Hawkesbury Institute for the Environment

COASTAL IFOA MONITORING PROGRAM

Review of the impact of injuries to retained trees during forestry operations conducted under the Coastal IFOA in New South Wales – Final Report

August 2023

A report submitted to the New South Wales Government Natural Resources Commission

Acknowledgement of country

With respect for Aboriginal cultural protocol and out of recognition that its campuses occupy their traditional lands, Western Sydney University acknowledges the Darug, Eora, Dharawal (also referred to as Tharawal) and Wiradjuri peoples and thanks them for their support of its work in their lands (Greater Western Sydney and beyond).

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1 Abbreviations

Abbreviation	Description
mm	millimetres
cm	centimetres
m	metres
km	kilometres
m^2	square metres
ha	hectare
CO_2	carbon dioxide
H_2O	water
DBH	diameter at breast height
DSHOB	diameter at stump height over bark
spp.	species
NSW	New South Wales
EPA	NSW Environment Protection Authority
FCNSW	Forestry Corporation of NSW
NRC	NSW Natural Resources Commission
Coastal IFOA	Coastal Integrated Forestry Operations Approval
WHS Act	Work Health and Safety Act 2011
ESA	Environmentally Significant Area
BNA	Base Net Area
NHA	Net Harvest Area

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2 Review context

2.1 Background

The Coastal Integrated Forestry Operations Approval (Coastal IFOA) was approved by the NSW Government in late 2018. It establishes the conditions and settings to enable forestry operations on NSW State Forest and Crown-timber land and includes provisions for the protection of the environment and for threatened species conservation.

The NSW Government intended the new Coastal IFOA to deliver a contemporary outcomes-based regulatory framework to reduce the costs associated with implementation and compliance and improve clarity and enforceability. It established over twenty outcome statements. The Coastal IFOA must be interpreted in a manner that is consistent with achieving and giving effect to the outcome statements. However, they are not enforceable on their own.

The conditions set mandatory actions and controls for protecting threatened plants and animals, habitats, soils and water. The conditions are supported by protocols, which set out additional enforceable actions and controls for effective implementation of the Coastal IFOA.

The Coastal IFOA requires continual monitoring of the effectiveness of its conditions and the extent to which its objectives and outcomes are achieved. This is achieved through the Coastal IFOA Monitoring Program, which is overseen by the Natural Resources Commission (the Commission) on behalf of the cross-agency NSW Forest Monitoring Steering Committee. Under this program, annual health checks are carried out to review emerging evidence, identify knowledge gaps and set monitoring and evaluation priorities for the coming year.

2.1.1 Assessment of the impact of damage to retained trees

At the 2022 Coastal IFOA annual health check chaired by the Commission, parties agreed to develop an evidence base to understand and objectively assess the impact of ***damage***[1] to ***retained trees*** (**Box 1**) during forestry operations on the ecological function and longevity of these damaged ***retained trees***.

The primary function of ***retained trees*** is to maintain shelter and food resources for native fauna to support the persistence of those fauna. However, ***retained trees*** may be injured during ***forestry operations*** through accidental impact by harvesting or roading machinery or impact by other trees during felling or extraction.

If the level of injuries compromises the ***retained tree's*** longevity or suitability to fulfil the purpose for which it has been retained under the approval, the impact is considered to be ***damage*** in accordance with the definition in the Coastal IFOA Protocol 39:

> ***damage*** "In the context of a ***retained tree***, means the tree's longevity or suitability to fulfil the purpose for which it has been retained under the approval has been compromised, including where a tree is intentionally felled, pushed or removed to comply with the ***WHS Act***."

Damaged retained trees are required to be replaced in accordance with Protocol 23.

Currently there is no agreed understanding of the type and level of injuries that ***retained trees*** can sustain above which they are unable to provide the function for which they were retained, i.e., level of injury at which retained trees are considered to be ***damaged***.

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[1] Bolded italics are terms defined in Coastal IFOA Protocol 39

Box 1: Retained trees

Retained trees are defined in Protocol 39 as:

- "1. A ***hollow-bearing tree***, ***nectar tree***, ***giant tree***, ***dead standing tree***, ***glossy black-cockatoo feed tree***, ***glider sap feed tree*** or ***koala browse tree*** retained for the purpose of conditions 63 and 64 of the approval; or
  2. A tree mapped on the:
  a. Retained_Trees' ***spatial dataset***;
  b. Assessed_Retained_trees' ***spatial dataset*** or
  c. a *FCNSW* ***field dataset***."

The relevant outcome statement is "Important trees are retained and protected for shelter and food resources for native species, and to support their persistence" (NSW EPA 2018).

Retained trees can occur within the ***Net Harvest Area*** (NHA) as individual ***retained trees*** or may be located within ***tree retention clumps***.

Some types of ***retained trees*** are required to be retained permanently, whereas others are required to retain their function during and at ***completion*** of the ***forestry operation***.

2.1.2 Relevant Coastal IFOA monitoring questions

The Coastal IFOA Monitoring Program established monitoring questions to focus monitoring on the highest risk activities. Relevant Coastal IFOA monitoring questions related to ***retained trees*** are:

- Are the Coastal IFOA conditions effectively meeting its objectives and outcomes?
- To what extent do retained habitat features maintain their function?
- Do the conditions support key habitat features to maintain fauna species within and across the forest?

The specific monitoring question related to ***damage*** to ***retained trees*** is:

- What level of injuries to individual ***retained trees*** resulting from ***forestry operations*** represents ***damage*** that compromises the ability of a ***retained tree*** to provide the purpose for which it was retained?

2.1.3 Review objective

The objective of this review is to provide a scientifically valid evidence base to inform decision-making about what constitutes ***damage*** to ***retained trees*** during ***forestry operations*** on State Forests and Crown Land within the Coastal IFOA region. The Commission engaged specialist researchers from the Hawkesbury Institute for the Environment at Western Sydney University to prepare this review. The review consists of:

- a review of published and grey literature covering current knowledge about the response mechanisms of trees found within the Coastal IFOA region to physical injuries, including recovery timeframes and/or impact on tree longevity with respect to ***retained tree*** functions
- an assessment of the risk to the ongoing function of ***retained trees*** due to different types and levels of injury, using the best available evidence. The assessment does not attempt to define damage thresholds for different types of injuries. Damage thresholds will be set through a separate process,
- a proposed evidence-based method that could be used as a framework for setting objective injury thresholds[2] for each category of ***retained tree*** beyond which a ***retained tree's*** longevity and function can no longer be maintained (i.e. the threshold above which an injury represents ***damage***).

[2] Threshold represents level of ***damage*** that ***retained trees*** can sustain above which they are unable to provide the function for which they were retained. Thresholds will be established through a subsequent project, subject to suitability of the proposed method and available funding.

3 Literature review

3.1 Summary

Mechanical injuries to **retained trees** during forestry operations are likely to have variable effects that depend on the severity of the injury, tree species (e.g. resprouter versus obligate seeder), future disturbances/external stressors such as fire, drought and biotic attack, and the health status of the tree at the time of injury. The effects of most external stressors are difficult to account for during a snapshot assessment of tree injuries, and monitoring or retrospective studies would be required to assess their impacts upon injuries over time. Some types of injuries are likely to be immediately catastrophic, with effectively no chance of tree recovery, such as uprooting a tree/knocking it over and bole injuries that cause a tree to become unstable or extensively impact conductive tissues that transport water and nutrients between the roots and shoot. Crown injuries are unlikely to prevent giant trees and hollow-bearing trees from performing their function, as long as they are species capable of resprouting and still possess the habitat attributes for which they were retained (e.g. hollows). However, crown injuries that remove a significant proportion of the canopy are likely to substantially reduce the function of most types of temporary feed trees, e.g. via impacts on sap flow and foliage/seed availability. The longer-term trajectory of retained trees that experience less extensive injuries to the crown or bole remains uncertain due to a lack of literature examining these aspects of tree health, although such injuries are unlikely to be detrimental to **retained trees** in the short-term. It is also likely that other agents of tree damage such as fire, drought and biotic attack may exacerbate injuries and subsequently impact future tree function. For example, if a fire impacts an existing injury prior to a wound healing (occlusion), it could lengthen the timeframe for wound occlusion and increase vulnerability to other agents of tree decline.

3.2 Introduction

3.2.1 Context of retained trees managed under to Coastal IFOA

Under the Coastal IFOA, a hierarchy of environmental protection mechanisms, regulatory requirements and conservation aims are applied at multiple landscape scales, from the level of compartments[3], the local landscape areas[3] and management zones[3] up to the Coastal IFOA region (EPA 2018). Within management zones, limitations are placed on the total area available for harvesting and the amount of forest that can be intensively harvested (EPA 2020). Within local landscape areas (areas up to 1500 ha), protected forest types, habitats, and threatened ecological communities are excluded from harvesting via delineation of Environmentally Significant Areas[3] (ESAs) and wildlife habitat clumps[3]. For example, a substantial area of forest (e.g. >55%) within the Coastal IFOA region is permanently excluded from harvesting and designated as an ESA, with the remainder designated as Base Net Area[3] (BNA) (NSW EPA 2018; FCNSW 2023). A minimum of 5% of BNA of each local landscape area is permanently protected in wildlife habitat clumps, independent of ESAs (EPA 2018). Any remaining forest represents the Net Harvest Area[3] (NHA), in which habitat trees serving a variety of ecological purposes are selected as formally **retained trees**. Within the NHA, at the compartment or coupe-level, **retained trees** are located within and outside of tree retention clumps[3][4].

The Coastal IFOA permits four types of harvesting operations: selective harvesting[3], mixed intensity harvesting[3], intensive harvesting[3] in intensive harvesting zones[3], and within the Eden subregion alternate coupe harvesting[3] is permitted (EPA 2020). Selective harvesting operations selectively harvest trees and groups of trees from the NHA (EPA 2020). Intensive harvesting operations and alternate coupe harvesting is restricted to their respective regions, the former includes harvesting with retention of seed trees and **retained trees** throughout a coupe and the latter includes harvesting with retention of seed trees and **retained trees** of up to 60% of the BNA of a compartment. Mixed intensity harvesting uses a combination of selective harvesting and intensive harvesting. **Retained trees** as defined by the Coastal IFOA must be identified and retained in advance of any harvesting operations (EPA 2020).

Selective harvesting is widely employed in mixed-age and mixed-species eucalypt forests across the Coastal IFOA region. This approach is based on the New South Wales

[3] See the following sources for the formal definition/meaning of these terms in relation to the Coastal IFOA: NSW EPA. (2018) Coastal Integrated Forestry Operations Approval - Conditions. p. 85, Sydney, NSW EPA. (2020) Coastal Integrated Forestry Operations Approval - Protocols. p. 275, Parramatta.

[4] 'tree retention clump' and 'wildlife habitat clump' have different meanings under the Coastal IFOA, see sources listed above for further information.

Selective Harvesting[3] silvicultural system and aims to minimise disturbance to retained trees and conserve growing stock (FCNSW 2015). The retained basal area is dependent on the mapping of the compartment in the regrowth[3] or non-regrowth zone datasets[3] (EPA 2018); a minimum average basal area of $10m^2$ per ha at breast height (e.g. 1.3 m) in the harvested area must be retained in the regrowth zone**,** and a minimum average basal area of $12m^2$ per ha in the non-regrowth zone (EPA 2018). The retained basal area[3] is composed of non-merchantable trees, pre-merchantable trees, trees retained for silvicultural purposes, and formally **retained trees**. Trees comprising the retained basal area are scattered across the harvested area (EPA 2018).

The terms '**retained tree**' or '**retained trees**', in bold text in this document refer to formal definition of a retained tree (see Box 1) as defined under the Coastal IFOA (NSW EPA 2020). **Retained trees** assist in providing resources needed by native fauna for their survival and persistence (NSW EPA 2018) and form part of broader multi-landscape level management goals in NSW native forests. **Retained trees** are required to be retained either permanently or temporarily in order to fulfill their intended ecological function (NSW EPA 2018). **Retained trees** are retained in accordance with the Coastal IFOA unless they sustain damage that inhibits the function for which they were retained. In this case, a tree is replaced with a comparable tree or, when a comparable tree is not available, a mature tree with healthy crown (NSW EPA 2018). The terms '**damage**' or '**damaged**', in bold text in this document refer to formal definition of damage (see **1.1.1**) as defined under the Coastal IFOA (NSW EPA 2020). The term 'function' in the context of this document refers the provision of resources to fauna and/or intrinsic value. Any reference to 'damage' or 'retained tree' not presented in bold text represents generic use of these terms outside the specific context of the terms in bold text stated above.

