Conservation Assessment of *Eucalyptus fracta* K.D.Hill (Myrtaceae)

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***Eucalyptus fracta* K.D.Hill (Myrtaceae)**
Distribution: Endemic to NSW
Current EPBC Act Status: Not Listed
Current NSW BC Act Status: Vulnerable
Proposed listing on NSW BC Act: Endangered.

Reason for change: Genuine change based on new observations and projections of adverse fire regimes causing decline in the population.

Summary of Conservation Assessment

Eucalyptus fracta was found to be eligible for listing as Endangered under Criteria B1ab(v)+2ab(v).

The main reasons for this species being eligible are: 1) *Eucalyptus fracta* has a highly restricted Area of Occupancy (AOO) of 52 km^2 and a highly restricted Extent of Occurrence (EOO) of 233 km^2; 2) *Eucalyptus fracta* is known from three threat-defined locations; and 3) continuing decline is inferred in the number of mature individuals due to adverse fire regimes, particularly increased frequency of severe wildfire.

Eucalyptus fracta in the Glen Gallic subpopulation, Wollemi National Park. Image: Gavin Phillips

Description and Taxonomy

Eucalyptus fracta (Broken Back Ironbark) is a conventionally accepted species (CHAH 2023) that lies phylogenetically within the ironbark clade of subgenus *Symphiomyrtus*, section *Adnataria*, series *Siderophloiae* (Nicolle 2022). It is described by Hill (1997) as a “Tree or mallee to 8 m tall. Bark hard ironbark to branches *c.* 7 cm diam., then smooth, whitish. Small branches slightly glaucous. Juvenile leaves blue-green, dull, disjunct-opposite, orbiculate, later ovate, 3–6 cm long, 2.5–3.5 cm wide; petioles 0.5–

0.8 cm long. Adult leaves dull to slightly glossy grey-green, disjunct-opposite, similifacial, lanceolate, acuminate, 7–11 cm long, 1–2.5 cm wide; petioles 0.8–1.8 cm long. Inflorescences compound, often axillary; umbellasters 7-flowered. Peduncles terete, 6–10 mm long. Pedicels terete, 1–5 mm long. Mature buds fusiform, 6–8 mm long, 2–3 mm diam. Calyptra conical, acute or apically rounded, slightly shorter than to about as long as hypanthium. Outer calyptra shed long before anthesis. Stamens irregularly flexed, all fertile. Anthers adnate, basifixed, cuboid to globoid, opening by lateral pores. Fruits cup-shaped, 3–4-locular, 5–8 mm long, 5–7 mm diam. Calyptra scar and stemonophore flat, < 0.2 mm wide. Disc vertically depressed, 1–1.5 mm wide. Valves broadly triangular, acute, steeply raised, level with staminophore or slightly exserted."

Eucalyptus fracta is closest morphologically to *E. siderophloia* that is widespread in the district in which *E. fracta* occurs. *Eucalyptus fracta* is distinguished from *E. siderophloia* by its smaller habit, smaller and more rounded juvenile leaves, broader, more cupular fruits, smaller buds, and more rounded calyptra that is shorter relative to the hypanthium (Hill 1997). These differences are slight though, with some botanists considering *E. fracta* to possibly be a synonym of *E. siderophloia* or form of that species from drier environments, suggesting further investigation is required in this regard (Slee *et al.* 2020; S. Bell *in litt*. June 2023). This Conservation Assessment follows the current circumscription of the National Herbarium of New South Wales and the Australian Plant Census in treating *E. fracta* as a distinct taxon (CHAH 2023; RBGDT 2023a).

Distribution and Abundance

Eucalyptus fracta is an uncommon species endemic to ranges along the southern edge of the Hunter Valley in New South Wales (NSW). This area lies within the Sydney Basin Bioregion (DAWE 2012) on the traditional lands of the Wonnarua people (Horton 1996; Wonnarua Nation Aboriginal Corporation 2011).

