The Australian Ecosystem Models Framework:

Eucalypt woodlands

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CSIRO acknowledges the Traditional Owners of the land, sea, and waters, of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture, and we pay our respects to their Elders past, present, and emerging.

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Cover image: *Eucalyptus salmonophloia* obligate-seeder eucalypt woodlands, Helena and Aurora Range, WA (Image: S. Prober)

Contents

The Australian Ecosystem Models Framework

This booklet of factsheets for '*Eucalypt woodlands*' is part of a series that has been developed within the Australian Ecosystem Models (AusEcoModels) Framework. The AusEcoModels Framework is a collaborative project between CSIRO and the Department of Climate Change, Energy, the Environment and Water, and describes a nationally comprehensive set of conceptual models (termed 'archetypes') of ecosystem dynamics in Australia[1]. These articulate an understanding of the dynamic expression of ecosystems under a set of endogenous or reference disturbance regimes. Endogenous disturbances are discrete events (in both space and time) that can disrupt ecosystem structure, or can change resources, substrate availability or the physical environment but maintain ecosystem integrity. They include both anthropogenic and non-anthropogenic-driven disturbances.

Each factsheet in this set describes an archetype model, i.e., a typical example. Boxes in the model diagram are ecosystem expressions that describe manifestations of an ecosystem along a disturbance and biomass recovery pathway where ecosystem attributes (structure, function, composition, abiotic characteristics) are significantly different to other expressions. Some ecosystem expressions will link to expressions that are also described in another archetype model. These are denoted by a white box with a thick green border. Arrows in the model describe pathways between ecosystem expressions, and they represent endogenous disturbances or biomass recovery processes. Endogenous disturbances may also maintain an ecosystem in a particular expression, these are represented by circular arrows attached to a single box. Archetype models may also describe the reference landscape composition of ecosystem expressions (the proportion of a landscape, across space and time, that would be in a particular expression under reference conditions). Please refer to Figure 1 below for a description of the archetype model components.

Each archetype model has been developed with input from ecosystem science experts and scientific publications. Sets of archetype models have been grouped into Umbrella Classes to assist in dissemination, and to demonstrate links to published vegetation classification schemes. Umbrella Classes represent a consolidation of the National Vegetation Information System (NVIS) Major Vegetation Groups (MVG)[2].

Archetype models in the AusEcoModels Framework describe the reference dynamics and ecosystem characteristics to which Australian ecosystems are adapted, and they provide a template to understand and predict how ecosystems respond to more recent, transformative disturbance processes. For example, the AusEcoModels Framework includes a methodology for the application of archetype models to the development of dynamic state and shift models. State and shift models include a reference state (informed by the archetype model) and a set of alternative expressions resulting from the introduction of recent and transformative anthropogenically-driven exogenous disturbances. Both the archetype models and their application to development of dynamic state and shift models inform forecasts of the likely direction and nature of change that ecosystems may experience in the future, and support contemporary ecosystem management, including approaches to maintain ecosystem resilience and adaptive capacity.

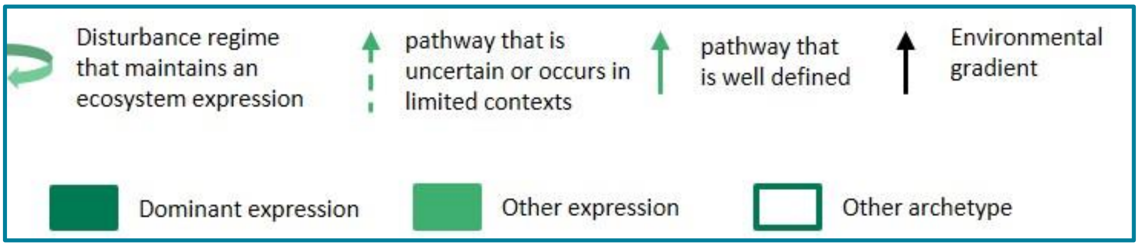

Figure 1: Key to diagrams in AusEcoModels Framework booklets.

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Eucalypt woodlands

Umbrella Class overview

The '*Eucalypt woodland*' umbrella group reflects the concepts of the NVIS (2018) Major Vegetation Groups MVG5 (Eucalypt woodlands), MVG11 (Eucalypt open woodlands), and MVG 12 (Tropical eucalypt woodlands).

Six key woodland types with differing disturbance dynamics can be identified within this umbrella group (Figure 2). The first major distinction is between *'Eucalypt woodlands'* dominated by non-resprouter, obligate-seeder eucalypts characterised by a regime of very infrequent intense fires (*Obligate-seeder eucalypt woodlands*), and the other five woodland types which are dominated by the more common resprouter eucalypts.

Five distinct dynamics are recognised within this latter resprouter eucalypt woodland group. First, *Wet-dry tropical eucalypt woodlands and forests* are distinguished from the other four *'Eucalypt woodlands'*, for their dynamics related to regular seasonal drought (wet-dry tropics) and frequent, low intensity fire.

The remaining four *'Eucalypt woodlands'* include the *Inland floodplain eucalypt woodlands and forests* with dynamics shaped by spatial and temporal variability in surface and groundwater availability, and three dryland temperate and sub-tropical eucalypt woodland types. Of these latter three woodlands, the group *Resprouter temperate eucalypt woodland with heathy understorey* represents more coastward, nutrient-poor woodlands with understorey dynamics that are similar to heathlands. The second group, *Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands* represent somewhat integrating woodland types with grass– to shrub–dominated understorey. These typically occur inland along a gradient from higher to lower ecosystem productivity, and the shrub to grass ratio can increase with decreasing fire. Finally, the *Sub-alpine resprouter eucalypt woodlands* represent the high elevation eucalypt woodlands. Fire regulates the shrub-grass balance in these woodlands as well, but with fire promoting rather than suppressing shrubs.

Ecosystem dynamic models for each of these groups are detailed below.

See also: '*Hummock grasslands'* booklet (Richards et al, In Prep) for related archetype model for *Hummock grassland with sparse eucalypt or other woody overstorey.*

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NVIS Technical Working Group (2018) *Australian Vegetation Attribute Manual, National Vegetation Information System*, Version 7.0. Australian Government Department of the Environment and Heritage, Canberra.

Richards AE, van Etten E, Friedel M, Nano CEM, Pavey C, Rogers D, Schlesinger C, Schubert AT, Watson I, and Wright BR (In Prep*) The Australian Ecosystems Model Framework: Hummock grasslands*, Version 1.0. CSIRO, Australia.