3.2.2 Context of tree injuries related to forestry operations

Injuries to retained trees on logged sites can affect all parts of the tree, including the crown, bole and roots (Jackson *et al.* 2002; Medjibe *et al.* 2011). Injuries to trees can occur due to impacts by machinery and other fallen trees. Although data for Australian tree species are scarce, direct impacts to trees retained during forestry operations generally result in low rates of immediate tree mortality or stem collapse (Whitford and Williams 2001; Medjibe *et al.*

2011; Shenkin *et al.* 2015). Data provided by the Forestry Corporation of NSW indicates that, on average, there are 11.4 **retained trees** per hectare and that 0.14 **retained trees** per hectare experience **damage** due to forestry operations (FCNSW 2023). At the level of a single forestry operational area, this equates to around 1.3% of **retained trees** being **damaged** (FCNSW 2023). At present, these figures provided by the Forestry Corporation of NSW do not incorporate any formal, evidence-based threshold for **damage**.

Injuries acquired through natural processes or due to forestry operations that expose the conductive tissues of the tree may impact tree health, e.g. via impacts on hydraulic function (Rundel 1973; Sillett *et al.* 2015). Injuries to tissues also provide opportunities for decay, termites and fire that can cause structural weakness and reduce stability (Vasiliauskas 2001; Whitford and Williams 2001; Watson *et al.* 2020), which can contribute to mortality or collapse of trees over longer time frames. For example, post-harvest fires can exacerbate injuries, leading to higher rates of tree collapse (Gibbons *et al.* 2008). There are major knowledge gaps in relation to how the severity of some types of injuries impact on tree survival, longevity and their capacity to provide resources for fauna. This literature review aims to contextualise injuries caused during forestry operations within other processes that influence tree health and mortality for different types of **retained trees** and understand how injuries may impact their continued function.

3.3 Forest eucalypt life cycle

Forest eucalypts experience a series of distinctive growth stages and the amount and diversity of resources they provide to other organisms changes over time. Initial growth stages, from germination to sapling are characterised by rapid vertical growth and the development of a compact crown. During the earliest stages, flowering, nectar production and deadwood production is limited (Bradshaw 2015a) as trees allocate resources to vigorous stem growth and defensive structures, such as bark and starch reserves. However, some early regrowth forests are known to produce substantial nectar resources at the stand-scale (Law and Chidel 2008). Allocation to stem growth enables plants to better compete for light, while allocation to defensive structures helps protect against disturbances including fire and herbivory (Clarke *et al.* 2013). As eucalypts approach maturity and become a component of the forest canopy, stem diameter, bark thickness, and leaf area increase, the crown begins to spread and open, and reproduction becomes more likely (Bradshaw 2015b). During this early-mature stage, trees provide nectar and seeds that are utilised by many nectivorous and seed-eating fauna. Once the mature stage is reached, the crown begins to fully extend, leaf area is maximised, reproduction is typically consistent and small hollows may begin to form (Gibbons *et al.* 2000b; Bradshaw 2015b). Hollow formation typically occurs due to limb-breakage (e.g. from wind, storms) or fire (e.g. fire scar formation) and subsequent interactions with wood consumers (e.g. termites, borers, fungi) and additional disturbances (Gibbons *et al.* 2000b; Koch *et al.* 2008). Most hollow formation occurs during the late-mature and over-mature growth stages, where the crown begins to senesce and limbs begin to fall with higher frequency. During this phase, extensive piping and hollowing of the main bole and major limbs can occur, increasing the number of large hollows available (Gibbons *et al.* 2000b). Hollows with very large internal dimensions suitable for species of large forest owls can take between 100-200 years to form (NSW TSSC 2007; Vesk *et al.* 2008). As trees age, they become less able to effectively occlude wounds and thus structural weaknesses may develop as hollowing becomes more extensive (Gibbons *et al.* 2000b). During these later stages, leaf area may decline but reproduction continues, hollow availability and size-diversity increases and there is typically regular production of coarse woody debris as limbs fall (Gibbons and Lindenmayer 2002). As a result, late- and over-mature trees provide substantial resources for fauna that rely on nectar/seeds, hollows and decaying wood, and contribute to forest nutrient cycling that maintains ecosystem function and productivity (O'Connell 1987; Scotts 1991; Gibbons and Lindenmayer 2002). Many trees may never reach this growth stage, due to impacts from disturbances such as fire, drought, wind, lightning strikes and biotic attack from insects and pathogens. For example, fire scar formation at the tree base is known to be a leading cause of stem collapse and mortality in eucalypt forests (Whitford and Williams 2001; Bendall *et al.* 2022). However, many eucalypt species are capable of vigorous resprouting following severe disturbance and so new stems may form following tree collapse. Collapsed stems become coarse woody debris that provides resources for ground-dwelling fauna and a source of organic carbon that may be incorporated into the soil or lost to fire. Some dead trees may remain standing for long periods, until decay and structural weakness cause them to fall or disintegrate.

3.4 Impacts of injury on tree physiology

The compromise between water loss (transpiration) and carbon gain (photosynthesis) is at the core of tree physiology. Plants must open stomata in order to take up CO_2 but in the process, they also lose water to the surrounding environment. The exchange is very uneven, with plants losing roughly 500 molecules of H_2O for every molecule of CO_2 assimilated into sugars (Taiz and Zeiger 2002). As such, large trees require an efficient long distance transport system to move water to the canopy at a rate that allows a net positive carbon balance and avoids desiccation. Water is transported from the roots to the canopy through the xylem tissue (sapwood), which is specialised to allow efficient transport of water while maintaining the structural integrity of the tree (Tyree and Zimmermann 2002). Water loss is controlled by the stomata, which must optimise the amount of carbon uptake for a given loss of water. Photoassimilate is transported from the leaves to non-photosynthetic sink tissues via the phloem. Layers of undifferentiated cells called the cambium are responsible for producing xylem, phloem and bark: xylem is typically formed on the inside of the cambium, while phloem and bark form to the outside (Tyree and Zimmermann 2002). Functioning xylem, the cambium and phloem typically comprise a relative narrow band of tissue located immediately underneath the bark. Any injury to sections of this tissue will have consequences for continued plant function. The capacity of trees to recover from injury varies broadly across species, depending on the size and location of the injury, as well as concomitant environmental stresses and biotic attack.

Trees that have evolved in disturbance-prone environments, such as eucalypts, possess various traits and adaptations that counter environmental stress, disturbance, injury and biotic attack. For example, thick protective bark minimises dehydration of living tissues and protects against fire and animals (Ferrenberg *et al.* 2014; Pausas 2015), while dormant growth buds and stored carbohydrates enable rapid regrowth of leaves (Burrows 2013; Clarke *et al.* 2013). Many eucalypts are also capable of osmotic adjustment and production of solutes that minimise water loss during drought (Merchant *et al.* 2006; Merchant *et al.* 2007). Relative differences in the investment of resources related to defensive strategies, such as thick bark and stored carbohydrates, versus investment in rapid vertical growth and reproduction, is an evolutionary trade-off driven by environmental conditions, disturbance regimes and competition (Keeley *et al.* 2011; Pausas *et al.* 2016; Pausas and Keeley 2017). As a result, eucalypts represent a spectrum of functional types that include species with and without the capability to resprout following disturbance (Nicolle 2006). Thus, depending on species, the capacity of a tree to survive an injury will inherently be different and will depend on the severity of the injury. For example, an obligate seeder (i.e. a species which does not survive complete defoliation following fire, but regenerates via seed) may be unlikely to survive a broken bole or loss of the canopy. Entry wounds on the stem provide a gateway for insects and decay to enter the tree and may cause fungal rot, wood defects and structural instability (Greaves *et al.* 1965; Whitford and Williams 2001), in addition to exposing the conductive and supportive tissues to fire and changes in atmospheric conditions. Injury to the conductive tissues may interrupt the flow of water and nutrients and affect the rate of transpiration and subsequently photosynthesis, which may impact tree health (Tyree and Zimmermann 2002). Environmental stresses such as drought and heat stress may exacerbate the consequences of these injuries by further disrupting physiological function and delaying recovery (Losso et al. 2022). Whether a tree can heal an injury will likely depend on its inherent ability to heal and whether or not additional disturbances occur that exacerbate the injury before healing is completed.

3.5 Eucalypt responses to drought and fire

What follows is a general summary of knowledge relating to fire and drought effects on eucalypts to provide some context around the structural and physiological limits of trees in native forests. Many eucalypt species, including the genera *Eucalyptus*, *Corymbia* and *Angophora*, recover from severe disturbance via resprouting from epicormic buds beneath the bark and/or from an underground storage organ called a lignotuber (Nicolle 2006; Burrows 2013; Clarke *et al.* 2015). Epicormic resprouting is primarily an adaptation to cope with the effects of crown fire, allowing trees to retain biomass through disturbances and quickly recover canopy foliage (Keeley *et al.* 2011; Clarke *et al.* 2013; Pausas and Keeley 2017). Epicormic resprouting thereby confers resilience to severe disturbances, as structural changes are minimised through mature tree persistence and recruitment is facilitated through shading and protection from surviving overstorey trees (Bond and Midgley 2001; Burrows 2013). Specifically, the present review assumes that certain injuries (i.e. disturbances) will likely result in successful tree resprouting and rapid recovery because there is significant demonstrable evidence that many eucalypts are capable of doing so (Nicolle 2006; Vivian *et al.* 2008; Clarke *et al.* 2013; Fairman *et al.* 2016; Collins 2020; Nolan *et al.* 2021a; Bendall *et* *al.* 2022). Injured trees that resprout epicormically are likely to recover their canopies and resume normal photosynthesis before the next forestry operation, likely rendering epicormic responses undetectable by that time. For example, once the canopy has recovered and epicormic growth no longer required then by default a tree will score higher during a canopy health assessment (Stone *et al.* 2008; Nolan *et al.* 2021b; Losso *et al.* 2022a). Successful resprouting in eucalypts depends on the severity of the disturbance and tree characteristics such as stem size, bark characteristics and previous fire damage (Collins 2020; Nolan *et al.* 2020; Bendall *et al.* 2022). However, there are a number of obligate seeder species with limited or no capacity to resprout following disturbance and regeneration is entirely from seed. Although many species can both resprout and recover from seed, some are weak resprouters (Bradford 2018). Thus, disturbance-related mortality and resprouting patterns across forests are likely to vary among species (Trouvé *et al.* 2021). A number of obligate seeders and weak resprouters occur throughout the Coastal IFOA management area (**Table 1**).

Table 1. List of species within Coastal IFOA management area with limited or no ability to resprout following disturbance.

Scientific name	Common name	Resprouting limitations
Eucalyptus oreades	Blue Mountains ash, White ash	Limited to no ability to resprout from lignotuber (Little and Gardner 2003).
Eucalyptus fraxinoides	White ash, White mountain ash	Limited to no ability to resprout from lignotuber (Little and Gardner 2003).
Eucalyptus pauciflora	Snow gum	Limited capacity to resprout epicormically, vulnerable to hydraulic failure, typically able to resprout from a lignotuber (Losso *et al.* 2022b).
Eucalyptus grandis	Flooded gum, Rose gum	Facultative seeder with 2-3 year recruitment timeline with limited resprouting capacity (Bradford 2018) .
Eucalyptus delegatensis	Alpine ash	Obligate seeder (mainland population only) with limited resprouting capacity (Rodriguez-Cubillo *et al.* 2020).

Widespread vegetation recovery has been recorded across forests since the extensive and severe fires of 2019-2020 and prior drought, largely attributed to above average rainfall (Gibson and Hislop 2022; Qin *et al.* 2022). However, some areas affected by fire are recovering more slowly or are yet to show any substantial signs of recovery (Gibson and Hislop 2022). Areas of dry forest and woodland that experienced significant canopy dieback due to the effects of drought and heatwaves during 2017-2020 (Nolan *et al.* 2021b; Losso *et al.* 2022b) have exhibited variable rates of recovery (Losso *et al.* 2022, Nichols *et al.* unpub). Work is underway to assess levels of tree mortality in NSW forests exposed to combined severe drought and severe fire in 2019-2020. Preliminary estimates indicate that tree mortality is within the range of 17-35% depending on forest and soil type (e.g. wet or dry sclerophyll forest, Bendall *et al.* unpub). Knowledge of the effects of fire, heat and drought stress on plants is integral to understanding the vulnerability of forests to future climate extremes and fire susceptibility (Collins *et al.* 2022). Projected increased temperatures under climate change are likely to compound drought effects on forests (Allen *et al.* 2021), leading to hotter, deadlier droughts (Naumann *et al.* 2018). For example, extreme temperatures may exacerbate plant hydraulic failure (Marchin *et al.* 2022a; Marchin *et al.* 2022b) and cause photosystem damage independent of hydraulic failure (Marchin *et al.* 2022b).