Eucalyptus fracta is restricted to upper escarpments of steep sandstone ranges along the Broken Back and Hunter Ranges which form the southern edge of the Hunter Valley west of Cessnock. When the species was initially described in 1997, it was only known from the northern section of the Broken Back Range (Hill 1997). More recently, sites from further northwest at Sentry Box Point in Yengo National Park and Glen Gallic Fire Trail in Wollemi National Park have been identified (Table 1; RBGDT 2023a).

The population of *Eucalyptus fracta* consists of three subpopulations. All sites around the northern part of the Broken Back Range form a single subpopulation spanning approximately 9.5 km east to west. In this area there are large tracts of continuous habitat between recorded sightings of the species and the size of stands in the area can be quite large, with *E. fracta* often being dominant (S. Bell *in litt.* April 2023). Given this, and that no records here are more than 3 km apart, these sites are likely to have ongoing gene flow based on pollen dispersal distances reported in other eucalypts (Ashton and Sandiford 1988; Butcher *et al.* 2005; Byrne *et al.* 2008; Jones *et al.* 2008; Breed *et al.* 2015). The two outlying sites, Sentry Box Point, approximately 11.5 km northwest of Broken Back Range, and Glen Gallic, approximately 42 km further

northwest, are likely to begenetically isolated given their geographic isolation. Thus, they are both considered distinct subpopulations as per the IUCN (2022) definition.

Table 1 – Population breakdown of *Eucalyptus fracta* from all known sites.

Site	Subpopulation	Minimum estimate of all Individuals	Tenure	Notes	References
Glen Gallic	Glen Gallic	450	NPWS	Targeted surveys in 2023 confirmed identity of a large stand; further stands are likely in the area.	DPE 2023b
Sentry Box Point	Sentry Box Point	50	NPWS	Small stand recorded incidentally during other surveys. Likely to be many plants further up ridges in the area.	S. Bell *in litt.* April 2023
Yellow Rock	Broken Back Range	unknown	State Forest		
Bees Nest Ridge	Broken Back Range	700	State Forest	Three stands, one counted with 344 individuals, one large, one with few, scattered individuals	A. Fawcett *in litt.* June 2023; NSW BioNet 2023
South Ridge	Broken Back Range	300	State Forest, Defence	Predominantly within Singleton Military Area. Likely many, many more here as stands are much more continuous than records indicate.	Copeland and Hunter 2005; Bell and Carty 2012
Mans Head Point	Broken Back Range	1000	State Forest, Defence		Copeland and Hunter 2005; Bell and Carty 2012
Sector 9, Singleton Military Area	Broken Back Range	400-500	Defence	Possibly many more plants here as *E. fracta* is recorded as co-dominant along the ridges at this site.	Bell and Carty 2012; S. Bell *in litt.* April 2023
Transmission Tower East	Broken Back Range	635	State Forest		A. Fawcett *in litt.* June 2023
Pokolbin Flora Reserve	Broken Back Range	4	State Forest Flora Reserve		A. Fawcett *in litt.* June 2023
TOTAL COUNT		3,539–3,639			

Most of the *Eucalyptus fracta* population lies within the Broken Back Range subpopulation, spanning the northern section of Pokolbin State Forest and a portion of the adjoining Singleton Military Area (SMA; Copeland and Hunter 2005, OEH 2019).

Here, it occupies a narrow band along the upper cliffs of sandstone escarpments (OEH 2019) and is co-dominant in this habitat with other *Eucalyptus* species (S. Bell *in litt.* April 2023). So far, the species has been found at seven sites in the area, with the largest being the type locality at Mans Head Point. This site contains approximately 1,000 mature *E. fracta* trees along 1.5 km of ridgeline (Copeland and Hunter 2005). The ridge to the south of this, which is predominantly within the SMA, has around 300 plants (Copeland and Hunter 2005) and the ridge to the north, which is fully within the SMA, is estimated to have 400-500 more (S. Bell *in litt.* April 2023). To the east of these core areas are the Transmission Tower East site, which surveys found to contain at least 635 individuals, and a small stand in the Pokolbin Flora Reserve with 4 individuals (A. Fawcett *in litt.* June 2023).