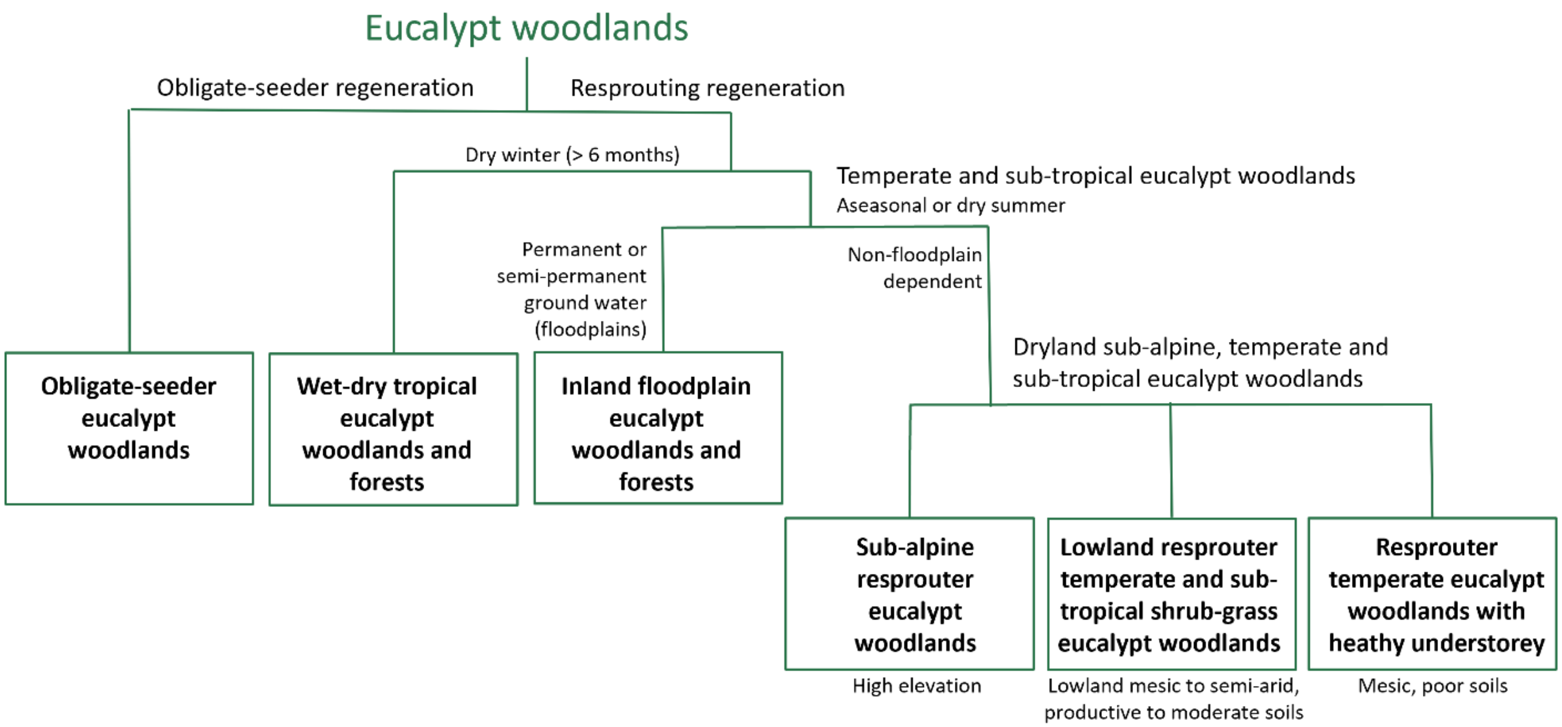

Figure 2: '*Eucalypt woodlands*' Umbrella Class model and ecosystem dynamics.

Obligate-seeder eucalypt woodlands

Obligate-seeder eucalypt species, i.e., those which are easily killed by fire and regenerate predominantly from seed, form extensive woodlands in dry to semi-arid (200-700 mm mean annual rainfall) south-western Western Australia (Prober et al. 2017, Gosper et al. 2018). These trees, including about fifty eucalypt species (e.g., *Eucalyptus salubris, E. salmonophloia* and *E. vittata*), lack well-protected epicormic buds, limiting their ability to resprout.

Consistent with this lack of resprouting after fire, local Aboriginal knowledge indicates that systematic Aboriginal burning was uncommon in these woodlands (Prober et al. 2016). Rather the predominant fire regime is characterised by very infrequent, intense wildfires that typically initiate mass seedling stand replacement (Gosper et al. 2018). This results in post-disturbance vegetation largely comprising a single-aged tree cohort. However, smaller scale disturbances such as storms, individual tree mortality, localised lightning strikes or floods, can lead to mixed-age stands. The understorey in *Obligate-seeder eucalypt woodlands* is typically shrubby, variously dominated by *Melaleuca*, *Eremophila*, *Maireana* or *Atriplex* species. Grasses and forbs contribute to plant diversity, but their cover is low in most seasons. The archetype model for the *Obligate-seeder eucalypt woodlands* (Figure 3) is drawn from Gosper et al. (2018), which includes an extensive bibliography that can provide further information and details on specific attributes of these woodlands.

Ecosystem dynamics

Recruiting woodland

Fire, drought, flood, and intense wind-throw can kill large stands of adult trees. This is followed by dense seedling recruitment, leading to a landscape dominated by recruiting individuals, sometimes with scattered surviving mature trees. After fire, plant species richness is high, reflecting fire-stimulated recruitment from persistent seedbanks of many species (Image 1). Over several decades, this state will shift to a *Dense sapling stand*.

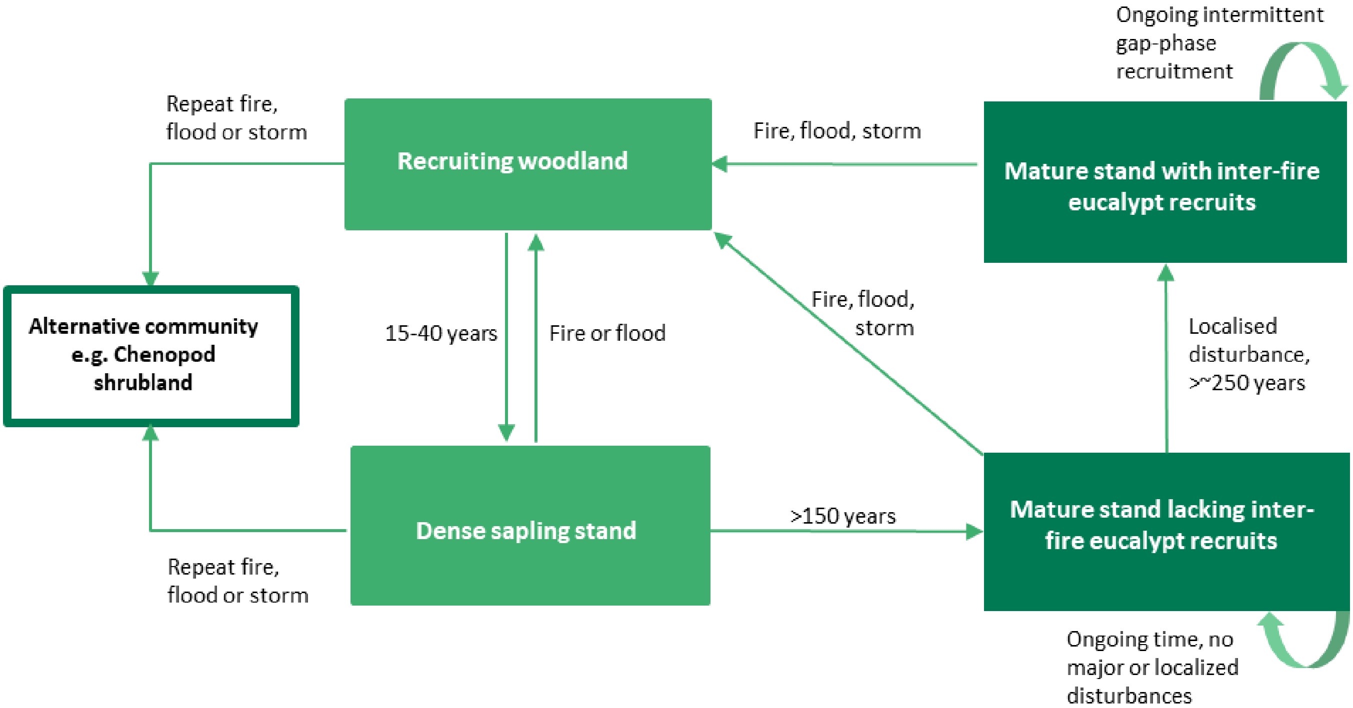

Figure 3: *Obligate-seeder eucalypt woodlands* archetype model.

