservation and Attractions (from 1 July 2017).

[99] www.sandalwood.org.au

International collaboration and engagement

Australia collaborates with tree breeding scientists and forestry organisations in other countries, particularly those with similar climates or where Australian species are planted, to exchange knowledge, seed and tree breeding selections or when collaborators are using integrated genetic evaluation platforms (TREEPLAN® and DATAPLAN®) developed and managed in Australia. For example, the Queensland Department of Agriculture and Fisheries is collaborating with South Africa and Brazil on *Corymbia* species that are suitable for plantations in cerrado, savannah and hot dry regions of 1,000–1,200 mm rainfall. The Forestry Program of the Australian Centre for International Agricultural Research (ACIAR) funds international collaborative projects in Indonesia, Papua New Guinea, Pacific islands, Vietnam, Laos, Nepal and Eastern Africa that address priority development themes, including germplasm conservation, improvement and distribution. The web-based genetic evaluation platform of the STBA also services tree breeding programs in China, France and Sweden, fostering international collaboration between tree breeding scientists on advanced-generation plantation species.

Australia is a party to many international organisations, agreements, treaties, conventions or trade agreements that are directly or indirectly relevant to genetic resource conservation (Singh et al. 2013). These include:

- the Food and Agriculture Organization of the United Nations and its Commission on Genetic Resources for Food and Agriculture
- the United Nations Forum on Forests
- the Convention on Biological Diversity
- the World Intellectual Property Organization and its Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore
- the International Union for the Protection of New Varieties of Plants, established under the International Convention for the Protection of New Varieties of Plants
- the Convention on International Trade in Endangered Species of Wild Fauna and Flora; and
- the International Plant Protection Convention.

In January 2012 Australia signed the 'Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization', which sits within the Convention on Biological Diversity, and is now developing its approach to implementation and ratification. The Nagoya Protocol establishes a legally binding framework for biotechnology researchers and other scientists to gain access to genetic resources. It also establishes a framework for researchers and developers to share any benefits from genetic resources, or traditional knowledge associated with those resources, with the provider country. The Protocol came into force on 12 October 2014. One of the mechanisms for implementing the Nagoya Protocol is the international Access and Benefit-sharing Clearing-House, which is a platform for exchanging information on access and benefit-sharing. The clearing house will exchange information on protocols, permits and permitted uses of genetic resources in different countries and jurisdictions. This will help to facilitate compliance, and provide evidence that genetic resources and associated traditional knowledge were acquired with prior informed consent and on mutually agreed terms.

Eucalyptus nitens seed orchard, Upper Castra, Tasmania, containing grafted clones of high-ranking genotypes selected for growth, basic density and Kraft pulp yield. Source: Sustainable Timber Tasmania.

Case study 1.11: Tree breeding work on northern sandalwood (*Santalum lanceolatum*)

Northern sandalwood (*Santalum lanceolatum*) grows in open forest and woodland forest, and is harvested in Queensland for sandalwood oil production. It is also used traditionally by north Queensland Aboriginal groups to repel insects (by burning wood or leaves), and for stomach upsets (bark and leaves). Local Aboriginal workers were involved in harvesting the wood in the early 1860s, in exchange for flour and tobacco. The wood was shipped to Thursday Island, Singapore or China. However, the industry collapsed in the 1940s (Wharton 2009). In the Cape York Peninsula, *S. lanceolatum* is locally endangered. There is very little regeneration and seed production, and the adult population is sparsely distributed in small clumps that may be clonal.

A University of the Sunshine Coast project, funded by ACIAR, has three goals:

- to conserve this locally endangered species
- to work with the local Aboriginal community to encourage caring for country including protection of this locally endangered species, and
- to select/breed sandalwood trees for potential commercial use.

The project has worked with Cape York communities over the past five years to evaluate the performance of about 30 different Cape York sandalwood trees. Two grafted seed orchards have been planted in north Queensland (Bamaga and Walkaman Research Station) with about 30 individuals in each, to produce seed for research and for plantation development (Figure 1.39). Although young, the seed orchard at Bamaga produced a large seed crop in 2015, and demonstration trials at Bamaga are planned. The long-term aim is that Cape York sandalwood can be used for commercial plantings or enrichment plantings, and a local industry developed to provide regional employment.

Figure 1.39: Young progeny trial of northern sandalwood (*Santalum lanceolatum*) in north Queensland

Case study 1.12: Conservation planting of Camden white gum (*Eucalyptus benthamii*)

The Camden white gum (*Eucalyptus benthamii*) is a medium-to-tall riverine forest tree restricted to the Nepean River and tributaries near Camden in New South Wales. Up to 6,500 individuals occur in Kedumba Valley in Blue Mountains National Park, and much smaller numbers are found in other locations on private land and public reserves. In 2002, the three populations were estimated to contain 10,000, 400 and 18 individual trees respectively (Skinner 2002).

Camden white gum was listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* in July 2000, due in part to its restricted distribution, the threat from land clearing and urban development, and loss of some populations due to the construction of the Warragamba Dam in 1933[100]. The species is of domestic interest for conservation, and is one of the 'big ten' eucalypt species in plantation usage internationally (see Harwood 2011; Grattapaglia 2016). The species has recently emerged as an important pulpwood species in Latin American countries such as Uruguay, because of its cold tolerance combined with rapid growth and an ability to grow well in climates with a summer-uniform rainfall distribution (Harwood 2011). It is also grown in southern China and the southern USA (Bush et al. 2016).

The Australian Tree Seed Centre currently holds seed from the majority of the genetic resources available for this species. Genetic analysis of the three populations found increased inbreeding and inter-species gene flow, a loss of rare alleles from the smallest population, and possible reduced seed set and seed viability in two populations, suggesting the species is at risk of inbreeding due to population fragmentation (Butcher et al. 2005).

Camden white gum is conserved ex situ in two seed orchards at Deniliquin, NSW and one at Kowen, ACT, and a conservation forest planted at the National Arboretum in Canberra (Figure 1.40)[101] (Larmour 1993; Gardiner and Larmour 1995). Grafting of isolated, wild trees into a clonal gene bank and seed orchard is currently underway (Bush et al. 2016). In 2014, the Australian Government published conservation advice on Camden white gum to highlight the actions that can be taken to reduce threats to the species, including seeking conservation agreements for populations on private land, surveying for additional populations, managing any changes to hydrology and riverine flooding that could affect natural regeneration of the species, and ensuring the species is considered in any plans to enlarge Warragamba Dam.

Figure 1.40: Conservation planting of Camden white gum (*Eucalyptus benthamii*) at the National Arboretum, Canberra

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[100] www.nationalarboretum.act.gov.au/living-collection/trees/tree-descriptions/forests-and-trees/forest-30; www.nationalarboretum.act.gov.au/living-collection/trees/tree_stories/camden_white_gum

[101] Ibid

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