To the west are two more ridges mostly within Pokolbin State Forest. Bees Nest Ridge has three stands, with one quantified as having 344 individuals (A. Fawcett *in litt.* June 2023). A large, unquantified stand, likely of similar size given the potential habitat area, is known further along Bees Nest Ridge and one with only a few scattered individuals also occurs, meaning a conservative estimate of approximately 700 individuals are found at this site. Further to the west, the Yellow Rock site has at least one stand in the State Forest with no indication of abundance (NSW BioNet 2023). Given the large amounts of suitable habitat near and between these sites that is not easily accessible, it is likely that more plants of *E. fracta* occur in the area. Two other records on private land abutting Pokolbin State Forest between Yellow Rock and Bees Nest Ridge of unknown size found in 2022 (NSW BioNet 2023) are indicative that other stands may easily be found in the area. At least 3,039–3,139 plants are in the Broken Back Range subpopulation with the potential for many more to be found with targeted surveys.

The Sentry Box Point subpopulation of *Eucalyptus fracta* is located approximately 11.5 km northwest of the Broken Back Range subpopulation, within the northern extent of Yengo National Park (Hager and Benson 2010). This relatively inaccessible site was found incidentally whilst traversing a ridge during plot surveys, with approximately 50 plants estimated on the section of ridge explored (S. Bell *in litt.* April 2023). However, the ridgelines and suitable habitat extend much further than have been currently surveyed, and so it is highly likely that many more plants may be in this subpopulation (S. Bell *in litt.* April 2023).

The Glen Gallic subpopulation of *Eucalyptus fracta* is in the Hunter Range in the northern part of Wollemi National Park approximately 42 km northwest of the Sentry Box Point subpopulation. This subpopulation is currently known from a single stand along a 1.1 km ridgeline with a minimum of 450 plants following surveys to confirm the identity of the plants on the site in 2023 (DPE 2023b). The full extent of this subpopulation is still unknown, however, as it extends onto ridges north of a fire trail that haven't been surveyed (DPE 2023a, 2023b). Therefore, many more than 450 plants may be present at Glen Gallic (DPE 2023b).

The population of *Eucalyptus fracta* is estimated to contain a minimum of 3,539–3,639 individuals across all three subpopulations, with this number considered to be highly conservative. All known plants are considered mature at this time, as seedling establishment appears rare and counts to date are based on mature sized and/or reproductively fertile plants (Copeland and Hunter 2005; Bell 2019; DPE 2023b).

Area of Occupancy and Extent of Occurrence

The Area of Occupancy (AOO) of *Eucalyptus fracta* is estimated to be 52 km^2 using 2 x 2 km grid cells, the scale recommended by IUCN (2022). The Extent of Occurrence (EOO) is estimated to be 233 km^2 and is based on a minimum convex polygon enclosing a cleaned dataset of known occurrences of the species, the method of assessment recommended by IUCN (2022). Both EOO and AOO were calculated using ArcGIS (Esri 2015), enclosing all confirmed survey records and cleaned spatial datasets. Based on these estimates, *E. fracta* has a highly restricted AOO and EOO.

Number of Locations

When the threat of adverse fire regimes, especially increased frequency of severe wildfires, is considered, the three subpopulations of *Eucalyptus fracta* can be considered to occur at three separate threat-defined locations, as per the IUCN definition (IUCN 2022). This is due to the increased frequency of severe wildfires being the most serious plausible threat that results in the lowest number of locations for the taxon. The fire history shows that these three locations have different fire histories and are unlikely to be impacted by the same individual fire event, or have the same fire regime (frequency and/or severity) now and in the future (NPWS 2022).

Cultural Significance

This assessment is not intended to be comprehensive of the traditional ecological knowledge that exists for *Eucalyptus fracta*, or to speak for Aboriginal people. Aboriginal people have a long history of biocultural knowledge, which comes from observing and being on Country, and evolves as it is tested, validated and passed through generations (Woodward et al. 2020). Aboriginal peoples have cared for Country for tens of thousands of years (Bowler et al. 2003; Clarkson et al. 2017). There is traditional ecological knowledge for all plants, animals and fungi connected within the kinship system (Woodward et al. 2020). Traditional ecological knowledge referenced in this assessment belongs to the relevant knowledge custodian and has been referenced in line with the principals of the NSW Indigenous Cultural and Intellectual Property protocol (ICIP) (Janke and Company 2023).