Image 1: Recruiting woodland after mature obligate-seeder *Eucalyptus urna* (merrit) were killed by fire, Dundas Nature Reserve, WA. (Image: S. Prober).

Dense sapling stand

As the small seedling eucalypts grow, intra-specific competition sets in, resulting in a *Dense sapling stand* with reduced individual growth rates (Image 2). New eucalypt recruits are absent, but canopy seed bank development commences typically 15-20 years after a fire. By 25-50 years post fire, approximately 50% of trees are reproductively mature. Overall native ground layer plant diversity declines as a result of strong competition from the dominant eucalypts and shrubs suppressing diversity. As illustrated in the model, a fire during this stage would cause a shift to a *Recruiting woodland*. Without further disturbance, the *Dense sapling stand* would shift to a *Mature stand lacking inter-fire eucalypt recruits*.

Image 2: Dense sapling stand of obligate-seeder eucalypts, Lake Cronin, WA. (Image: S. Prober)

Mature stand lacking inter-fire eucalypt recruits

If there are no major or localised disturbances within 150 years since fire, the woodland community develops to a stand of large trees of a largely single-aged cohort (Image 3). Tree density will be substantially lower than in *Recruiting woodland* or *Dense sapling stands* as a result of natural thinning processes over time.

Image 3: Even-aged mature stand of obligate-seeder *Eucalyptus salubris* (gimlet) woodland, Lake Johnston, WA. (Image: S. Prober)

Within this mature aged stand an extensive canopy seed bank is maintained, and overall plant species richness is relatively high and increasing, with understorey taxa able to recruit in suitable low-competition microsites (Image 4). A major disturbance would cause a rapid shift to a *Recruiting woodland*, while localised disturbances would cause the gradual development of a *Mature stand with inter-fire eucalypt recruits*.

Image 4: Mature multi-aged obligate-seeder *Eucalyptus salmonophloia* (Salmon gum) woodland, Coolgardie, WA. (Image: S. Prober)

Mature stand with inter-fire eucalypt recruits

This woodland state can occur when small patches of eucalypt recruits develop and grow in localised canopy/root zone gaps following the death of some mature trees. This will then increase the age-diversity of stands and understorey species richness as trees age and thin with stands becoming increasingly open, supporting a diversity of herbaceous and shrubby understorey species. This state can persist indefinitely, but a major disturbance would cause a rapid shift to a *Recruiting woodland.*

Shift to alternative ecosystem types

If young obligate-seeder woodlands are burnt again too soon after a fire, there is likely to be limited seed supply for dense seedling recruitment. In extreme cases this could result in local loss of the eucalypt overstorey, resulting in a shift to other ecosystem types.

This shift has not been well documented but could include the shift to chenopod shrubland in areas of chenopod-dominant understorey, or mallee where mallee was already present.

Experts consulted

Garry Cook, Carl Gosper, Judith Harvey, Adam Liedloff, Lachie McCaw, Suzanne Prober, Kevin Thiele, Libby Rumpff, Colin Yates.

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Wet-dry tropical eucalypt woodlands and forests

Most *Wet-dry tropical eucalypt woodlands and forests* comprise mixed-age tree stands dominated by various eucalypts (*Eucalyptus* spp. and *Corymbia* spp.) over a grassy understorey. These woodlands can grade into open and tall open eucalypt forests in areas of high, but still strongly seasonal rainfall, and the use of the term 'woodlands' here encompasses these taller wet-dry tropical eucalypt forests (see Figure 4 for archetype model).

The tropical eucalypt species in these woodlands are highly tolerant of the frequent, relatively low intensity of fires that dominate the wet-dry tropical landscapes, including Indigenous fire management that has been practised for millennia (Russell-Smith et al. 2003). If top-killed, these species generally resprout from their lignotuberous bases or root suckers (Williams et al. 1999). Other associated tropical genera contribute many midstorey species and co-dominants. They may be less fire-tolerant but are also generally strong resprouters.

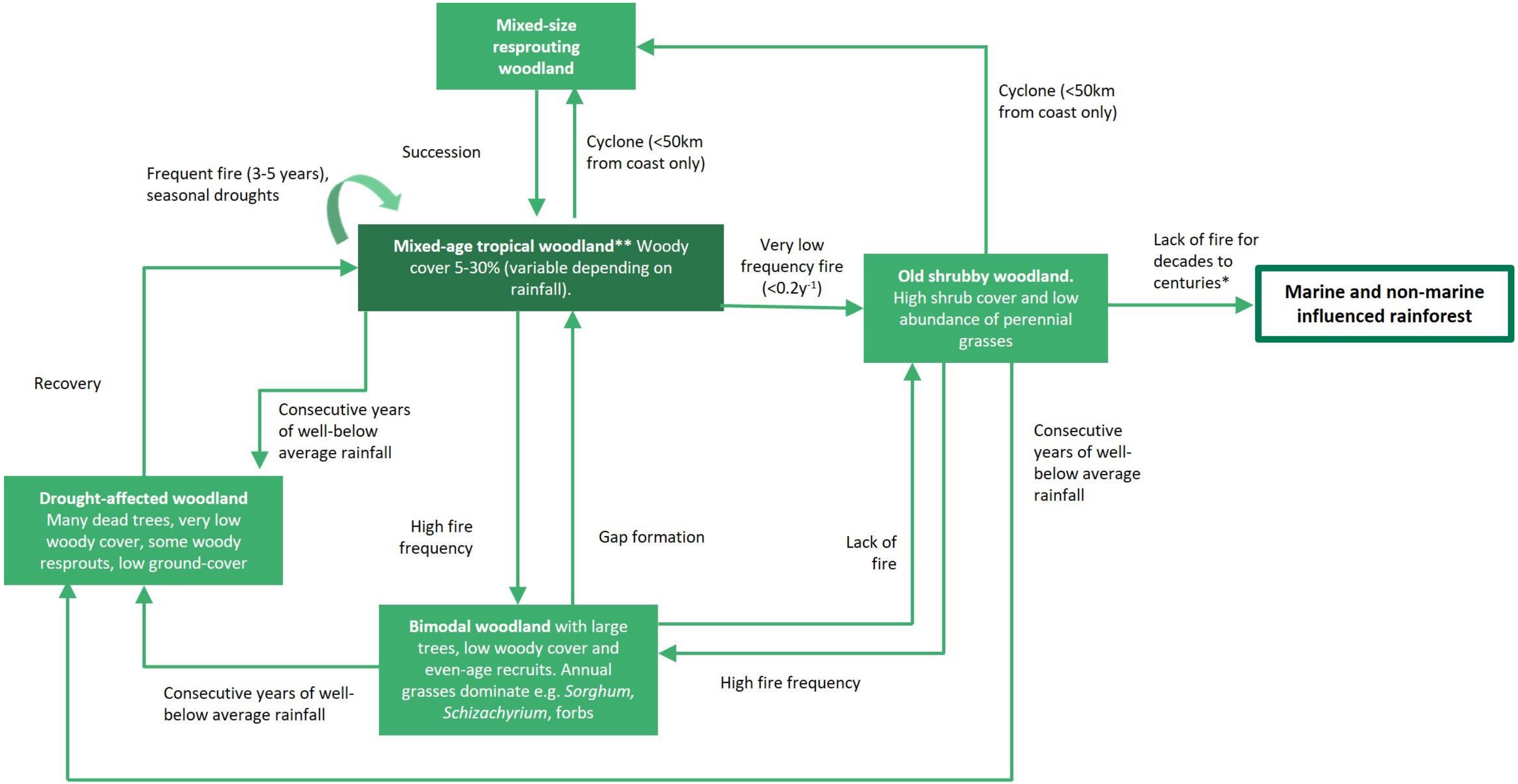
Many of these ecosystems are called savannas in Australian literature. In savannas elsewhere on the globe, fire can cause a bottleneck limiting tree recruitment into the canopy, but in these Australian ecosystems, eucalypts are much less affected by the fire-induced bottleneck.