Drought-induced dieback occurs by three interdependent mechanisms, hydraulic failure, carbon starvation and biotic attack, which may work in tandem or as a cascade of effects (Brodribb and Cochard 2009; Choat *et al.* 2018; Nolan *et al.* 2021b). The underlying cause of drought-induced dieback is air embolism (blockage caused by cell desiccation) formation in the water transport tissues (xylem) of a plant. Air emboli form when critical thresholds of water stress are reached in the xylem, causing vaporisation of water in vessels (Mantova *et al.* 2022). Embolism reduces water transport capacity and causes depletion of carbon stores which can lead to tree mortality. Eucalypt species vary broadly in their resistance to drought-induced embolism and their ability to survive extreme levels of water stress (Bourne *et al.* 2017; Li *et al.* 2018). When released from drought stress, some eucalypts are capable of recovering from very high levels of xylem embolism by growth of new xylem and epicormic resprouting (Gauthey *et al.* 2022; Losso *et al.* 2022b); thus embolism mortality thresholds are challenging to define, although evidence suggests that they occur at levels of water stress causing 80-90% loss of hydraulic capacity (Hammond *et al.* 2019; Duan *et al.* 2023). In cases where trees survive hydraulic failure, they are rendered more vulnerable to future stressors (Mantova *et al.* 2022).

Future occurrence of fire and drought may impact the status of trees with pre-existing injuries and impacts may vary among species (e.g. resprouters versus obligate seeders). For example, the presence of a naturally-occurring basal fire scar injury is a strong predictor of stem/tree mortality following severe fire and in areas where trees are retained as part of silvicultural systems (Whitford and Williams 2001; Gibbons *et al.* 2008; Bluff 2016; Bendall *et al.* 2022). Mechanical injuries that resemble fire scars (e.g. loss of bark and vascular tissues on the main bole) could therefore decrease the longevity of a **retained tree** through increased vulnerability to fire effects and their interaction with other agents of tree injury (e.g. biotic attack). Future impacts of disturbance on the function of different types of **retained trees** that have an existing injury are currently difficult to predict as the type of disturbance (e.g. drought, fire, biotic attack), severity and frequency would need to be considered, along with the type of injury (e.g. crown versus bole) and the capacity of a tree to heal wounds, regenerate structural tissue and resume normal levels of function. Nonetheless, such predictions are necessary to integrate estimates of the potential effects of future disturbances into a threshold-based system of **damage** to **retained trees**. Extensive data collection and modelling would be required to produce thresholds that explicitly incorporate these variables, which is beyond the scope of this literature review and associated content.

3.6 Types of retained trees and their purpose under the Coastal IFOA

This section provides the formal definitions of different types of **retained trees** relevant to the Coastal IFOA. Any content within later sections of this review and the associated assessment that describes impacts to **retained tree** function or longevity that could represent **damage** relates to **retained trees** as described in this section. Some broader ecological context is given in the descriptions where appropriate to highlight key ecological values.

3.6.1 Permanently retained trees

3.6.1.1 Hollow-bearing trees

Hollow-bearing trees are defined under the Coastal IFOA as:

> "A tree that is alive and has:
>
> 1. visible hollows, holes or cavities that have likely formed because of decay, injury or other damage as the tree has aged; or
>
> 2. clearly inferred hollows as it is an older growth stage tree (in particular in a senescent tree) with one or more obvious deformities such as a burl, large protuberance or broken limb.

> *Note: Guidance will support the application of this definition*" (NSW EPA 2020).

Under the Coastal IFOA, hollow-bearing trees are permanently retained in landscape-scale exclusions (i.e. areas that are never harvested), compartment-scale exclusions (i.e. ESAs) and patch-scale exclusions (i.e. tree retention clumps). In addition, prescribed numbers of hollow-bearing trees are permanently retained within the Net Harvest Area (NSW EPA 2018). Across NSW, tree hollows provide shelter and nests to 174 hollow using species, composed of 46 mammals, 81 birds, 31 reptiles and 16 frogs; 40 of which are threatened with extinction (NSW Government 2023). Loss of hollow-bearing trees is listed as key threatening process under the NSW *Biodiversity Conservation Act* (2016).

Fauna hollow use is determined by species-specific requirements including hollow depth, hollow entrance size, tree species, diameter at breast height (DBH), and abundance of hollows (Gibbons *et al.* 2002; Goldingay 2011; Hofman *et al.* 2022). Harvesting disturbance and fire regimes can influence hollow availability. For example, forestry operations can cause crown damage which may lead to branch-end hollow formation (Hofman *et al.* 2022). Fire can influence both hollow creation and loss, e.g. by forming hollows and increasing the size of existing hollows but also by consuming branches and stems that contains hollows (Haslem *et al.* 2012; Stares *et al.* 2018).

3.6.1.2 Large diameter tree cohort

Large diameter trees meeting the folhlowing definition are permanently retained under the Coastal IFOA:

> "['giant tree'] In relation to Blackbutt or Alpine Ash trees, means any live tree of these ***species*** with a ***diameter at stump height over bark*** (***DSHOB***) of 160 centimetres or greater.
>
> In relation to all other tree ***species***, means a live tree with a ***diameter at stump height over bark*** (***DSHOB***) of 140 centimetres or greater" (NSW EPA 2020).

The rationale for permanent retention of trees in this size-class is that hollow abundance and diversity increases with tree diameter and the likelihood of fauna occupancy increases with the number of hollows (NRC 2016). Thus, large diameter trees are likely to provide habitat and contribute to maintaining viable populations of flora and fauna across landscapes (NRC 2016). All hollow-bearing trees continue providing hollows following senescence and are therefore a key enduring resource for hollow-using animals.

Lindenmayer & Bowd (Lindenmayer and Bowd 2022) suggest that historically, forestry operations selectively targeted large-diameter trees which has reduced their abundance in some areas, potentially impacting genetic diversity and forest resilience to stressors (Lowe *et al.* 2005; Lindenmayer and Laurance 2017). Decline of large diameter trees has negative impacts on nutrient cycling, water production, and biodiversity (Lindenmayer and Laurance 2017; Lindenmayer and Bowd 2022). Some tall, mature wet forests that inherently contain a higher proportion of larger-diameter trees than dry forests (Koch *et al.* 2008; McLean *et al.* 2015), may be capable of mitigating against severe fires, as they retain higher moisture levels and greater separation of vertical fuels (Zylstra 2018; Furlaud *et al.* 2021).

3.6.1.3 Dead standing trees

Dead standing trees meeting the following definition are permanently retained under the Coastal IFOA:

> "a dead standing tree: (1) where the bark is fully separated from the sapwood due to decay and is greater than 30 centimetres in diameter at breast height and greater than three metres tall; or (2) that has hollows" (NSW EPA 2020).

Dead standing trees contribute to forest structural diversity and provide sources of decaying wood that ultimately influences nutrient cycling in forests (NSW TSSC 2003). Dead standing trees that contain hollows provide habitat for hollow-dependent fauna and hollows in dead trees are preferred by some marsupials (Goldingay 2011).

3.6.2 Temporarily retained trees

Some trees are retained during and at completion of the forestry operation under the Coastal IFOA in order to provide resources for koalas, gliders and birds (NSW EPA 2018). However, these 'temporarily **retained trees**' are not required to be retained in the next cutting cycle, e.g. different trees may be selected depending on operational circumstances.

3.6.2.1 Koala browse trees

Koala browse trees meeting the following definition are retained during and at completion of the forestry operation under the Coastal IFOA:

> 1. In the ***Upper North East Subregion*** and ***Lower North East Subregion***, means a live tree which may be selected for retention under condition 65 of the ***approval*** that is:
>
> (a) greater than 20 centimetres ***DBH*** or 22 centimetres at ***DSHOB***; (b) live and healthy; and (c) of the following tree ***species***:
>
> (i) primary browse trees –
>
> Tallowwood (*E. microcorys*); Swamp Mahogany (*E. robusta*)*;* or Red Gums (*E. tereticornis*, *glaucina*, *seeana* + hybrids); or
>
> (ii) secondary browse trees –
>
> Grey Gums (*E. biturbinata*, *propinqua*, *punctata*, *canaliculata*)*;* Grey Box (*E. moluccana*, *largeana*)*;* Peppermints (*E. radiata*, *acaciaformis*); Sydney Blue Gum (*E. saligna*); Ribbon Gum (*E. nobilis*, *viminalis*); Messmate (*E. obliqua*); Snow Gum (*E. pauciflora*); Mountain Gum (*E. dalrympleana*); or New England Blackbutt (*E. andrewsii*, *campanulata*).
>
> 2. In all other ***Coastal IFOA subregions***, means a live healthy tree, greater than 30 centimetres ***DBH*** of the following tree ***species***:
>
> *Eucalyptus longifolia; E. cypellocarpa; E. globoidea; E. mannifera; E. rossii; E. viminalis; E. tereticornis; E. amplifolia; E. bosistoana; E. maidenii; E. muelleriana; E. tricarpa; E. punctata; E. nortonii; or E. eugenioides"* (NSW EPA 2020).

Prescribed numbers of koala browse trees are required to be retained during and at completion of the forestry operation under the Coastal IFOA (NSW EPA 2018). Koala browse trees are retained primarily to: "ensure viable populations of koalas are maintained in landscapes" (NRC 2016; Law *et al.* 2022). Koala browse trees represent live, healthy trees of specific sizes and species, which depends on the location of a forestry operation within the Coastal IFOA management area and the probability of koala occurrence (see NSW EPA 2020b).

3.6.2.2 Glider sap feed trees

Trees meeting the following definition are retained during and at completion of the forestry operation under the Coastal IFOA:

> A living tree that exhibits incisions, including V-notch incisions, made by a *Petaurus* species for feeding on exuding sap which has not been fully occluded by bark or scar tissue" (NSW EPA 2020).

3.6.2.3 Glossy black-cockatoo feed trees

Trees meeting the following definition are retained during and at completion of the forestry operation under the Coastal IFOA:

> "A tree of an *Allocasuarina* spp. which shows evidence of glossy black-cockatoo feeding by the presence of characteristic crushed cones at, or around, its base" (NSW EPA 2020).

Glossy black-cockatoos (*Calyptorhynchus lathami*) feed on the seeds within the cones produced by *Allocasuarina spp*. and less commonly *Casuarina spp*. (Glossy Black Conservancy 2022). Feed trees are identified by the presence of crushed cones at or around the base of the tree (NSW EPA 2020).

3.6.2.4 Nectar feed trees

Trees meeting the following definition are retained during and at completion of the forestry operation under the Coastal IFOA:

> Means a live tree which may be selected for retention under condition 64 of the ***approval*** that is:
>
> 1. mature or late mature;
> 2. is live and healthy; and
> 3. of the following tree ***species***:
>
> (a) Alpine Ash *Eucalyptus delegatensis*; (b) Mountain Gum *E. dalrympleana*; (c) Manna Gum *E. viminalis*; (d) Black Sallee *E. stellulata*; (e) Snow Gum *E. pauciflora*; Eurabbie *E. bicostata*; (f) stringybark species *E. agglomerata, E. globoidea, E. muelleriana*; (g) red stringybark *E. macrorhyncha*; (h) needlebark stringybark *E.*

planchoniana; Tyndale stringybark *E. tindaliae*; (i) white mahogany *E. acmenoides, E. umbra, E. carnea*; (j) ironbark species *E. siderophloia, E. paniculata, E. tricarpa, E. fergusonii, E. placita, E. ancophila, E. fusiformis, E. caleyi, E. crebra, E. fibrosa. E. tetrapleura, E. sideroxylon, E.ophitica*; (k) River Peppermint *E. elata*; (l) Mountain Grey Gum *E. cypellocarpa*; (m) Maiden's Gum *E. maidenii*; (n) Forest Red Gum *E. tereticornis*; Swamp Mahogany *E. robusta*; (o) Swamp Gum *E. ovata*; (p) spotted gum species *Corymbia* spp.; (q) bloodwood species *Corymbia* spp.; or (r) box species *E. rudderi, E. conica, E. molucanna, E. largeana, E. rummeryi, E. melliodora* and *E. albens*.

A minimum of five nectar trees per hectare of Net Harvest Area are required to be retained during and at completion of the forestry operation, where the harvest area contains or is within close proximity to known records of swift parrots (*Lathamus discolor*) or regent honeyeaters (*Anthochaera phrygia*) (NSW EPA 2018).