The Wonnarua people were intimately connected with their land, and higher, rocky parts of the landscape such as that occupied by *Eucalyptus fracta* were important sites for ceremony and tool making (Miller 1985; Brayshaw 1987). Boomerangs from the Wonnarua lands have been noted to have been made from ironbark wood (Brayshaw 1987), so it is possible that *E. fracta* was also used for this purpose. Stands of *E. fracta* also occur near to the southern boundary of Wonnarua country, so the neighbouring Darkingjung people may also have utilised *E. fracta* (Horton 1996; Wonnarua Nation Aboriginal Corporation 2011).

Ecology

Habitat

Eucalyptus fracta is restricted to shallow and skeletal soils along the upper ridgetops of a series of sandstone escarpments (Hill 1997; Copeland and Hunter 2005; DPE

2023b). It only occurs on very steep slopes and around cliff lines where rocky boulders and exposed rock are common (S. Bell *in litt.* April 2023) and appears to favour dry, exposed northerly aspects (Copeland and Hunter 2005). In Pokolbin State Forest it is the dominant tree along a narrow band of the upper escarpments, where it occurs most commonly with scattered individuals of *Corymbia maculata* and *Eucalyptus punctata,* with an open, sparse understorey containing *Olearia elliptica*, *Acacia parvipinnula* and *Pultenaea spinosa, Cleistochloa rigida, Plectranthus parviflorus* and *Dichondra repens* (Hill 1997; S. Bell *in litt* April 2023). Where this community merges with taller forest downslope, scattered *E. fracta* can be found with more abundant *C. maculata* and *E. punctata,* along with *Eucalyptus sparsifolia* and *Angophora costata* subsp. *euryphylla* (Hill 1997; S. Bell *in litt.* April 2023). In Wollemi National Park, *E. fracta* often co-occurs with *Eucalyptus sparsifolia* and *Eucalyptus punctata* as co-dominants in the canopy, with an understorey of *Daviesia acicularis, Bursaria spinosa, Acacia piligera, Grevillea montana* and *Macrozamia reducta* (DPE 2023b). *Eucalyptus fracta* also co-occurs with other threatened flora such as *Leionema lamprophyllum* subsp. *fractum* and *Prostanthera cineolifera* (G. Phillips pers. obs. November 2021).

The vegetation in which *Eucalyptus fracta* is co-dominant in Pokolbin State Forest is described as Escarpment Ironbark Forest, with occasional occurrences in Escarpment Stringybark-Apple-Grey Gum Forest where these two communities merge (S. Bell *in litt.* April 2023). This aligns most closely with the plant community type (PCT) of Hunter Range Grey Gum-Stringybark Forest (PCT 3604), in which many records of *E. fracta* are mapped (DPE 2022a, 2022b) and which it has been confirmed to be within at Glen Gallic (DPE 2023b). At Glen Gallic, *E. fracta* is also found in Western Hunter Range Grey Gum-Stringybark Forest (PCT 3778; DPE 2023b). However, *E. fracta* may not be confined to these PCTs and may be found within other PCTs that occur in the area.

Life History

Eucalyptus fracta has been recorded vigorously resprouting following fire (Copeland and Hunter 2005) and this is likely to be the primary response of the species following major disturbance. Eucalypts such as *E. fracta*, in which a mallee or stunted form can be derived due to environmental constraints and where a tree is the main form evident on better soils, employ a combination sprouting strategy when burnt (Nicolle 2006). In combination resprouters, resprouting from epicormic shoots in the stems will occur after most fires, with resprouting from the basal lignotuber only occurring after complete crown destruction (Nicolle 2006).