These woodlands do not release seeds after fire but typically have a large bank of lignotuberous resprouts. Recruitment of these resprouts into the canopy is slow, but continuous at a landscape scale so that most of these woodlands have mixed-age stand structures (Cook et al. 2016).

Ecosystem dynamics

Two main disturbance processes drive the ecosystem dynamics of the *Wet-dry tropical eucalypt woodlands and forests*. These are frequent (typically several per decade), relatively low intensity fires (usually < 15 MW m^{-1}) and both seasonal (late dry season) and major multi-year droughts with return periods of many decades (Murphy et al. 2015). Seasonal drought is a major factor that sets the carrying capacity of a landscape for trees, as evidenced by observations of juvenile tree death in the late dry season and the decline in the total tree basal area with decreasing rainfall.

In these ecosystems, tropical C4 (warm season) grasses and forbs thrive on frequent fires of intervals < 5 years, as long as those fires are not implemented in the driest months (August to November) where they can be damaging to grass tussocks. Having regular fires every two to five years, especially during times when there is higher soil moisture, promotes a patchily burnt landscape with a mosaic of patches of different ages.



*Only occurs in ecotones where there is sufficient moisture

**Common woody genera include *Eucalyptus, Corymbia, Acacia, Bauhinia, Terminalia, Grevillea, Carissa.* Cover / height of woody overstorey declines with increasing aridity

Figure 4: *Wet-dry tropical eucalypt woodlands and forests* archetype model.

Mixed-age tropical woodland

The most familiar expression of *Wet-dry tropical eucalypt woodlands and forests* is *Mixed-age tropical woodland*. This is characterised by mixed-age eucalypt stands over a grassy understorey (Image 5). This expression is maintained by frequent, relatively low intensity fires as described above. Decreases or increases in fire intensity or cyclones (within 50 km of the coast) can drive this towards a range of other expressions described in the model.

Image 5: Mixed-age *Eucalyptus miniata* (Darwin woollybutt) woodland, Litchfield NP, NT. (Image: S. Prober)

Bimodal woodland with large trees and even-age recruits

Modelling and observational studies indicate that in some circumstances fire regimes can lead to ecosystems dominated by larger trees, with relatively few small to intermediate trees (Cook et al. 2015). Large-scale disturbances such as regional droughts and hot fires can subsequently lead to pulsed recruitment and the development of stands with a bimodal size class distribution. Such ecosystems would be unstable, with the death of older trees creating gaps that could be colonised by juveniles, leading to the redevelopment of mixed-age stands (Image 6).

Image 6: Bimodal woodland with a young and an old age class evident, East Arnhem land, NT. (Image: G. Cook)

Large overstorey trees can suppress the growth of juveniles, causing top-kill late in the dry season. Evidence of woodland thickening in savannas of north-eastern Australia – both of increasing size of existing trees and recruitment of saplings have been interpreted as a consequence of reduced use of fire associated with the advent of commercial grazing (Burrows et al. 2002), but is more likely to be a response to historic droughts (Murphy et al. 2015).

Old shrubby woodland

The eucalypt-dominant tropical woodlands typically have an understorey of perennial tussock grasses or annual sorghums in high rainfall areas (Williams et al. 2017). However, there is also a wide range of shrubs which may be obligate-seeders e.g., many species of *Acacia*, or strong resprouters. Long periods without intense fires can lead to a shift of these shrubs into trees. Longer fire-free intervals promote shrub growth in many ecosystems, especially those with sandy soils (Image 7). Under these circumstances, grass growth may be suppressed (Scott et al. 2012).

Image 7: Long-unburnt shrubby woodland with shrub and liana understorey, Berrimah, NT. (Image: S. Prober)

Mixed-size resprouting woodland

Northern Australian woodlands, unlike those of most of the world's tropics, are affected by tropical cyclones and the effects of these are strongest within 50 km of the coast. Cyclonic winds cause savanna trees to be uprooted or snapped and the subsequent fires can then kill damaged trees (Hutley et al. 2013). Such disturbances lead to pulsed recruitment that can be seen in stand age structures (Image 8).

Image 8: Mixed-size resprouting eucalypt woodland, showing resprouting, recruiting and dead trees after cyclone then fire, Lockhart River, Qld. (Image: S. Prober)

Shift to marine-influenced and non-marine influenced rainforest

Eucalypt-dominant tropical woodlands are rarely observed to shift to other vegetation types. Long fire-free periods (decades to centuries) can lead to conversion to monsoon forest or vine thicket (captured in the archetype models: *Marine-influenced rainforest* and *non-marine influenced rainforest*) and the probability of this conversion is greater in higher rainfall regions (e.g., Russell-Smith J et al. 2004).

Experts consulted

Garry Cook, Anna Richards.

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Inland floodplain eucalypt woodlands and forests

Inland floodplain eucalypt woodlands and forests occur on floodplains and line watercourses across most of inland Australia. A common and widespread dominant is *Eucalyptus camaldulensis* (river red gum), which can form forests along more frequently flooded edges of large watercourses, and woodlands in less frequently flooded areas. Other common inland floodplain eucalypts include *E. rudis, E. largiflorens, E. microtheca, E. coolabah* and *E. victrix.* Established trees often use ground water if it is accessible and of adequate quality but are susceptible to mortality if ground water declines and rainfall is low. The dynamics of the *Inland floodplain eucalypt woodlands and forests* are thus controlled by hydrological regimes, including flood and drought cycles, with uncommon and poorly understood influences of fire (Figure 5; Mac Nally et al. 2011, Good et al. 2017).