3.7 Impacts of injuries to retained trees and their functions

Impacts by machinery or other trees during forestry operations can cause injuries to trees such as uprooting, broken stems, crown injuries and injuries to the bole or roots. Studies focused on the categorisation and quantification of different types of injuries caused by forestry activities and their impacts on trees are scarce in the Australian context (but see Whitford and Williams 2001; Binns and Bridges 2003; Watson et al. 2020). Binns and Bridges (2003) observed and classified tree injuries related to forestry activities in the Eden area, which included felled/knocked over trees, broken boles (e.g. crown destroyed, <50% of bole length remaining), partial or entire crown injuries and bole injuries affecting the cambium. Watson *et al.* (2020) attempted to utilise this classification system in a study of harvesting and fire effects on tree mortality in the Eden forests, but reduced the classification to a binary predictor (i.e. with or without mechanical injury) due to a lack of samples. Watson *et al.* (2020) found that trees sustaining a mechanical injury and then subject to multiple fires over ~30 years were on average 20% more likely to experience mortality than trees without an injury, although this estimate varied with tree diameter and harvesting intensity (i.e. amount of basal area removed). For example, the probability of mortality increased to 40-50% for smaller trees (<20 cm DBH) with average harvesting intensity (basal area removed = 17 m^2/ha) and by approximately 40% for intense harvesting (35 m^2/ha) compared to light harvesting (5 m^2/ha). Studies from other global regions exist that provide more comprehensive classification and quantification of forestry operation-related tree injuries and their consequences; although they are not representative of Australian forests or forestry techniques, they may still provide a framework for future research (see Jackson *et al.* 2002; Medjibe *et al*. 2011). These studies provide significant insights into the relationships between harvesting, roads and skid trails and the types and levels of injuries sustained by retained trees. Similar research in Australian forest systems would be required to fully evaluate the impacts of injuries on tree function and mortality.

Much of the evidence for tree injuries in NSW forests managed under the Coastal IFOA is preliminary and previous research in the Australian context has involved more intensive silvicultural systems (e.g. clearfell or low retention) and now superseded management protocols (Gibbons 1999; Gibbons *et al.* 2000a; Whitford and Williams 2001; Gibbons *et al.* 2008). Forestry-related impacts to habitat trees, such as their net loss, destruction or injuries leading to mortality are now considered to be managed effectively at federal-level, to the extent that it is not considered a key threatening process (DCCEEW 2023). However, loss of hollow-bearing trees, which are a significant component of the **retained tree** cohort under the IFOA, is considered a key threatening process within NSW (NSW TSSC 2007). For example, forestry activities that cause damage to hollow-bearing trees have previously been identified as a potential cause of their premature mortality and eventual depletion as a wildlife resource (DSE 1988; NSW TSSC 2007). However, modern forestry prescriptions, harvesting techniques and regulatory protocols have since evolved in NSW. For example, the Coastal IFOA aims to minimise impacts and conserve habitat using integrated multi landscape-level conservation and management methods (see **1.3.1**) (NRC 2016; NSW EPA 2020). Ultimately, any injury that exposes conductive tissues or heartwood will have some impact on the physiological function of a tree, which has the potential to be exacerbated by fire and/or insects and decay and may reduce resilience to future disturbances. Close proximity of trees to harvesting tracks is a key risk factor for injuries to retained trees (Jackson *et al.* 2002). Changes to tree function and likelihood of mortality resulting directly or indirectly from injury sustained during forestry operations has not been adequately quantified in Australian forestry systems, and long-term monitoring of trees that have sustained injuries is lacking. It would be of considerable benefit to both scientific and industry knowledge if injuries to **retained trees** were monitored over time, for example during each forestry operation, to quantify the potential for increased risk of tree mortality and changes to tree function.

3.7.1 Knocked over / uprooted / broken or snapped tree

A tree is no longer free-standing when its roots have become detached from the ground, and it is either leaning on other trees or has fallen to the ground. In this case the tree is now either coarse woody debris or in an intermediary state prior to becoming coarse woody debris. Trees may no longer be free-standing if accidentally knocked over during a forestry operation, either directly by machinery or due to being knocked over by another felled tree. Trees may also be no longer free-standing due to wind, storms, fire, insects and decay. Evidence from Western Australian forests suggests that tree injuries caused by forestry operations accounts for less than 1% of fallen trees, with fire, termites and wind more likely to be the ultimate cause of tree fall (Whitford and Williams 2001). However, fallen trees are unlikely to recover, and in addition are rarely recorded to have an intact root plate (Whitford and Williams 2001), so may be at least partially disconnected from their water supply. Therefore, fallen and uprooted trees that initially remain alive are likely to be especially vulnerable to further external stressors, such as drought, fire or biotic attack.

Breakage or snapping of the main bole is likely to result in the complete loss of the crown, leaving only a partial bole or stump. However, there is limited evidence that such injuries actually occur due to harvesting in eucalypt forestry systems and mortality rates are likely to be low when they do occur (Whitford and Williams 2001), potentially due to the ability of many eucalypt species to vigorously resprout new foliage and stems following extreme disturbance (Burrows 2013). For example, ‘topkill’, i.e. loss of the above-ground live biomass may not result in the mortality of a **retained tree** as it may be able to resprout new stems but the function of that **retained tree** could potentially be lost. Loss of the crown/breakage of the main bole (i.e. ‘topkill’) may occur due to impact by machinery, impact from another felled tree or due to wind, storms, fire, insects and decay. This type of injury includes where the main stem has broken near the base due to a previous injury/defect. Animals that rely on foliage, flowers or seeds in the canopy would no longer have access to these resources once the canopy has been lost. Sap flow in trees experiencing this type of injury will be severely diminished or non-existent (Cunningham *et al.* 2009). Gliders, for example, demonstrably feed on trees with higher sap flow, and this level of injury would drastically reduce the utility of the tree to gliders (Goldingay 1991). The loss of the entire crown would necessitate resprouting in order to resume photosynthesis and replenish carbohydrate stores. These resprouts are usually established within a year following a disturbance, although the severity of the disturbance and potential compounding stressors may lead to longer recovery timelines (Losso *et al.*; 2022, Nichols *et al.*, unpub) or mortality. Species that have limited capacity to resprout (**Table 1**) are unlikely to survive this level of injury.

3.7.2 Mechanical crown injury

Crown injury may occur due to impact by machinery, impact from another felled tree or due to wind and storms. The majority of eucalypt species are capable of vigorous epicormic resprouting and should be able to withstand crown injuries, e.g. mortality rates in resprouting eucalypt forests are typically low following severe disturbances that affect the canopy (Vivian *et al.* 2008; Catry *et al.* 2013; Collins 2020). The extent of crown injury will likely determine whether a tree can still provide the function for which it was retained.

Permanently **retained** live **trees** (i.e. hollow-bearing and giant trees) are likely to continue performing their function despite significant crown injury if they meet the following conditions: (i) they are a species capable of epicormic resprouting and; (ii) the injury has not resulted in the complete loss of the attributes for which the tree was retained, i.e. loss of hollows. Damaged crowns could potentially create future conditions beneficial to some fauna, e.g. branch-end hollows, which may be formed by branch breakage, exhibit higher occupancy of gliders in comparison to hollows at other location in the tree (Hofman *et al.* 2022), and glossy black-cockatoos and sugar gliders (*Petaurus brevices*) may prefer trees with simplified canopies (Lindenmayer *et al.* 1991; North *et al.* 2020). Temporarily **retained trees** that acquire significant injury to their crown may experience a reduction in their capacity to perform their function in the short-term or permanently, due to severely reduced sap flow, reductions in hydraulic capacity, and altered gas exchange dynamics (Brodribb *et al.* 2010). For example, Cunningham *et al.* (2009) applied insecticide to 16 dry woodland eucalypts (*Eucalyptus blakelyi*) and found that a corresponding amount of untreated trees experienced a halving of sap flow velocity due to a 20% reduction in leaf area likely caused by insect herbivory. Trees experiencing this level of sap flow reduction may be unable to support glider foraging (Goldingay 1991). Below is a summary of the requirements of other fauna in terms of canopy condition.

Leaf nutrient content, availability, palatability, and leaf composition are the predominant factors which drive koala browsing and tree preference (Moore and Foley 2000).

Some early work suggested that koalas preferentially used trees with larger amounts of foliage (e.g. >301 kg estimated dry weight) in the canopy (Hindell 1978) and selected larger emergent trees with extensive crowns (Jurskis and Potter 1997). However, more recent work on the NSW North Coast suggests that although koalas use trees of most sizes, they preferentially use medium-sized trees (20-60 cm DBH), varying with time of day and gender (Law *et al.* 2022). Tree diameter, foliage density, crown depth and size are generally reliable predictors of leaf area in eucalypt forests (Whitford 1991), which suggests that koalas preference for medium-sized trees implies that they also prefer medium-sized, rather than large canopies.

In a Victorian study, koalas showed reduced preference for their highly favoured *Eucalyptus ovata* feed trees when the trees developed poor canopy condition (e.g. >50% loss of canopy leaves) due to defoliation caused by overbrowsing (Martin 1985). Defoliation and leaf browning are also characteristics of drought stress, so this behaviour may also serve to avoid drought affected leaves with a lower relative moisture content (Clifton 2010). However, koalas will forage in trees recovering from severe disturbance and will readily consume epicormic regrowth (Martin 1985; Matthews *et al.* 2007; NRC 2022b). Within the northern Coastal IFOA management area, many key koala browse tree species such as Sydney blue gum (*Eucalyptus saligna*), small-fruited grey gum (*E. propinqua*), northern grey ironbark (*E. siderophloia*) and red mahogany (*E. resinifera*) have been observed to produce post-fire epicormic regrowth that contains leaves with higher nutritional quality than mature pre-fire leaves, which may benefit koalas (NRC 2022b). More generally, transpiration per unit leaf area is known to increase in resprouting eucalypt leaves, resulting in higher leaf water content (Nolan *et al.* 2014).

Some koala populations are reported to have high fidelity to trees within their home ranges, although these populations were either introduced and reliant on relatively small patches of suitable food trees (Whisson *et al.* 2016), were isolated due to being on islands (Marsh *et al.* 2013) or were in areas where koala occurrence is generally restricted to small occurrences of higher productivity forest (Gallahar *et al.* 2021). Under these circumstances, koala tree re-use can be within the range 22-37% of sightings (Marsh *et al.* 2013; Gallahar *et al.* 2021). However, tree re-use may be less frequent in areas where koala density is lower (Matthews *et al.* 2007; Ellis *et al.* 2009) and particularly low where landscapes provide large-scale contiguous resources, such as forested areas of the NSW North Coast (Law *et al.* 2022; NRC 2022a). For example, Law *et al.* (2022) tracked 10 koalas over an average of seven months each across all seasons and found that they typically used trees once. Based on the evidence presented above, koalas appear to have low reliance on individual trees within the NSW North Coast region and so the occasional loss and subsequent replacement of browse trees following damage is unlikely to detrimentally impact koala populations. Koalas also appear to be capable of browsing in smaller trees with correspondingly small canopies and so it seems plausible that crown injuries resulting in non-complete removal of leaf-bearing branches may not pose a barrier to koala browsing. It is also plausible that crown injuries resulting in vigorous epicormic resprouting may provide koalas with a higher quality food resource, although this would likely depend on the extent of the initial injury (e.g. **damage** to koala habitat attributes other than food availability) and tree species.

Gliders show feed tree preference based on several tree characteristics, which may impact their use of **retained trees**. For example, yellow-bellied gliders (*Petaurus australis*) demonstrably prefer trees with higher sap flow (Goldingay 1991) and prefer trees within patches that have minimal numbers of dead trees and stumps, likely due to a higher proportion of potential forage (Eyre and Goldingay 2005). Yellow-bellied gliders have also been reported to spend almost half their time foraging for honeydew or arthropods under the bark of smooth-barked eucalypts (Kavanagh 1987a; Kavanagh 1987b). Sugar gliders (*Petaurus breviceps*) have been reported to prefer sparser canopies, likely due to the positive effect of greater light availability on sap production (Lindenmayer *et al.* 1991; Heise-Pavlov *et al.* 2018). Higher sap flow has also been linked with higher foliar nutrients, which is a significant predictor of greater glider occurrence (Smith *et al.* 2007). Some dry woodland eucalypt species are likely to experience a substantial reduction (e.g. up to 50%) or pause in sap flow once around 20% in the crown have been lost due to insect herbivory (Cunningham *et al.* 2009). However, reported ambient sap flow rates appear to be variable among eucalypt species, individual trees and between studies and methods (Goldingay 1991; Barrett *et al.* 1995; Bleby *et al.* 2004; Zeppel *et al.* 2004) and could potentially be higher in coastal species, so it is not clear whether the magnitude of reductions in sap flow due to disturbance can be generalised. Further, if a eucalypt species is capable of epicormic resprouting, then following crown injury the sap resource may only be diminished until new leaves begin producing photosynthate (Burrows 2013). For example, full epicormic recovery of canopy leaf weight following the loss of all live leaves can occur within eight months in some resprouting eucalypt species (Gill 1978). Overall, crown injury will likely have some impact on sap flow and subsequently may affect the usage of trees by gliders, although the available evidence is likely inadequate for defining an accurate threshold for **damage** (see **4.2.1** and **4.2.2** for further discussion on this).