Lignotuber development in many eucalypts is most significant in fire- and drought-prone habitats, with more substantial, more tolerant lignotubers developing in sites where abiotic conditions are most marginal to a species' requirements, pushing them to their ecological limit (Noble and Diggle 2013). The mallee form of *E. fracta* in exposed sites shows that it too can develop lignotubers (G. Phillips pers. obs. November 2019). This is likely driven by the harsh conditions experienced on the rocky escarpments, with taller, single-stemmed trees often found on better soils adjacent to the cliffs (DPE 2023b). Lignotuber development in *E. fracta* is also likely comparable to other lignotuberous species associated with skeletal soils, which can take 7–10 years to develop sufficient tolerance to resprout post-disturbance (Auld *et al.* 1993). Stem resprouting tends to develop in larger stem sizes in other combination

resprouters, with resprouting limited to basal coppicing only in plants with smaller stems (Zimmer *et al.* 2021) and this appears to also be true for *E. fracta* (DPE 2023b). This points to a situation where species, such as *E. fracta,* could be driven to increased reliance on lignotuber resprouting following continued events that cause stem death, such as heavy drought and severe fire. In these situations, stems are not afforded sufficient time to grow to a size that can support epicormic reshooting. This has been seen in other combination resprouters with small geographic ranges affected by too frequent fire, resulting in lowered chances of escape from fire and negative demographic shifts (Zimmer *et al.* 2021).

Seedling recruitment in eucalypts is typically intermittent and rarely observed without disturbance (Keeley 1995) and this also appears true for *Eucalyptus fracta* (DPE 2023b). As with other eucalypts, *E. fracta* develops an aerial seed bank where seeds can be stored for several years in the canopy, with seed being slowly released over time or *en masse* following death of a stem or branch (Tozer and Bradstock 1997; G. Phillips pers. obs. November 2019). Once released, seedling establishment and survival in eucalypts is often dependent on soil moisture availability and competition for resources when growing in nutrient poor soils (Wellington and Noble 1985; Auld *et al* 1993; Tozer and Bradstock 1997). Reduced competition, increased light levels, and nutrient influxes provided by fire are then all thought to bolster recruitment (Etchells *et al.* 2020). Little data on seedling recruitment regimes has been collected for *E. fracta* to date, but given the sparse recruitment observed on site in years away from disturbance (G. Phillips pers. obs. November 2019, November 2021) it is possible that the species requires fire to stimulate stronger germination events. This however may depend heavily on the fire regime, as limited seedling recruitment has also been observed in areas where repeat severe fires have occurred (DPE 2023b).

Lifespan and Generation Length

The maximum lifespan of *Eucalyptus fracta* is estimated to be 200–300 years given similar proposed ages in other remnant coastal ironbarks (National Trusts of Australia 2023). While the aboveground stems in lignotuberous plants may be relatively young, the overall age of the plant may be much older, with lignotubers in some species reaching thousands of years of age (Nicolle 2006), though lifespans are more commonly in the hundreds of years (Wellington and Noble 1985; Head and Lacey 1988). Single-stemmed *E. fracta* plants may therefore have a 200–300-year lifespan when undisturbed, with mallee-form plants having a similar overall lifespan but with much younger aboveground stems due to their disturbance history. The mean primary juvenile period for resprouting eucalypts has been calculated as 3.5–8 years (Nicolle 2006), with *E. fracta* suspected to be at the longer end of this range given the slow observed growth rates in related ironbark species (Ghannoum *et al.* 2009; Hager and Benson 2010). The secondary juvenile period for resprouting stems appears to be much shorter however, with resprouting *E. fracta* observed to be flowering just under two years following severe fire in the Broken Back Range (Copeland and Hunter 2005).

The generation length of *Eucalyptus fracta*, which relies on resprouting from long-lived lignotubers and epicormic buds for stand maintenance with limited seedling recruitment outside of disturbance cycles, can be estimated using the age of first

reproduction + *z* * length of reproductive period (IUCN 2022), where *z* is a constant between 0 and 1 calculated using survivorship and the relationship between fecundity and age. Using a maximum lifespan of 200–300 years, a primary juvenile period of eight years and a value for *z* of 0.33 as calculated for other long-lived tree species (Fung and Waples 2017), the generation length of *E. fracta* is estimated at approximately 71–104 years.