Image 9: Mature *Eucalyptus camaldulensis* (river red gum) floodplain forest, Perricoota State Forest, NSW. (Image: S. Prober)

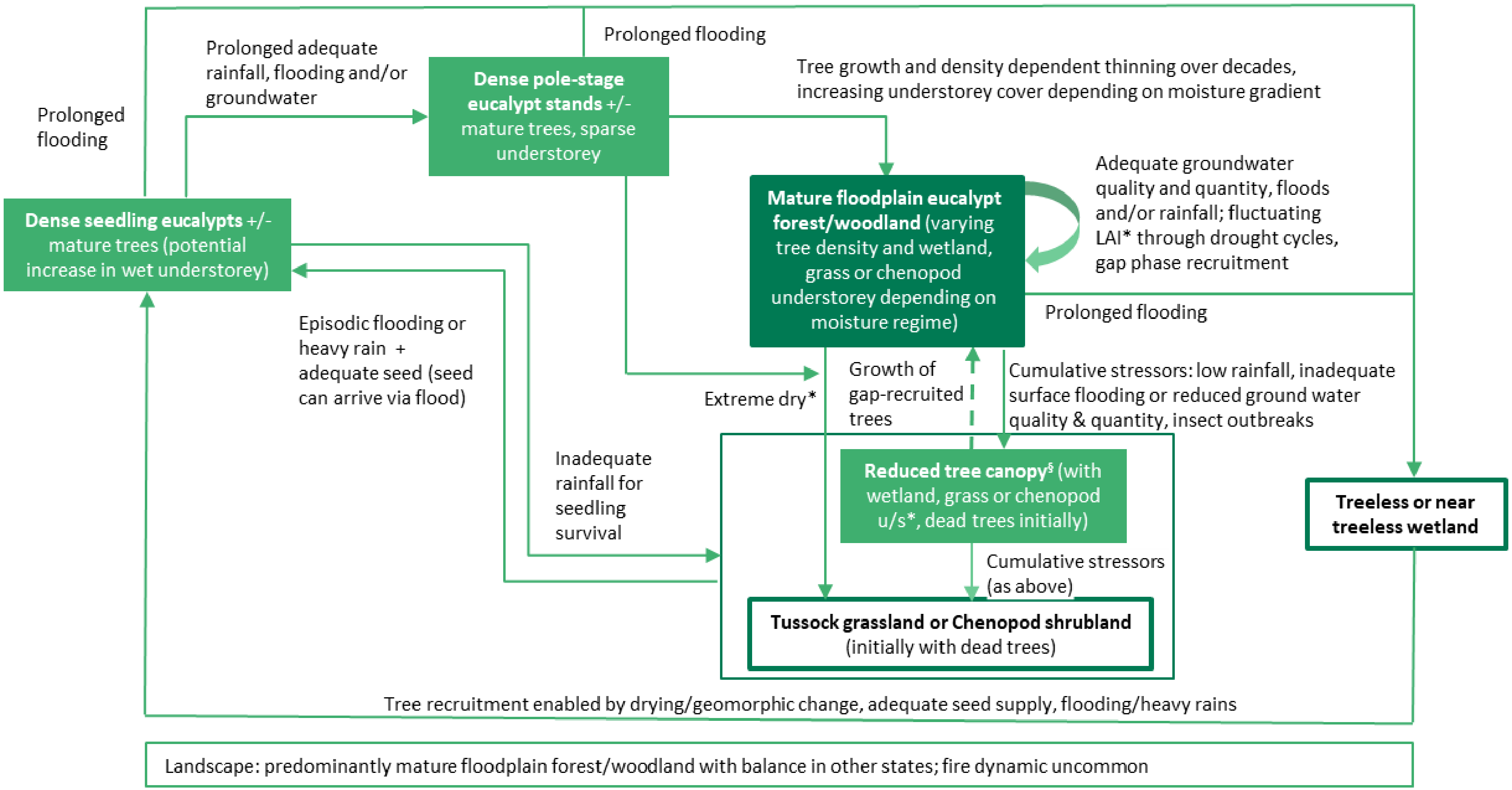
Ecosystem dynamics

Mature floodplain woodland/forest

The mature forms of floodplain woodlands and forests grade in structure from open eucalypt woodlands on drier floodplains (Image 9) to open eucalypt forests in more mesic environments (Image 10). Under adequate water regimes, mature stands can be maintained through gap-phase recruitment (Good et al. 2017).

Image 10: *Eucalyptus largiflorens* (black box) mature floodplain woodland with *Duma florulenta* (lignum) understorey, Jerilderie NSW. (Image: S. Prober)

Understorey composition and cover also varies with moisture regime. For example, on broad floodplains, understorey of mature woodlands and forests can grade from a moderate cover of grasses, forbs and/or chenopods in less frequently flooded areas, peaking at a high cover of reeds, sedges, rushes, and forbs in regularly flooded areas, and sometimes declining to a low understorey cover in very frequently inundated areas. Shrubs such as *Duma florulenta* (Lignum) and *Melaleuca* and *Acacia* species can also be present.



*>century scale
*LAI=leaf area index
*u/s= understorey
§reduced canopy of large mature trees

Figure 5: ***Inland floodplain eucalypt woodlands and forests*** **archetype model.**

Reduced tree canopy and grassland/ chenopod shrubland expressions

Excessive periods with inadequate groundwater, flooding, and rainfall and/or severe invertebrate outbreaks, can result in patchy to extensive mortality of mature eucalypts. Patchy mortality results in a *Reduced tree canopy* expression (Image 11), whereas extensive mortality leads to a shift in vegetation structure to *Tussock grassland* or *chenopod shrubland*. Where these canopy changes are driven by a lack of rain or flood, the shrub and ground layer are also expected to show a drying trend, for example from wetland to grassland species.

Standing dead trees can remain apparent and serve as habitat trees for many decades. Under appropriate conditions and where seed is available, e.g., from remnant trees or via floodwaters, trees may recruit densely into these expressions, leading to a return to a mature forest or woodland structure over long timeframes.

Image 11: Reduced tree canopy in *Eucalyptus camaldulensis* (river red gum) woodland associated with drought (also exacerbated by anthropogenic stressors), Koondrook State Forest, NSW. (Image: S. Prober)

Treeless or near treeless wetland

Prolonged flooding can result in the death of mature, seedling or sapling eucalypts, leading to a *Treeless or near treeless wetland* across parts of the range of floodplain forests and woodlands where such floods occur (e.g., Murray-Darling Basin). Eucalypts can also recruit back into the wetland when drying occurs, assuming an adequate seed supply is present.

Dense seedling eucalypts

Episodic flooding in treeless (grassland, shrubland, wetland) or reduced canopy expressions promotes mass recruitment of seedling eucalypts, leading to dense stands or patches of seedling eucalypts respectively. Mature trees may be emergent. Flooding may also promote a temporary shift towards more wetland or aquatic plant species in the understorey.