Glossy black-cockatoos are reliant on seed from *Allocasuarina* spp. as their primary food source (Joseph 1982; Clout 1989). Population decline of glossy black-cockatoos has been attributed to loss and degradation of feeding habitat, largely due to human impacts (Glossy Black Conservancy 2022). Glossy black-cockatoos likely select trees on the basis of profitability, which at the highest level involves remote visual cues such as fruit abundance (Sallabanks 1993; Crowley and Garnett 2001), tree height and tree diameter (Pepper *et al.* 2000; North *et al.* 2020), followed by proximal cues such as the percentage of seed containing kernels, kernel weight/cone weight, seed mass per cone and food value (Pepper 1997; Crowley and Garnett 2001; North *et al.* 2020). Glossy black-cockatoos are highly selective of the trees they feed on, utilising only around 16% of cone bearing trees in some cases (Robinson and Paull 2009; Partelli-Feltrin *et al.* 2023). Trees which are of higher profitability and preferred as feed will generally have larger crops of cones (Clout 1989), and can be recognised by greater numbers of cones fragments near the tree base (Robinson and Paull 2009). A large-scale study by Clout (1989) in the NSW South Coast region examined foraging in *Allocasuarina littoralis* trees by glossy black-cockatoos (i.e. extracting seeds from cones). In one survey area, over 50% of trees containing >200 cones (n = 388 trees) had been foraged by cockatoos, while only 15% of trees containing <200 cones (n = 1284) had been foraged. In another survey area, cockatoos were observed feeding in trees with >200 cones over 70% of the time (n = 46 trees) suggesting that cockatoos select for trees with higher cone crops (Clout 1989). Overall, this suggests that retaining larger feed trees with higher numbers of cones should be prioritised for glossy black cockatoos.

Feed tree appearance also has a significant influence on whether it will be chosen as a feed tree. For example, *A. littoralis* feed trees exhibit significantly greater trunk diameter and height, and sparser canopy than co-occurring non-feed trees (North *et al.* 2020). This trend is not observed in *A. torulosa* feed trees, which show a tendency towards having a larger canopy than surrounding tress. This preference may be due to different investments in cones or germination rates that determines canopy to cone ratio.

The key feed species *A. littoralis* is an obligate seeder and unable to recover via resprouting (Lunt 1998). This means that any injury resulting in complete defoliation is likely to remove the food resource from an individual tree permanently. However, *A. littoralis* is known to readily colonise disturbed areas and can reach high densities, so it seems unlikely that occasional loss and subsequent replacement of browse trees following damage will detrimentally impact cockatoo populations in the long-term.

Regent honeyeaters have a general tendency to forage in emergent or taller trees with larger DBH, within areas containing high numbers of large flowering trees and high nectar abundance (Webster and Menkhorst 1992; Menkhorst *et al.* 1999; Oliver *et al.* 1999; Kennedy and Tzaros 2005). In woodland areas, regent honeyeaters are also more likely to be present where there is higher canopy cover, e.g. approximately 50% probability of occurrence at 50% canopy cover at the site level (Oliver 1998; Oliver *et al.* 1999). Within these areas, they tend to select for tall trees with full canopies and few signs of decline (Oliver 2000). In some areas, canopy cover shows documented declines (Nolan *et al.* 2021b; Losso *et al.* 2022b) or projected declines (Angel and Bradley 2021) in response to decreasing rainfall.

Swift parrots have also been widely reported to forage in larger trees (Kennedy and Overs 2001; Kennedy and Tzaros 2005; Brereton *et al.* 2016), particularly those that flower more profusely than surrounding trees (Brereton *et al.* 2016) and typically forage in the upper canopy (Hingston and Potts 2005). Swift parrots have also been reported to have high site fidelity across many locations in southeastern Australia (Saunders *et al.* 2007; Saunders and Heinsohn 2008). However, there is at least one example in Victoria where neither fidelity nor a link between eucalypt flowering and swift parrot foraging was detected (Mac Nally and Horrocks 2000). Overall, conservation of remnant patches of suitable forest within cleared agricultural landscapes is likely to be important for the survival of swift parrots (Saunders and Tzaros 2011). Nonetheless, it has been recommended that forestry prescriptions include retention of all trees 60 cm DBH or greater, along with a minimum of five trees per ha in a range of smaller size classes, to ensure future food resource availability (Saunders and Tzaros 2011).

3.7.3 Mechanical bole injury

Bole injuries may occur due to impact by machinery, impact from another felled tree or fire and its interactions with termites and decay. There are three levels of organisation of a woody stem: protective bark, conductive and growth tissues (phloem, xylem, cambium), and dead heartwood. Smaller injuries may affect the bark only or bark and conductive/growth tissues over a relatively small surface area, while more substantial injuries may affect bark and conductive/growth tissues over a wider surface area, which may impact the transport of water, nutrients and solutes and reduce the amount of structurally important wood supporting the bole. For example, a major reduction in horizontal cross-sectional area on the main bole has been linked to an increase in the probability of tree failure and collapse due to structural weakness (Gibbons *et al.* 2000a; Whitford and Williams 2001; Bluff 2016). Whitford and Williams (2001) sampled 2526 retained habitat trees and logs in Western Australian eucalypt forests and found that 194 had collapsed. Hollowing out of the tree base due to fire alone, or due to fire and its interactions with termites/decay was identified as the primary cause of stem collapse. For collapsed trees, the mean loss of cross-sectional area was 62%, and 72% of collapsed trees had lost a cross-sectional area of 50% or more. Only 7% of standing trees had lost a cross-sectional area of 50% or more. Only four trees were determined to have collapsed as a direct result of being injured during a forestry operation (Whitford and Williams 2001). Bluff (2016) also found that loss of cross-sectional area of the main stem was a reliable predictor of tree collapse, e.g. for each unit increase in loss of cross-sectional area the probability of collapse increased by 1.35.

Another method of diagnosing the likelihood of stem collapse in hollowed trees is to calculate the ratio of remaining solid wood-to-total radius, which assumes a circular cylinder (Mattheck *et al.* 1994). For example, if the ratio falls below 0.35 then the stem is likely to collapse (Mattheck *et al.* 1994). This metric was tested and confirmed to be accurate in a study of retained eucalypts on logged sites (Gibbons *et al.* 2000a). However, the ratio value at which stem collapse occurs has been shown to differ from 0.35 when other pipe shapes are considered, e.g. oval, and can vary due to species (Huang *et al.* 2017). The more practical method of assessment during forestry operations is estimation of the remaining cross-sectional area.

There may be instances where there has been minimal loss of cross-sectional area (e.g. the bole is still structurally sound), but there has been significant loss of bark and active vascular tissues (e.g. sapwood) due to impact with machinery or fallen trees. Unfortunately, the body of evidence assessing how much vascular tissue is required to sustain specific tree functions, such as providing leaves, sap, nectar and seeds over the long term is limited. The effects of these injuries can vary substantially depending on the amount of vascular connectivity remaining between the roots and shoot and the depth of the injury (e.g. loss of phloem tissues versus xylem tissues). Many species are also capable of healing (occluding) wounds over time (Gill 1980; Smith *et al.* 2006; Zuhair *et al.* 2010; Moore 2013; Ow *et al.* 2013; Tavankar *et al.* 2019). For example, the closure rates of experimental stem wounds for the obligate seeder *Eucalyptus regnans* are known to range between 1.3-1.5 cm per year and therefore an injury 10 cm wide may fully occlude within 7-8 years (White and Kile 1993; 1994). In another example, Smith *et al.* (2006) tracked the closure rates of cut live branches of varying diameters for *E. grandis*, *E. pilularis*, *E. dunni* and *E. coleziana* and found that all species were able to fully occlude wounds of approximately 20 cm diameter within 2-4 years. There is, however, potential for disturbances such as fire and drought, or biotic attack to slow or prevent occlusion or exacerbate injuries. For example, in a study of wound occlusion in the obligate seeder *Pinus ponderosa* which is native to North America, Baker and Dugan (2013) found that for trees experiencing two sequential fire scar injuries, the overall size of the injury was 38% larger than trees experiencing only one injury and subsequently the estimated time to wound closure increased by 20-25 years. This suggests that the wound occlusion trajectory for trees with mechanical bole injuries is strongly influenced by subsequent disturbances. However, fire scars typically affect the leeward side of the tree (Gutsell and Johnson 1996), so the location of mechanically-caused bole injuries would likely need to align with the probable location of naturally-forming fire scars in order for compounding temporal effects to be realised. If both types of injuries (mechanical and fire-related) occurred at different locations on the bole there would likely still be cumulative impacts on conductive and structural tissues.

Much research investigating the effects of bole injuries on tree health relates to fire scars and intentional agroforestry/horticultural methods such as ringbarking or stem girdling. While these methods are not utilised in modern Australian forestry systems, knowledge of their effects can provide general insights into how trees respond to stem injuries. For example, ringbarking/girdling can be used to manipulate tree growth, stimulate reproduction and increase fruit/seed yield and quality in commercial species such as walnut, citrus, conifers (Wheeler *et al.* 1985; Woods 1989; Rivas *et al.* 2007; McFadyen *et al.* 2013; Christopoulos *et al.* 2021). This occurs because girdling of the phloem tissues leads to accumulation of photosynthates in the tree above the injury and therefore increases the availability of carbohydrates in the canopy while maintaining transport of water from root to shoot, as the xylem is left intact (Högberg *et al.* 2001; Moore 2013). However, complete girdling of the phloem in some species is known to result in eventual mortality (Percival and Smiley 2015; Fajstavr *et al.* 2017).

Ringbarking/girdling of the phloem in *Myrtaceae* may be less likely to kill trees compared to other angiosperms due to anomalous growth of phloem, e.g. embedded within the xylem (Carlquist 2013; Moore 2013; Rajput *et al.* 2022). As such, some eucalypts are known to survive extreme (e.g. 90%) or complete ringbarking/girdling (Priestley 2004) and in most cases may be able to resprout from the region below the injury due to the presence of carbohydrates stored in the lignotuber. Injuries that penetrate into the deeper layer of xylem-containing sapwood will interrupt water flow and will likely result in rapid mortality if the vascular tissue is completely severed around the circumference of the tree (McLuckie and McKee 1954; Taiz and Zeiger 2002; Moore 2013). For example, complete ringbarking of the phloem and sapwood was historically used for killing eucalypts at large-scale to convert landscapes for industrial purposes (Stubbs 1998).

Where transport of water is concerned, double sawcut experiments in temperate deciduous species have shown that trees can survive interruptions of more than 50% of the stem sapwood due to redundancy in the xylem vessel network, although in these cases the saw cuts must be made an appropriate distance from each other based on the xylem anatomy (vessel length) of the tree species in question (Tyree and Zimmermann 2002). While these experiments have not been performed for eucalypt species, it is very likely that they are similarly resilient to loss of vascular tissue caused by mechanical injury. However, major reductions in sapwood area (e.g. >50%) could potentially make a tree more vulnerable to mortality during future disturbances such as: (i) drought, by reducing hydraulic function and introducing air entry points; (ii) fire, by accelerating fire scar development that can lead to stem collapse and (iii) termites and fungi, by creating access points for insects and decay that consume wood and reduce structural integrity. For example, fire scars and the associated compounding processes implicated in their development (i.e. subsequent fires, termites, decay) have been identified as an important mechanism of tree mortality and stem collapse across a range of eucalypt species and other fire-adapted trees globally (Whitford and Williams 2001; Gibbons *et al.* 2008; Bendall *et al.* 2022; Shive *et al.* 2022). While effects on collapse and mortality have largely been discussed above (see **3.7.3**), other potential impacts of bole injuries on tree functions are discussed in more detail below.

3.7.3.1 Impacts of bole injuries on tree function

Fire scars are a type of naturally-occurring bole injury and their effects on tree function may closely resemble those of mechanical injuries, as both types of injuries typically result in the removal of an area of protective bark and conductive/structural tissues. Evidence for how such injuries may affect tree function comes from studies of redwoods (*Sequoiadendron giganteum, Sequoia sempervirens*) in northern hemisphere temperate forests. Sequoias are extremely long-lived (e.g. thousands of years), experience regular fire and have subsequently developed a range of adaptations to cope with fire, such as extremely thick bark near the tree base (e.g. more than half a metre), and some observed capacity for epicormic resprouting (O'Hara *et al.* 2008; Sillett *et al.* 2015). The development of a condition known as 'snag top' (i.e. partial crown mortality) and a reduction in the amount of foliage has been linked to the presence and size of fire scar injuries (Rundel 1973; Sillett *et al.* 2015). For example, Rundel (1973) sampled >2000 giant sequoias and found that 85.7% of trees with intact crowns and 75.1% of trees with normal foliage levels did not have a fire scar. In contrast, trees that did have a fire scar were more likely to have partial crown mortality and reduced foliage levels and the proportion of these tree increased with fire scar size, e.g. for trees with large fire scars 47.7% had partial crown mortality and 36.3% had reduced foliage levels. More recently, Sillett *et al.* (2015) developed models of tree growth, health and form in relation to a broad range of variables including fire scar presence. Sillett *et al.* (2015) found that >90% of giant sequoias and around 50% of coast redwoods with fires scars had partial canopy mortality. Fire scars are thought to impact upon canopy function by decreasing the amount of conductive tissue available, resulting in water stress in the upper canopy that causes branches to die (Rundel 1973; Sillett *et al.* 2015). Studies of fire-scarred white oak (*Quercus alba*) suggest that overall potential hydraulic conductivity (derived from measurements of xylem vessels) is significantly reduced for two years following the formation of fire scars, regardless of the size of fire scars (Dee *et al.* 2019). Such losses of hydraulic conductivity often result in reduction in leaf area, as trees must balance evaporative surface area of leaves with the capacity to supply water through the xylem (Tyree and Zimmermann 2002). A recent review of fire-related injuries on tree physiology suggests that fire-caused tissue necrosis is a key process impacting tree function and that carbon starvation and hydraulic impairment may result through additional linked impacts from drought and biotic attack (Bar *et al.* 2019). However, the specific processes that link these mechanisms of tree functional decline are not yet fully understood (Bar *et al.* 2019).