Reproductive and Seed Ecology

Eucalyptus fracta has been observed flowering in July, November and December (Copeland and Hunter 2005; Bell 2019; RBGDT 2023a). The flowers are protandrous and a mixed mating system that favours outcrossing is likely, as found in many other eucalypts (Breed *et al.* 2015). Other rare, rock outcrop eucalypts have been shown to be primarily insect-pollinated (Peters *et al.* 1990) and this is a common interaction in eucalypts with relatively small flowers (Wilson 2002; Byrne *et al.* 2008; Jones *et al.* 2008). Given the relatively small flowers displayed by *E. fracta* (Hill 1997; G. Phillips pers. obs. November 2019), the species likely relies on insects for the bulk of pollination services, with birds and small mammals playing a lesser role in pollen dispersal. Therefore, regular local and more occasional long-distance pollen dispersal is highly likely between stands, in line with findings in other eucalypts (Jones *et al.* 2008; Breed *et al.* 2015).

Seed dispersal in eucalypts is typically highly localised and dependent on plant height, canopy width, seed weight, and prevailing wind conditions (Booth 2017). Given the low tree heights and ridgetop habitat typical of *Eucalyptus fracta*, seed dispersal is likely restricted to the area immediately around and downslope of parent plants. While occasional strong winds may promote further dispersal, this is likely minimal in most instances given the rocky outcrops and cliffs immediately adjacent to most stands. However, rain and gravity may move seed into other pockets of suitable habitat downslope. Predation of seed by ants is also known to commonly occur in eucalypts (Booth 2017). Furthermore, soil seed banks are relatively short-lived, with seeds typically germinating within one season of release if not predated (Wellington and Noble 1985; Keeley 1995). Seed supply is therefore maintained in the canopy, potentially for several years, with seeds held in capsules and released intermittently over time or once disturbance results in stem or branch death (Tozer and Bradstock 1997).

Released seed of eucalypts tend to have no dormancy aside from a number of montane species (Close and Wilson 2002, Booth 2017). *Eucalyptus fracta* also possesses no dormancy, with germination trials indicating the species freely germinates upon release from the capsule (RBGDT 2023b).

Threats

The NSW Scientific Committee (1999) noted the restricted distribution of *Eucalyptus fracta* was the primary contributor to its extinction risk with no mention of decline in the population at the time. However, subsequent surveys have uncovered more subpopulations (Copeland and Hunter 2005; Bell 2019) and serious threats have become apparent. These include adverse fire regimes (Copeland and Hunter 2005; A. Fawcett *in litt.* September 2018; DPE 2023b), which are now considered the most

serious plausible threat to the species. Of particular concern are higher frequencies of high severity wildfire, following observations of reduced resprouting vigour in the Glen Gallic subpopulation due to this mechanism (DPE 2023b). Physical disturbance due to land uses including timber harvesting, firewood collection and track maintenance activities may also have adverse effects on the species (OEH 2019).

Adverse Fire Regimes

Adverse fire regimes are inferred to be causing decline in the population of *Eucalyptus fracta* where severe fires affect the population too frequently (DPE 2023b). Currently, most subpopulations of *E. fracta* experience a very infrequent fire regime (Table 2). Return intervals range from four to 41 years since 1979 (NPWS 2022). Large-scale fires have affected multiple sites within the Broken Back Range subpopulation, including the 1979 wildfire, the December 2002 Oakley Lane Fire and the January 2020 Owendale Fire, though even these fires did not burn completely through all sites (Copeland and Hunter 2005; G. Phillips pers. obs. November 2021). Separate large-scale fires also affected multiple subpopulations during the 2019–2020 summer, though no single fire impacted more than one subpopulation (NPWS 2022). Given the area is regarded as highly fire-prone (A. Fawcett *in litt.* September 2018; Barker *et al.* 2022), large-scale fires appear to be normal when fires occur in *E. fracta* habitat, albeit relatively uncommonly. Thus, individual stands of *E. fracta*, except for the Glen Gallic subpopulation in recent years, are not known to have historically experienced frequent fires of high severity as these dry habitats take time to reaccumulate fuels sufficient to carry high severity fire (S. Bell *in litt.* June 2023).

Table 2 – Fire history for all known *Eucalyptus fracta* sites as per NPWS (2022).