Dense pole stage eucalypt stands

Survival of seedlings after mass recruitment events depends on adequate follow-up rainfall, groundwater and/or flooding and evasion of herbivory over extended periods (e.g., ten years). Low levels of competition from adult trees also promote survival – favouring survival in areas where trees were removed by earlier stressors or more recent flooding. These interacting drivers can result in a pattern of patchy stands of pole stage eucalypts across a landscape (Image 12).

Where there is adequate post-flood moisture for survival, young eucalypts in dense regeneration stands are subject to density dependent thinning, likely expedited during dry periods and eventually resulting in the mature woodland structure.

Image 12: Dense pole stage stand of *Eucalyptus camaldulensis* (river red gum), Gunbower Icon Forest, Vic. (Image: K. Bennetts)

Knowledge gaps

The role of fire, including Aboriginal burning regimes, is poorly understood for *Inland floodplain eucalypt woodlands and forests*.

Experts consulted

Kate Bennetts, Matt Colloff, Jean Dind, Tanya Doody, Doug Frood, Tim Lersch, Gillis Horner, Heather McGuinness, Megan Good, Stephen Roxburgh, Libby Rumpff, Suzanne Prober, Genevieve Smith.

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Sub-alpine resprouter eucalypt woodlands

Sub-alpine resprouter eucalypt woodlands are prominent on cold mountain slopes and in frost hollows across the highlands of south-eastern Australia, at elevations from c. 1000 –1800 m (extending to the treeline). They are typically dominated by snow gum (*Eucalyptus pauciflora* or its close relatives *E. niphophila* or *E. debeuzevillei*) or black sally (*E. stellulata*) and can reach up to 15 m in height (Keith 2004).

These woodlands show a characteristic fire-related dynamic leading to two main expressions: *Sub-alpine eucalypt woodlands with a grassy understorey*, and *Sub-alpine eucalypt woodlands with a shrub understorey* (Figure 6). Woodlands can also rarely shift to grasslands or shrublands in the event of extremely hot fires that leave insufficient eucalypt propagules (lignotubers or seed) for post-fire regeneration (Banks 1982). It is not clear how easily these revert back to woodland as eucalypt propagules arrive from nearby stands.

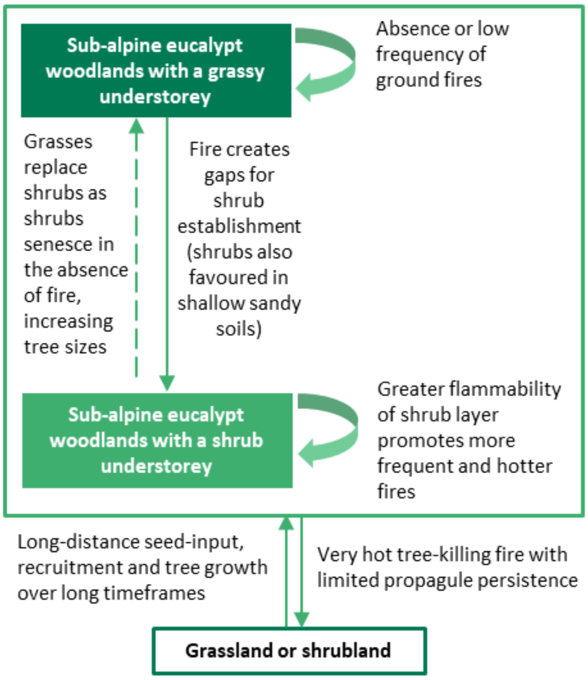

Figure 6: *Sub-alpine resprouter eucalypt woodlands* archetype model.

Ecosystem dynamics

Sub-alpine eucalypt woodlands with a grassy understorey

Sub-alpine eucalypt woodlands with a grassy understorey are the iconic open woodlands of Australia's sub-alpine landscapes, characterised by well-spaced, large-boled trees above an open grassy understorey with numerous forb species (Image 13 and 14). Trees are notable for their ribboned bark and can become particularly colourful and gnarled at the highest elevations due to snow and harsh winds.

Image 13: Sub-alpine eucalypt woodland with a grassy understorey, Bogong High Plains, Victoria. (Image: J. Morgan)

Image 14: Sub-alpine eucalypt woodland with a grassy understorey, Charlotte's Pass, NSW. (Image: L. Watts)

Fire is considered to have been uncommon in these open, grassy woodlands. Trees can live for up to 400 years, and eventually die due to the cumulative burdens of windthrow, ground-fire, snow, and insect damage. Thus, long periods without intense or frequent fire promote increasingly mixed-age stands with gap recruitment (Banks 1982).

Higher fire frequency or intensity of fire can create gaps in the grassy ground-layer, enabling shrub establishment and damaging mature trees (Banks 1982, Good 1982). This can drive shifts to *Sub-alpine eucalypt woodlands with a shrub understorey*.

Sub-alpine eucalypt woodlands with a shrub understorey

The *Sub-alpine eucalypt woodlands with a shrub understorey* expression is characterised by a higher prominence of shrubs in the understorey and a dense, more even-aged overstorey. The more frequent wildfires that promote the shrub layer can kill above-ground stems of eucalypts or progressively weaken and kill large trees. This leads to dense 'whipstick'-like or multi-stemmed overstoreys developing from basal resprouts and/or seedlings, that can persist for decades. Seedling eucalypt recruitment may continue to occur for about 10 years after fire, but late-recruits are less competitive and more likely to perish through natural thinning (Banks 1982).

The fire- driven increase in shrubs in *Sub-alpine resprouter eucalypt woodlands* is counter to the pattern of shrub encroachment associated with fire suppression in more semi-arid shrub-grass eucalypt woodlands. Lunt et al. (2012) suggest this different dynamic could be due to greater flammability and continuity of the shrub layer in the sub-alpine compared with semi-arid woodlands. Indeed, encroaching shrubs in *Sub-alpine resprouter eucalypt woodlands* increase the potential fire frequency and spread (Williams *et al.* 2006, Fraser et al. 2016), acting to maintain the *Sub-alpine eucalypt woodlands with a shrub understorey* expression. These observations are consistent with the high flammability of *Bossiaea foliosa* and other prominent legumes in the understorey (Banks 1982), noting though that wildfires, and hence the shrubby expression, were considered uncommon prior to European colonisation (Banks 1982, Good 1982).

A greater balance of shrubs in the understorey can also be influenced by interactions with substrate, with shrubs favoured in shallower, sandy, or dry soils, and grasses and forbs favoured by deeper, alpine humus soils (Image 15; Banks 1982; Keith 2004, Williams et al. 2014).

It is expected to take over 100 years without fire to return to the *Sub-alpine eucalypt woodlands with a grassy understorey.* Sufficient time is needed for eucalypt stems to thin and reform into open stands of larger trees, and for shrubs to senesce and make way for the return of grasses and forbs.

Image 15: Sub-alpine eucalypt woodland with a shrub understorey, Mt Baw Baw, Victoria. (Image: S. Prober)

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Suzanne Prober, Richard Williams.