While eucalypts have received less attention in this research area, current work suggests that they are capable of recovering from significant hydraulic impairment (i.e. xylem embolism) in their water transport tissues (average of 78% loss of the xylem to embolism), although embolism mortality thresholds are difficult to define precisely (Barigah *et al.* 2021; Gauthey *et al.* 2022). Recent field measurements suggest that some eucalypts may lose substantial xylem functionality and still be capable of recovery within a few years if conditions remain favourable during the recovery period (Losso *et al.* 2022, Nichols *et al.* unpub).

In relation to immediate mortality (see **3.7.3**), there is no clear evidence to suggest that anything less than 100% separation of phloem tissue between root and shoot, or anything less than 80% loss of active xylem tissue, will result in immediate stem mortality in eucalypts. However, in relation to impacts on tree function, the northern hemisphere studies described above suggest that trees with a basal fire scar, which are generally comparable to mechanical bole injuries, are likely to experience impacts on their function, such as partial canopy mortality and a reduction in leaves. Therefore, **retained trees** could potentially experience loss of crown branches and/or leaves (and therefore reductions in sap flow and nectar production) due to bole injuries, although the magnitude of functional decline for eucalypts is currently uncertain[5]. Estimation would be possible if trees with injuries are monitored through time, or retrospectively studied, to assess how additional factors such as fire, drought and biotic attack influence the progression of injuries and their subsequent impact on tree function.

[5] While beyond the scope of this review, data currently exists that would allow for an analysis of eucalypt canopy condition as predicted by trees with and without fire scars. In relation to mechanical injuries, there would be potential for a retrospective study of tree responses to historical injuries (see **Appendix B**), provided that the date of injury could be estimated and other environmental factors are known, e.g. fire history, harvesting history. One major challenge for such a study is that injuries heal over time and may become undetectable, so the study may be temporally constrained to recently harvested areas (e.g. the last 20 years). Fire in the intervening period between mechanical injury and sampling could also confound tree responses, e.g. a mechanical injury that has been severely burnt could be similar in appearance to a fire scar. Thus, developing a method to differentiate fire scars vs mechanical injuries that have been burnt would be required, and could be based on the shape and edge contour characteristics. For example, while fire scars typically form an ‘A-frame’ shape at the tree base, mechanical injuries are likely to be much more variable and may contain jagged edges from machinery impact (see **Figures** in **Section 2**).

3.7.4 Insects and fungi

Investigations into levels of insect damage and fungal rot in eucalypts indicate that fire scars predispose trees to fungal infection, which creates conditions suitable for the founding of insect colonies (Perry *et al.* 1985; Hopkins *et al.* 2005). The relationship between fire scarring, subsequent fungal infection and insect colonisation has long been recognised in the forestry industry and has been attributed to significant economic losses due to timber damage and tree mortality (Stickel and Marco 1936; Harris 1955; Greaves 1959). These linked processes can cause significant hollowing of the main bole (Werner and Prior 2007; N'Dri *et al.* 2011), increasing the likelihood of stem collapse (Mattheck *et al.* 1994). For example, Whitford and Williams (2001) found that termites, in combination with wind and fire effects, were directly responsible for stem collapse in 16% of fallen habitat trees (n = 194) retained on logged sites in Western Australia. Any injury to a tree that allows access to fungi and termites could potentially be detrimental to its longevity. However, insect activity is known to be an important contributor to the formation of hollows in eucalypts (Hopkins *et al.* 2005; Werner and Prior 2007; Woolley *et al.* 2018), which are critical to the survival of hollow-dependent fauna. Thus, termites present a conflicting management issue, as they are required for the development of hollow-bearing trees but may also reduce their longevity as permanently **retained trees**. In some ecosystems, termite abundance increases with mean temperature, and decreases with humidity, which means understanding their role is increasingly important in the face of climate change (Alamu and Ewete 2021).

3.7.5 Root injury

Injury to roots may occur due to impact by machinery or impact from another felled tree and may be exacerbated by fire and its interactions with termites and decay in similar ways to the processes described in **3.7.3** and **3.7.3.1**. The biomechanics of root structure, anchorage and stability of roots under stress is complex and quantification generally requires complete extraction of the organism to examine physical properties and breakage points (Coutts 1983; 1986). Major lateral roots, particularly on the windward side of the tree may have a disproportionally important role in providing anchorage and stability (Coutts 1986; Yang *et al.* 2014). Root injuries are likely to occur when soils around the tree base are compacted by machinery (Shepperd 1993a). Avoiding repeatedly driving over the root zone, especially in wet weather, could reduce injuries due to root zone compaction (Moehring and Rawls 1970; Shepperd 1993a; Han and Kellogg 2000). For example, soil compaction is likely to lead to root injury in aspen (sogme *Populus* spp.) (Shepperd 1993b). Soil compaction around eucalypt roots has been linked to reduced root growth, nutrient absorption (Silva *et al.* 2018) and water infiltration (Clemente *et al.* 2005). Soil compaction can also result in topsoil displacement and profile disturbance, which could potentially affect tree growth (Williamson and Neilsen 2003). Introduction or spread of pathogens such as *Phytophthora cinnamomi* can potentially occur in forests due to the introduction of infected materials associated with roads (e.g. soils, gravel) or on equipment (Weste *et al.* 1973; Fagg *et al.* 1986; FPA 2019). The risk of this occurring is assumed to be controlled for via biosecurity protocols and other mechanisms, such as washing down vehicles and equipment before entering some areas, as per the site harvest plans (e.g. see FCNSW 2017). For the purposes of this review, the impacts of soil-borne pathogens on roots are encompassed and treated under the term 'decay'. Although root injury may be difficult to observe unless it occurs above-ground, attempts should be made to incorporate it into an assessment of **damage** to **retained trees**, as injuries to major roots could destabilise trees and present similar issues to that of bole injuries, such as increased vulnerability to fire, drought and biotic attack.

4 Potential approach to assessment of risk to retained trees

4.1 Summary

This section describes a potential approach to assessment of the risk to the ongoing function of retained trees due to different types and levels of injury, using the best available evidence. This should be viewed as a qualitative assessment approach based on the literature and using the proposed decision matrix outlined in **Appendix A**. This assessment does not attempt to define damage thresholds for different types of injuries. Damage thresholds will be set through a separate process. It is recommended that monitoring and/or retrospective studies are undertaken to obtain data that could be used in a quantitative assessment that would improve the accuracy of any potential **damage** thresholds that are eventually set. In particular, monitoring tree injuries over time, e.g. following stochastic disturbances such as fire and drought, will be important, as these, and other environmental factors, may alter the trajectory of tree recovery and therefore impact tree function. Types of injuries and proposed categories for assessment covered in this section are summarised in **Table 2**. Each reference to a 'section' (e.g. Section A, B, C) refers to both the way that **Table 2** is organised and the way that **Appendix A** is organised.

Table 2. Types of injury and proposed assessment criteria

SECTION	**A**				**B**		**C**	
TYPE OF INJURY	Knocked over / uprooted / broken or snapped tree		Mechanical crown injury		Mechanical bole injury		Roots and termites	
PROPOSED CRITERIA	**1** Not free-standing	**2** Broken or snapped tree	**3** Crown injury type A	**4** Crown injury type B	**6** Bole injury type A	**7** Bole injury type B	Condition **A** Root injury	Condition **B** Termite infestation

Overall, the majority of injuries to **retained trees** shown to Western Sydney University staff during field visits in 2023 appear unlikely to inhibit tree function in the near term. Some examples of injuries were observed (however these were not necessarily formally **retained trees**) where a tree could potentially be **damaged**, depending on its intended function, e.g. an individual tree of a koala browse tree species that had lost a large part of its crown. While future disturbances such as fire, drought and biotic attack could worsen the current cohort of injuries, they are unable to be accounted for explicitly in this assessment. Rather, knowledge of how these types of natural disturbances/stressors impact tree function is implicitly part of the assessment, as much of the background information that informs the proposed methods (and therefore this assessment) is derived from literature relating to naturally-acquired injuries. This document outlines both observed and hypothetical examples of types of injuries that have occurred/could potentially occur due to forestry operations and are therefore included in the assessment. All definitions of terminology used in this assessment relating to '**retained tree'**, '**damage**', 'function' or any types of **retained trees**, including uses with and without bold font follow the definitions and protocols described in sections **2**, **3.2** and **3.6**.

4.2 SECTION A

4.2.1 Type of injury: Knocked over / uprooted / broken or snapped tree

Criteria 1: ***Not free-standing***

Description: The tree is no longer free-standing.

Figure 1. Hypothetical example of a knocked over tree meeting the definition of Criteria 1. This tree could potentially be unable to perform the function it was retained for.

Assessment: Any category of **retained tree** meeting the definition of Criteria 1 could potentially be unable to perform the function it was retained for.

Criteria 2:* *Broken or snapped tree

Description: Crown of tree has been entirely broken off and only the main bole or a stump remains.

Figure 2. Hypothetical example of a temporarily retained feed tree with crown broken off, meeting the definition of Criteria 2 (i.e. 'broken or snapped tree'). This tree could potentially be unable to perform the function it was retained for.

Assessment: Some categories of **retained tree** meeting the definition of Criteria 2 could potentially be unable to provide the function they were retained for, including giant trees and hollow-bearing trees matching the species list in Section D of the **Appendix A**, i.e. species known to have limited capacity to resprout from epicormic buds in the stem or canopy (Nicolle 2006; Fairman *et al.* 2017). Koala browse trees and nectar feed trees that have lost their crown are unlikely to continue performing their intended function, which is to provide resources to fauna during and at completion of the forestry operation. Total loss of the canopy would likely reduce sap flow (Cunningham *et al.* 2009) and diminish the utility of a tree for gliders (Goldingay 1991). Therefore, glider sap feed trees meeting the definition of Criteria 2 could potentially be unable to provide the function they were retained for. Tree categories meeting the definition of Criteria 2 may still provide the function of trees required to be retained include:

Giant tree or hollow-bearing tree not matching species list in Section D: Giant trees and hollow-bearing trees meeting the definition of Criteria 2 but do not match the species list in Section D are likely to be capable of successful resprouting following loss of tree crown. Breakage of the crown or stem may potentially lead to the development of further hollows (Gibbons *et al.* 2000b; Hofman *et al.* 2022). A tree may contain hollows in the main bole or tree base that are unaffected by loss of the upper part of the tree. Therefore, provided the tree can resprout and still meets the definition of a retained tree it should continue performing its function. An exception to this could be that the tree also meets the definition of criteria in Section B and/or C.

Dead standing tree: A dead standing tree is defined under the Coastal IFOA as:

> "a dead standing tree: (1) where the bark is fully separated from the sapwood due to decay and is greater than 30 centimetres in diameter at breast height and greater than three metres tall; or (2) that has hollows" (NSW EPA 2020).

Therefore, if a dead standing tree has acquired an injury that meets Criteria 2 but: (i) is still greater than 30 cm DBH and greater than three metres tall; or (ii) still contains hollows, then it is likely to still perform its function. An exception to this could be that the tree also meets the definition of Criteria 6 in Section B.

4.2.2 Type of injury: Mechanical crown injury

***Criteria 3:* Crown injury type A**

Description: An amount above the damage threshold but less than 100% of crown branches have been broken off.

***Criteria 4:* Crown injury type B**

Description: An amount below the damage threshold but some crown branches have been broken off.

Figure 3. Hypothetical example of a koala browse tree that had lost a large part of its crown due to impact by another felled tree. This tree could potentially meet the definition of Criteria 3 (i.e. 'crown injury type A'), depending on the damage threshold that is set. In that case, the tree would be unlikely to continue performing the function it was retained for.