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Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands

Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands in their mature form are dominated by an open woodland of resprouter eucalypts with a mixed-age distribution. They are common across inland south-eastern Australia, central Queensland, and south-western Australia. Tree stand structures are thought to be typically mixed-age, maintained by gap-phase recruitment. Dynamics are characteristically driven by frequent to episodic low intensity fires, drought cycles and/or fire exclusion (Figure 7; Prober et al. 2017a, b).

The understorey can be dominated by shrubs, or by C3 (cool season) and C4 (warm season) tussock grasses with diverse native forbs. The probability of shrub dominance in the understorey increases as the ecosystem productivity decreases, related to increasing aridity and/or decreasing soil fertility.

Along this productivity gradient, low intensity fires can increase the relative prominence of the grass layer, as reflected in the model. C3 grasses are more common in the south, and C4 grasses are prominent in the north or with more frequent fire (Prober et al. 2017a, b).

In mesic areas of eastern Australia, most often west of the Great Divide and associated Tablelands, native pine (*Callitris* spp.) can become prominent, leading to mixed *Eucalypt-native pine woodlands* (Prober et al. 2017a).

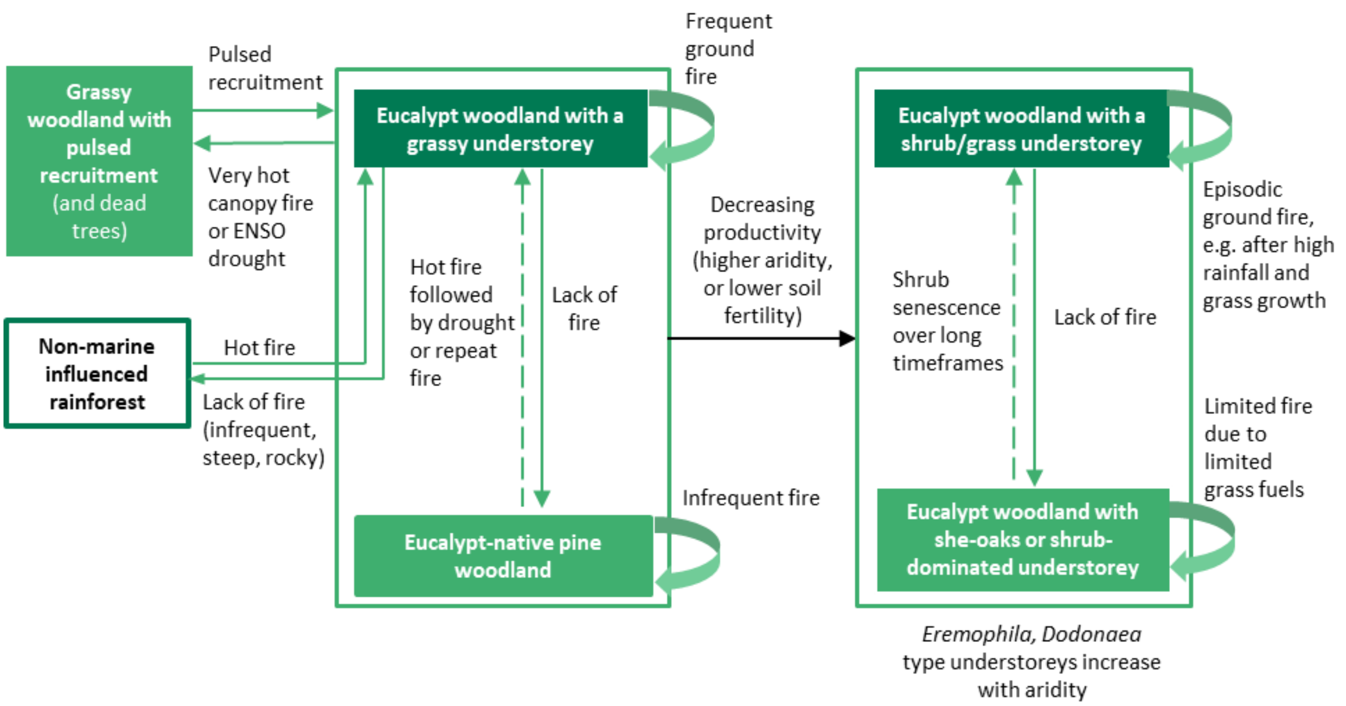

Figure 7*: Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands* archetype model.

Ecosystem dynamics

Eucalypt woodland with a grassy understorey

Eucalypt woodland with a grassy understorey is characterised by an understorey of tussock grasses with diverse native forbs, scattered or patchy shrubs and by a suite of resprouter eucalypts in the overstorey (e.g., *Eucalyptus albens, E. melliodora, E. loxophleba*) (Image 16). Grassy woodlands predominate in mesic parts of the woodland zone, with the grassy understorey likely also promoted by low intensity fires.

Image 16: *Eucalyptus albens* (white box) grassy woodland, Orange, NSW. (Image: S. Prober)

Grassy woodlands with pulsed recruitment

Regional droughts, particularly in southern Queensland can lead to mass tree mortality followed by pulsed recruitment. Similarly fires of extreme intensity can cause widespread top-kill of trees. Stands of dead trees can persist for decades. This process is similar to that in central Queensland savanna ecosystems (see *Wet-dry tropical eucalypt woodlands and forests*). Pulses of recruitment of trees could occur via either seedling germination or basal resprouts. Over time these trees will enter the mature canopy overstorey (Fensham et al. 2017).

Eucalypt-native pine woodland

In the absence of frequent fire, species of native pine (e.g., *Callitris glaucophylla or C. endlicheri*) can colonise gaps to create a mixed *Eucalypt-native pine woodland* (Image 17). During the first decade or two after *Callitris* recruitment, they resemble a shrub layer within the woodland, and gradually become canopy trees. If a seed source and favourable conditions occur, mass recruitment of *Callitris* can occur after major disturbances such as a very intense fire. *Callitris* has limited fire tolerance, and if killed by subsequent fires the ecosystem can return to a grassy woodland (see *Callitris woodland* dynamic ecosystem model). *Callitris* is absent from substantial parts of the *Lowland resprouter temperate and subtropical shrub-grass eucalypt woodland* particularly some higher elevation eastern parts of NSW.

Image 17: *Eucalyptus melliodora* (yellow box) – Callitris woodland, Barellan, NSW. (Image: S. Prober)

Eucalypt woodland with a shrub/grass understorey

This ecosystem occurs in more arid or less productive environments than the grassy woodland. It has a more consistently developed shrub layer above the grassy understorey (Image 18). Episodic fire after good rains promotes grass growth, preventing the shrub layer from becoming more continuous.

Image 18: *Eucalyptus populnea* (poplar box) shrub-grass woodland, Condobolin, NSW. (Image: S. Prober)

Eucalypt woodland with she-oaks or shrub-dominated understorey

Shrub woodlands may have occurred on plains in drier ecosystems in the long absence of fire, including a prominence of shrub species in the genera *Dodonaea* and *Eremophila* (Image 19). It is uncertain how prevalent they were prior to 1750. Woodlands with shrub-dominated understoreys are also prominent on poor soils and steeper sites (e.g., Warrumbungle Ranges).

Image 19: *Eucalyptus populnea* (poplar box) shrub woodland, Ungarie, NSW. (Image: S. Prober)

In areas such as the Western Australian wheatbelt, she-oaks (*Allocasuarina huegeliana* and *Casuarina obesa*) can similarly establish in *Resprouter temperate shrub-grass eucalypt woodlands* (e.g., *E. loxophleba* woodlands) in specific parts of the landscape when fire becomes too infrequent. *A. huegeliana* can become prominent in areas with shallow soils over granite, and *C. obesa* in areas where water accumulates.

As she-oaks and understorey shrub species in this expression typically resprout or sucker it is not clear whether or how eucalypt woodlands with she-oaks or shrub dominated understoreys return to eucalypt-dominated expressions. It is likely, that a long period without fire is required for the woody species to senesce and permit grass re-establishment.

Knowledge gaps

Aboriginal burning regimes are not well documented for *Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands*, and greater understanding of the dynamics of potential non-eucalypt overstorey dominants is needed.

Experts consulted

Garry Cook, Chris Curnow, Carl Gosper, Mike Griffiths, Nathan McQuoid, Helena Mills, Libby Rumpff, Suzanne Prober, Colin Yates.

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Resprouter temperate eucalypt woodlands with heathy understorey

Resprouter temperate eucalypt woodlands with heathy understorey are typically found in more mesic or sandy parts of the distribution of eucalypt woodlands, with dominant eucalypts including *Eucalyptus ovata, E. baxteri*, *E. amygdalina, E. wandoo*, *E. accedens*, *E. gomphocephala*, and *Corymbia calophylla*. Their typically diverse heathy understorey is maintained by intermittent fires. The frequency and intensity of those fires are likely to play a significant role in their dynamics, however, information about fire regimes and vegetation response is limited (Figure 8). The concepts put forward below represent plausible hypotheses based on extrapolation from pure heathland ecosystems.

Ecosystem dynamics

Heathy woodland with diverse shrub/sedge understorey

Mature *Resprouter temperate eucalypt woodlands with heathy understorey* are dominated by an open woodland of resprouter eucalypts with a mixed-age distribution (Image 20). The understorey is dominated by perennial woody shrubs and graminoids with the abundant families being Proteaceae, Fabaceae, Mimosaceae, Myrtaceae, Ericaceae and Cyperaceae (Bell and Heddle 1989, Chick 2016, Chick et al. 2018). Intermittent low intensity fires that do not top-kill trees maintains this state.

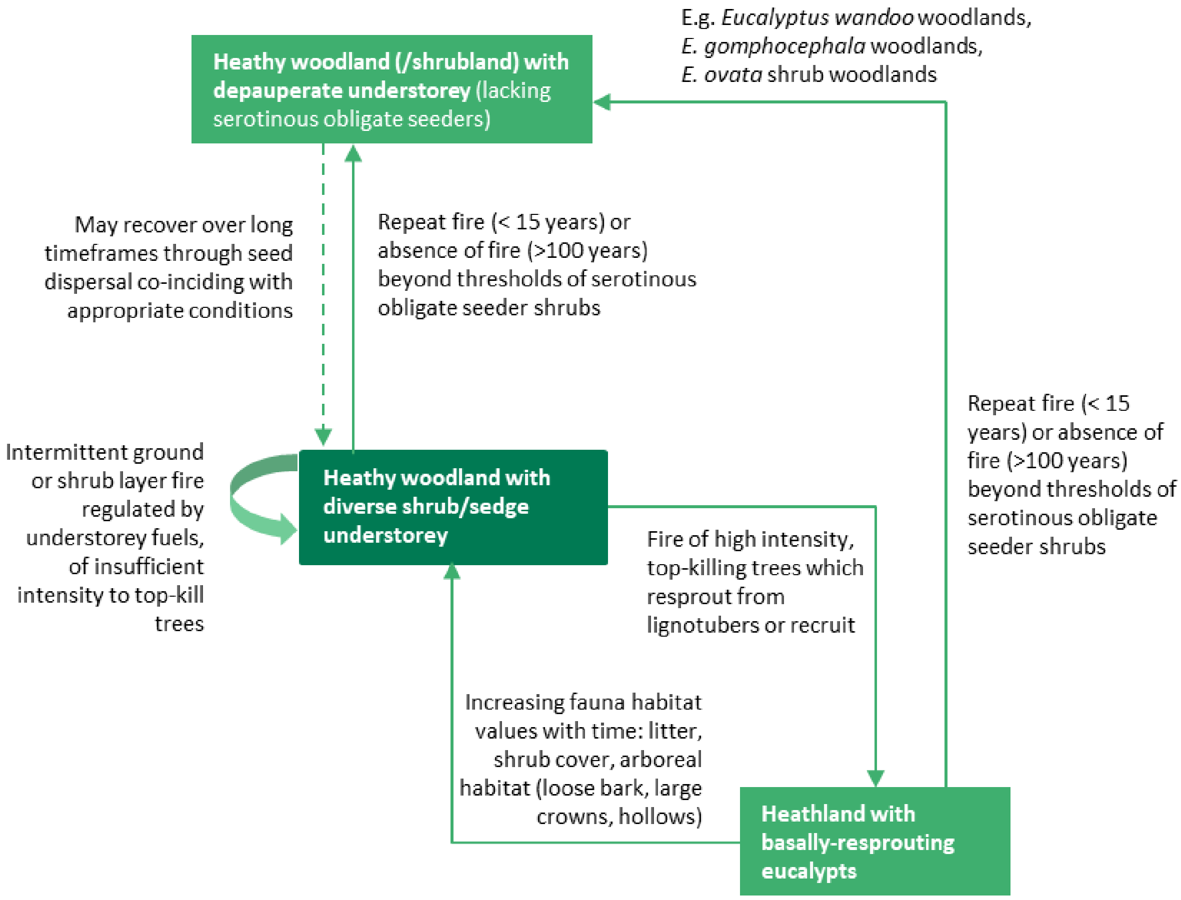

Figure 8: *Resprouter temperate eucalypt woodlands with heathy understorey* archetype model.

Image 20: *Eucalyptus accedens* (powderbark wandoo) woodland with heathy understorey, Uberin Rock, WA. (Image: S. Prober)

Heathland with basally resprouting eucalypts

A fire of high-intensity may top-kill most of the canopy eucalypts. The heathy shrubs and overstorey eucalypts may resprout basally or regenerate from seed (Image 21). Over time without another high-intensity fire, the eucalypts can reform a canopy. Frequent fires could lead to the establishment of a heathy woodland with depauperate understorey.

Image 21: Basal resprouting in burnt *Eucalyptus wandoo* (wandoo) woodland with heathy understorey, Brookton, WA. (Image: S. Prober)

Heathy woodland with a depauperate understorey

These ecosystems have a reduced abundance of obligate-seeder shrubs that lack soil seedbanks. Graminoids may have a higher dominance although this is not well documented. This ecosystem can result after very frequent fire, so that obligate-seeder shrubs are killed before they produce seed. Alternatively, a long absence of fire may lead to senescence of shrubs without replacement. The ecosystem may resemble heathland if overstorey eucalypts are in basal resprouter stage.

It is not known how easily and under what conditions the obligate-seeders can re-establish.

Experts consulted

Carl Gosper, Suzanne Prober, Colin Yates

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