Figure 4. Hypothetical example of a nectar feed tree that had lost some branches from its crown due to impact by another felled tree. This tree does would be unlikely to meet the definition for Criteria 3 (i.e. ‘crown injury type A’) but could be likely to meet the definition for Criteria 4 (‘crown injury type B’). In that case, the tree would be likely to continue to perform its function and its longevity is unlikely to be impacted.

Figure 5. Hypothetical example of a koala browse tree that had lost some branches from its crown due to impact by another felled tree. This tree would be unlikely to meet the definition for Criteria 3 (i.e. 'crown injury type A') but could be likely to meet the definition for Criteria 4 ('crown injury type B'). In that case, the tree would be likely to continue to perform its function and its longevity is unlikely to be impacted.

Assessment: Crown injury alone may not be sufficient evidence that a permanently **retained** giant **tree** or hollow-bearing **tree** is **damaged**. This follows the reasoning described for these types of retained trees under Criteria 2 (broken or snapped tree, **4.2.1**). Permanently **retained** giant **trees** or hollow-bearing **trees** that meet the definition of Criteria 3 should firstly be referred to Section B and then Section C. For example, in Section B, if bole injury is type A, then the tree is likely to collapse and longevity and function could potentially be impacted. However, if bole injury is type B or absent then the tree should be assessed for additional injuries (root injury, termite infestation) that could potentially increase the risk of tree collapse or impact upon tree function. If none of the Criteria in Section B apply or the Conditions in Section C have not been met then the tree is likely to persist and provide its function.

The following tree categories meeting the definition of Criteria 3 could potentially be unable to perform the function they were retained for: koala browse tree, glider sap tree, glossy black-cockatoo feed tree, nectar feed tree. The general rationale for **damaged trees** in these categories follows that crown loss of an amount above the damage threshold is equivalent to major loss of the currently available food resources, i.e. these resources are typically found in the crown of the tree and trees in these categories are required to perform their intended ecological function at the time of and during completion of the forestry operation. Details for each tree category are as follows:

Koala browse tree: There is no literature that quantifies koala tree use in the context of forestry operation-related crown injury or general crown condition that can confidently be used to define injury thresholds for koala browse trees. Specifically, there is insufficient evidence to suggest that koalas will not use trees with crown injuries, and they appear capable of browsing in smaller trees with reduced crowns. This implies that koalas may still browse in trees with type A or B crown injuries. Epicormic regrowth triggered by non-terminal injuries may be also nutritionally beneficial to koalas. This suggests that caution should be applied when considering replacement of koala browse trees due to crown injury. One management approach to this problem could be to only consider replacement of trees within a subset of type A crown injuries (e.g. the damage threshold is set higher for koala browse trees).

Glider sap tree: The evidence suggests that crown injury may have an impact on a **retained tree's** sap flow. In one study (Cunningham *et al.* 2009), as little as 20% reduction in leaf area due to insect herbivory reduced sap flow by half, which could potentially discourage gliders from visiting trees (Goldingay 1991). However, as described in **3.7.2** it not clear whether the studies of sap flow in woodland trees in

Cunningham *et al.* (2009) can be generalised to the higher productivity forests relevant to the Coastal IFOA. If a **damage** threshold of 20% canopy loss was set for glider sap trees then this would result in the replacement of trees with only very light injuries to the crown. Sap flow reduction in such cases is only likely to be temporary (Gill 1978; Burrows 2013) and it has been demonstrated that gliders have high fidelity to sap trees (Goldingay 1991; Goldingay 2000), so it would seem potentially unwise to set such a low threshold until better evidence can be obtained. Based on the above it seems likely that the **damage** threshold for glider sap trees may lie somewhere above 20% crown loss but lower than that which may be set for koala browse trees.

Glossy black-cockatoo feed tree: The evidence suggests that larger feed trees with higher numbers of cones should be prioritised for glossy black cockatoos. A type A injury that results in loss of cone-bearing branches, to the extent that less than 200 cones remain on the tree, could potentially cause loss of function. However, consideration would need to be given to overall levels of food availability in the landscape. For example, the key browse species *Allocasuarina littoralis* is an obligate seeder that responds favourably to disturbance (i.e. mass germination, see Crowley 1986, Lunt 1998) and therefore the amount of cones/seeds available on trees is likely to be dependent on the maturity of the feed tree cohort with respect to fire history (e.g. some *Allocasuarina* species are obligate seeders). In some dry western forests, diminished rainfall during spring and autumn has been observed to detrimentally impact *Allocasuarina* cone production, with many trees failing to produce seed during severe drought (Cameron 2006), which may indicate that food resources fluctuate with climate. Given the issues with counting cones and that other cone/seed-related metrics would likely have similar uncertainties, another management approach to this problem could be to only consider replacement of trees that have a substantial proportion of their crown (i.e. type A crown injury), with the aim of maximising food resources for glossy black-cockatoos.

Nectar tree: The evidence suggests that providing the highest number of large nectar feed trees possible will be of greatest benefit to swift parrots and regent honeyeaters.

However, there is no evidence to suggest that these species do not utilise nectar trees with crown injuries. As long as some resources remain on the uninjured branches, trees may still be able to provide resources during and at completion of the forestry operation, although nectar production may be reduced or delayed for several seasons until the tree has recovered (Law *et al.* 2000; Hingston and Piech 2011). There is also evidence that some early regeneration forests are capable of producing substantial nectar at the stand-level, which suggests that harvesting effects on nectar production are not uniform across landscape and will depend on the eucalypt species present (Law and Chidel 2008). Therefore, a conservative approach to trees with crown injury could be applied, as follows:

(i) trees with type B crown injury (i.e. minority of crown branches broken off) are likely to be capable of providing adequate resources;

(ii) trees with type A crown injury (i.e. majority of crown branches broken off) could have their function impacted, as the resource has been substantially diminished in the short-term and further nectar production may be temporarily reduced

4.3 SECTION B

4.3.1 Type of injury: Mechanical bole injury

<u>Criteria 6:</u> Bole injury type A (immediate/near-term loss of function)

<u>Short description:</u>

(1) Impact on cross-sectional area: An amount above the damage threshold of horizontal cross-sectional area of bole at widest point of injury has been removed but tree still standing OR

(2a) Impact on xylem or phloem: An amount above the damage threshold of active xylem tissues (sapwood) down to the level of the heartwood have been removed around circumference of bole OR

(2b) Impact on xylem or phloem: An amount above the damage threshold of phloem tissues down to the level of the sapwood have been removed around circumference of bole.

Criteria 7: Bole injury type B (potential future loss of function)

Short description:

(1) Impact on cross-sectional area: An amount below the damage threshold of horizontal cross-sectional area of bole at widest point of injury has been removed but tree still standing OR

(2) Impact on xylem or phloem: An amount below the damage threshold of active xylem tissues (sapwood) down to the level of the heartwood have been removed around circumference of bole.

Description **(1)** Impact on cross-sectional area: 'Bole injury' in the context of this assessment refers to injuries on all areas of the main bole below the level of the crown but above any exposed roots. 'Type A' injury to the bole is intrinsically likely to cause stem collapse due to the instability of a vertical cylindrical object once a substantial amount of the cross-sectional area (e.g. structural wood) has been removed (see below). Therefore, injuries that do not meet the definition of type A injury (i.e. 'type B') should be considered within the context of additional known agents of tree decline such as termites and decay-causing fungi, using Section C.

Description **(2)** Impact on xylem or phloem: There may be instances where there has been minimal loss of cross-sectional area (e.g. the bole is still structurally sound), but there has been significant loss of bark and vascular tissues (i.e. phloem, xylem) due to impact with machinery or fallen trees. The effects of these injuries can vary substantially depending on the amount of vascular connectivity remaining between the roots and shoot and the depth of the injury (e.g. loss of phloem tissues versus xylem tissues).

Figure 6. This hypothetical example of a **retained tree** was injured due to machinery impact. Depending on the damage threshold that is set, the injured tree could potentially meet the criteria for Criteria 6 (i.e. 'bole injury type A') or Criteria 7 (i.e. 'bole injury type B') as it had lost some of its vascular tissue down to the level of the heartwood. This tree was healthy and growing with a complete crown, and substantial regrowth of the vascular tissues was evident, despite losing much vascular tissue due to the injury. Future fires, drought, insect attack and decay could exacerbate this injury. Therefore, if this tree was required to be retained permanently then the injury could be reassessed at the next forestry operation.

Figure 7. This hypothetical example of a **retained tree** was injured due to machinery impact and may have initially met the definition of Criteria 7 (i.e. 'bole injury type B'). However, the tree has since partially occluded the injury and if assessed now it could potentially fall below the level of a type B injury, depending on the damage threshold that is set. Future fires, drought, insect attack and decay could exacerbate this injury. Therefore, if this tree was required to be retained permanently then the injury could be reassessed at the next forestry operation.

Figure 9. This hypothetical example of a **retained tree** (same tree in both panels) was injured due to machinery impact. Depending on the damage threshold that is set, the injured tree could potentially meet the criteria for Criteria 6 (i.e. 'bole injury type A') or Criteria 7 (i.e. 'bole injury type B') as it had lost some of its vascular tissue down to the level of the heartwood. The injury appears to have initiated an epicormic resprouting response but otherwise the tree appears healthy and growing. Future fires, drought, insect attack and decay could exacerbate this injury. Therefore, if this tree was required to be retained permanently then the injury could be reassessed at the next forestry operation.

Figure 10. Further hypothetical examples of **retained trees** that have sustained injuries due to impact by machinery. All of these examples would likely fall below the threshold for Criteria 7 (i.e. 'type B bole injury), but this would depend on the damage threshold that is set.

Figure 11. Examples of trees with bole injuries due to impact with machinery or fallen trees at various stages of wound occlusion, demonstrating the capacity of eucalypts to recover from bole injuries. (a) shows a **retained tree** that was impacted by a falling tree with partial occlusion; (b) and (c) show trees impacted by machinery with substantial occlusion; (d) shows a tree impacted by machinery that has fully occluded.

Assessment: There is evidence that trees may become structurally unstable once the majority of the cross-sectional area of the bole has been structurally compromised (see **3.7.3**). There is no clear evidence to suggest that anything less than 100% separation of phloem tissue between root and shoot, or anything less than 80% loss of active xylem tissue, will result in immediate stem mortality in eucalypts. However, there is evidence that some species of trees (e.g. some conifers and oaks which do not naturally occur in forests managed under the Coastal IFOA) may experience partial canopy mortality and loss of leaves following the formation of basal fire scars, which are likely to have similar effects on tree physiology to mechanical bole injuries. There is also evidence that eucalypts may have an increased risk of future mortality (e.g. ~20% higher on average) following mechanical injuries to the bole and crown[6]. Therefore, live permanently **retained trees** meeting the definition of Criteria 6 (type A injuries, i.e. immediate / near-term loss of function due to **(1)** structural instability or **(2)** complete loss of hydraulic function) could potentially lose their function or have their longevity compromised unless they still meet the definition of a **retained tree** following the injury, e.g. the lower bole/stump may still contain hollows below the point of injury. Koala browse trees, nectar feed trees and glider sap feed trees that have lost >80% of active xylem tissues down to the level of the heartwood around the circumference of the bole (type A **2a**) or 100% of phloem tissues down to the level of the sapwood around the circumference of the bole (type A **2b**) could potentially have their function compromised, as they are unlikely to continue leaf growth or produce nectar/sap. Glossy black-cockatoo feed trees with a type A injury (both **(1)** and **(2)**) may still temporarily provide seeds for 2-3 weeks if the tree dies (Glossy Black Conservancy 2023; SA Government 2023); the functional longevity of any surviving trees would be severely compromised. Type B injuries (i.e. potential future loss of function) are unlikely to result in immediate loss of function but should be considered within the context of additional known vectors of tree decline such as termites and decay fungi, using Section C. Future fire and drought could also exacerbate bole injuries over time, by slowing wound occlusion and maintaining conditions suitable for fungal and insect attack (see **3.7.3.1**).

[6]Study did not model crown and bole injuries separately or provide the number of samples of each type of injury. Injured trees were also subject to different fire regimes over the decades between the time of injury and sampling. See: Watson G. M., French K. & Collins L. (2020) Timber harvest and frequent prescribed burning interact to affect the demography of Eucalypt species. *Forest Ecology and Management* **475**, 118463.

4.4 SECTION C

This section contains additional types of injuries that alone may not be significant enough to constitute **damage**, or the extent to which they affect the tree may be difficult to visually assess. In some circumstances the decision matrix will refer the user to Section C, which attempts to account for the combined effects of injuries in Section A and/or B and those in Section C. For example, a tree that has acquired a type B bole injury may not be considered **damaged**, but when there is also substantial injury to roots or termites have infested the tree, then there may be an elevated risk that the tree may fail in the long term and this may constitute **damage**. Section C only applies to giant trees and hollow-bearing trees which are required to be retained permanently, i.e. the Conditions do not apply to other types of temporarily **retained trees** as they are likely to continue to perform their functions during and at the completion of the forestry operation regardless of root damage or termite infestation. Section C requires that at least two Conditions are met before the tree could potentially be considered **damaged**, i.e. each Condition in isolation is likely not significant enough to constitute **damage**, even when other types of damage are present (e.g. crown or bole damage). The requirement of two Conditions being met also helps to minimise unintended outcomes, such as a hollow-bearing tree being replaced only due to the presence of termites, which are important contributors to the formation of hollows.

*4.4.1 **Condition A:** Root injury*

Description: Injury to major roots visible (i.e. breakage, snapped) due to machinery or another fallen tree. Does not include superficial scrapes or cuts. 'Root injury' in the context of this assessment refers to all areas of the roots below the main bole; includes roots, buttress roots and the root collar area clearly visible above ground, as well as roots that may be below ground but injury is still evident.

Assessment: Assessing injuries due to soil compaction without obvious evidence of broken roots is likely to require intensive investigation of disturbed root area. The practical method of root assessment is inspection of broken roots that are visible, which are likely to be large and shallow lateral roots that contribute to tree stability. To meet Condition A, there must be evidence that one or more major lateral roots have partially or completely broken, i.e. scrapes or cuts that only affect the bark or vascular tissues are not considered in the assessment.

Ultimately, the operator is required to make a decision about the long-term stability of the tree given the level of root damage present. If a tree meets Condition A then it must also meet Condition B to potentially have its longevity impacted.

*4.4.2 **Condition B:** Termite infestation*

Description: Termite activity present at tree base and/or bole, evidenced by significant areas of mud packing on tree/termite galleries visible on main bole or tree base OR a large termite mound is visible within 1m of tree base.

Assessment: To meet Condition B, there must be evidence of a substantial termite infestation, evidenced by termite activity present at the tree base and/or bole, which may be observed as significant areas of mud packing on the tree or termite galleries visible on main bole/tree base and/or a large termite mound is visible within 1m of the tree base, as in Whitford and Williams (2001). If a tree meets Condition B then it must also meet Condition A to potentially have its longevity reduced, or function compromised.

Figure 12. This tree has a bole injury that likely falls below the threshold for Criteria 7 (i.e. 'bole injury type B') and so it is unlikely to lose its function or have its longevity compromised, despite the termite infestation at the tree base. If the bole injury did meet Criteria 7 then the user would be referred to Section C. Following Section C, the tree would meet Condition B as the termite mound is within 1 m of the tree base. However, as no major roots are visibly broken the tree does not satisfy both Conditions in Section C and is unlikely to have its function or longevity compromised. The tree could be re-assessed at the next forestry operation.

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6 Appendix A – Draft Injury Threshold Decision Matrix

SECTION A

COMPLETE SECTION **A** AND **DO NOT MOVE TO SECTION B OR C** UNLESS IT IS INDICATED

TYPE OF INJURY	KNOCKED OVER / UPROOTED / BROKEN OR SNAPPED TREE		MECHANICAL CROWN INJURY		
CRITERIA	CRITERIA 1	CRITERIA 2	CRITERIA 3	CRITERIA 4	CRITERIA 5
FOR **SECTION A** MOVE THROUGH THE CRITERIA TO THE RIGHT UNTIL THE TREE MEETS THE CRITERIA DESCRIPTION	NOT FREE-STANDING	BROKEN OR SNAPPED TREE	CROWN INJURY TYPE A	CROWN INJURY TYPE B	
CRITERIA DESCRIPTION	Tree is **no longer free-standing**, i.e. the tree has fallen to the ground or has fallen and is leaning on another tree	**Crown of tree has been entirely broken off** and only the main bole or a stump remains	**An amount ABOVE DAMAGE THRESHOLD but LESS THAN 100%** of crown branches have been broken off	**An amount BELOW DAMAGE THRESHOLD** but some crown branches have been broken off	**If no options so far have been applicable then now move to Section B**
TREE CATEGORIES					
Dead standing tree	POTENTIAL LOSS OF FUNCTION	IF LESS THAN 3 METERES TALL AND DOES NOT CONTAIN HOLLOWS, TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN GO TO SECTION C	DOES NOT APPLY	DOES NOT APPLY	
Giant tree	POTENTIAL LOSS OF FUNCTION	IF SPECIES MATCHES ANY SPECIES LISTED IN SECTION D TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN GO TO SECTION C	GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN GO TO SECTION C	GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN RETAIN AND CHECK AGAIN AT NEXT FORESTRY OPERATION. OTHERWISE FOLLOW INSTRUCTIONS IN SECTION B	
Hollow-bearing tree	POTENTIAL LOSS OF FUNCTION	IF SPECIES MATCHES ANY SPECIES LISTED IN SECTION D TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN GO TO SECTION C	GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN GO TO SECTION C	GO TO SECTION B - IF SECTION B DOES NOT APPLY THEN RETAIN AND CHECK AGAIN AT NEXT FORESTRY OPERATION. OTHERWISE FOLLOW INSTRUCTIONS IN SECTION B	
Koala feed tree	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	FUNCTION LIKELY TO BE MAINTAINED	
Glider sap tree	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	FUNCTION LIKELY TO BE MAINTAINED	
Glossy black cockatoo feed tree	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	FUNCTION LIKELY TO BE MAINTAINED	
Nectar tree	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	POTENTIAL LOSS OF FUNCTION	FUNCTION LIKELY TO BE MAINTAINED	

SECTION B

COMPLETE SECTION **B** AND **DO NOT MOVE TO SECTION C** UNLESS IT IS INDICATED. THIS SECTION ONLY APPLIES TO THE MAIN BOLE BELOW THE PRIMARY CROWN BRANCHES AND ABOVE EXPOSED ROOTS

TYPE OF INJURY	MECHANICAL BOLE INJURY		
	CRITERIA 6	CRITERIA 7	CRITERIA 8
FOR **SECTION B** MOVE THROUGH THE CRITERIA TO THE RIGHT UNTIL THE TREE MEETS THE CRITERIA DESCRIPTION	BOLE INJURY TYPE A	BOLE INJURY TYPE B	
CRITERIA DESCRIPTION	**(1) An amount ABOVE DAMAGE THREHOLD** of horizontal cross-sectional area of bole at widest point of injury has been removed but tree still standing **OR (2a) an amount ABOVE DAMAGE THRESHOLD** of active xylem tissues down to the level of the heartwood have been removed around circumference of bole **OR (2b) an amount ABOVE DAMAGE THRESHOLD** of phloem tissues down to the level of the sapwood have been removed around circumference of bole	**(1) An amount BELOW DAMAGE THRESHOLD** of horizontal cross-sectional area of bole at widest point of injury has been removed but tree still standing **OR (2) an amount BELOW DAMAGE THRESHOLD** of active xylem tissues down to the level of the heartwood have been removed around circumference of bole	**If no options so far have been applicable then tree is not damaged. Do not go to Section C**
TREE CATEGORIES			
Dead standing tree	FUNCTION LIKELY TO BE MAINTAINED. CHECK AGAIN AT NEXT FORESTRY OPERATION	FUNCTION LIKELY TO BE MAINTAINED. CHECK AGAIN AT NEXT FORESTRY OPERATION	
Giant tree	POTENTIAL LOSS OF FUNCTION	GO TO SECTION C	
Hollow-bearing tree	POTENTIAL LOSS OF FUNCTION	GO TO SECTION C	
Koala feed tree	WHEN AN AMOUNT ABOVE DAMAGE THRESHOD OF ACTIVE XYLEM TISSUES OR AN AMOUNT ABOVE DAMAGE THRESHOLD OF PHLOEM TISSUES HAVE BEEN LOST AROUND CIRCUMFERENCE, TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE RETAIN	FUNCTION LIKELY TO BE MAINTAINED	
Glider sap tree	WHEN AN AMOUNT ABOVE DAMAGE THRESHOD OF ACTIVE XYLEM TISSUES OR AN AMOUNT ABOVE DAMAGE THRESHOLD OF PHLOEM TISSUES HAVE BEEN LOST AROUND CIRCUMFERENCE, TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE RETAIN	FUNCTION LIKELY TO BE MAINTAINED	
Glossy black cockatoo feed tree	WHEN AN AMOUNT ABOVE DAMAGE THRESHOD OF ACTIVE XYLEM TISSUES OR AN AMOUNT ABOVE DAMAGE THRESHOLD OF PHLOEM TISSUES HAVE BEEN LOST AROUND CIRCUMFERENCE, TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE RETAIN	FUNCTION LIKELY TO BE MAINTAINED	
Nectar tree	WHEN AN AMOUNT ABOVE DAMAGE THRESHOD OF ACTIVE XYLEM TISSUES OR AN AMOUNT ABOVE DAMAGE THRESHOLD OF PHLOEM TISSUES HAVE BEEN LOST AROUND CIRCUMFERENCE, TREE HAS POTENTIALLY LOST ITS FUNCTION. OTHERWISE RETAIN	FUNCTION LIKELY TO BE MAINTAINED	

SECTION C

ONLY USE SECTION C IF SECTION **A OR B** HAS INDICATED THAT YOU NEED TO MOVE TO **SECTION C**

ROOTS AND TERMITES	
CONDITION **A**	CONDITION **B**
ROOT INJURY	TERMITE INFESTATION
Injury to major roots visible (i.e. breakage, snapped) due to machinery or another fallen tree. Does not include superficial scrapes or cuts.	**Termite activity present** at tree base and/or bole, evidenced by **significant areas of mud packing** on tree/termite galleries visible on main bole or tree base **OR** a large termite mound is visible within 1 m of tree base
DOES NOT APPLY	
IF BOTH CONDITIONS (A + B) ARE MET THEN **LONGEVITY AND FUNCTION MAY BE COMPROMISED. OTHERWISE RETAIN** AND CHECK AGAIN AT NEXT FORESTRY OPERATION	
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SECTION D

LIST OF EUCALYPT SPECIES WITH LIMITED CAPACITY TO RESPROUT EPICORMICALLY FOLLOWING SEVERE DISTURBANCE

REGIONS	SCIENTIFIC NAME	COMMON NAMES
NORTH COAST; SOUTH COAST	*Eucalyptus oreades*	Blue Mountains ash; white ash; smooth-barked mountain ash
NORTH COAST; SOUTH COAST	*Eucalyptus pauciflora*	snow gum; cabbage gum; white sally
NORTH COAST	*Eucalyptus grandis*	flooded gum; rose gum
SOUTH COAST	*Eucalyptus fraxinoides*	white ash; white mountain ash
SOUTH COAST	*Eucalyptus delagatensis*	alpine ash; gum-topped stringybark; white-top

7 Appendix B – Draft study design

Below is one potential study design that could be further developed for quantifying the impact of mechanical injuries and their interactions with future disturbances on tree functions. This approach would aim to assess both short- and longer-term impacts on tree function. This could be done by comparing the health of injured trees to uninjured trees across sites with varying time-since-harvesting and fire history. Trees could be revisited annually to assess any changes to tree function and to investigate whether any threatened fauna have been using trees.

a. Identify 20-30 compartments, with a range of time-since-harvesting and fire. Drought severity during the most recent severe drought (i.e. 2019) would be standardised:

    i. Harvested within 5 years and burnt 2019/2020 (i.e. harvested prior to 2019/2020)

    ii. Harvested approx. 10-15 years ago and burnt 2019/2020

    iii. Harvested within 5 years and has not burned since

    iv. Harvested approx. 10-15 years ago and has not burned since

    v. Note: Ideally each site would be subject to the same silvicultural system.

b. Within each of these compartments, conduct systematic searches for live trees with mechanical injuries.

c. For each injured tree, locate additional uninjured trees matching species and size.

d. Permanently tag each tree for use in potential future monitoring.

e. For each tagged tree conduct a comprehensive tree health assessment, which could include measurements of the following:

    i. Dimensions/classification of mechanical injury

    ii. Whether or not tree has other naturally-acquired injuries, e.g. fire scar.

iii. For fire-affected sites, an investigation of additional fire impacts on mechanical injury site, such as changes to the size/shape of injuries due to fire.

iv. Detailed canopy health assessment (e.g. see Stone *et al.* 2008; Nolan *et al*. 2021).

v. Swabbing of injury site to collect sample of fungal colony

vi. Investigation of presence of insect colonies at injury sites and insect damage to leaves

vii. Measurement of leaf litter underneath trees, including taking samples that could be used to estimate levels of seed fall.

viii. A subset of trees could potentially have sap flow meters installed, although these are expensive. Also potential for tensiometers (although expensive and single use) which continuously monitor water potential going forward.

ix. Investigation of whether threatened fauna species are using the tree.

f. In addition to the above, counts of dead trees/logs could be performed across the compartment and when located to investigate whether or not the tree had mechanical injury and/or make inferences about other potential mechanisms of failure (e.g. due to fire, termites, drought).