Site	Subpopulation	Fire	Date	Type
Glen Gallic	Glen Gallic	Kerry Ridge	February 2020	Wildfire
		Hungerford Creek	Nov 2013	Wildfire
			1989	Hazard Reduction
Sentry Box Point	Sentry Box Point	Little L Complex	Jan 2020	Wildfire
		Broke Trig	May 2016	Hazard Reduction
			Feb 2002	Wildfire
			1991	Wildfire
Yellow Rock	Broken Back Range	Owendale	Jan 2020	Wildfire
			1979	Wildfire
Bees Nest Ridge	Broken Back Range	Owendale	Jan 2020	Wildfire
			1979	Wildfire
Ridge South of Mans Head Point	Broken Back Range	Oakley Lane	Oct 2002	Wildfire
			Dec 1997	Wildfire
			1979	Wildfire
Mans Head Point	Broken Back Range	Oakley Lane	Oct 2002	Wildfire
Sector 9, Singleton Military Area	Broken Back Range	Oakley Lane	Oct 2002	Wildfire

Higher severity wildfire can alter stand structure and understorey species competition, as well as increase mortality of dominant eucalypts (Etchells *et al.* 2020). In a combination resprouter species like *Eucalyptus fracta*, this can push the species to rely more on basal coppicing alone to regenerate, as larger stems capable of epicormic regrowth are eliminated by hot fire (Zimmer *et al.* 2021). This pattern is intensified if severe fires become more frequent, further limiting the species' ability to coppice and reducing the chance of escape from subsequent fires (Zimmer *et al.* 2021).

This process appears to now be underway in the Glen Gallic subpopulation, where a significant portion of trees were observed to have been burnt at high severity in the February 2020 Kerry Ridge wildfire (DPE 2023b). This area had also burnt at high severity in November 2013, with both fires resulting in complete canopy consumption in a large portion of the *E. fracta* stand (NPWS 2022; DPE 2023b). While no mortality was observed following the 2020 fire, approximately 3 years post-fire the coppice growth of *E. fracta* remained on average only 1-1.5 m in height (DPE 2023b). This is substantially smaller than what was expected following observations in Pokolbin State Forest in 2004 of vigorous, flowering growth after three years following severe wildfire (Copeland and Hunter 2005). Furthermore, the period since the 2020 fire has been quite wet, favouring growth. In 2023, the shrub layer was seen to be competing strongly with the coppice growth and overtopping it in many areas, and the overall health of the coppice growth in the more severely burnt areas was observed to be very

poor compared to areas burnt at lower intensity, with insect galling and damage common (DPE 2023b). Epicormic regrowth was also observed to be confined to larger stems only, with plants in the fire scar being already of much lower stature than those in the adjacent unburnt woodland, with coppicing much more heavily favoured (DPE 2023b). Thus, a process of structural change is inferred to now be underway in the Glen Gallic subpopulation after a seven-year interval between high severity fires, with the number of mature individuals projected to undergo continuing decline as a result, especially if fire again impacts the subpopulation in the near future.

The absence of noticeable seedlings at Glen Gallic indicates that a limited canopy seedbank may have developed prior to the 2020 fire following on from the 2013 fire at Glen Gallic, and it is therefore possible that the lack of seedlings may also be attributed to the short return fire interval (DPE 2023b). Seedling recruitment is also dependent on fire cycles in many resprouting eucalypts (Zimmer *et al.* 2021; Phillips 2022), and so the shortened fire return intervals may also reduce recruitment to very low levels in a short amount of time.

The Hunter Region in which *Eucalyptus fracta* occurs, is predicted to become hotter, have fewer colder nights under 2°C annually, more hot days over 35°C annually and an increase in average and severe fire weather by 2079 (CSIRO and BOM 2022; AdaptNSW 2023). Additionally, fire weather is predicted to become harsher, and the time spent in drought is predicted to increase on the East Coast through the 21st century (CSIRO 2023). Therefore, it is highly plausible that more frequent and/or severe fires driven by these changes in climate will impact the *E. fracta* population in the future, which is not known to have been previously exposed to short fire intervals (NPWS 2022). Indeed, populations affected by the severe wildfires in 2019/20 appear now to be at increased risk given the observations of loss of coppice vigour at the Glen Gallic site following repeat severe fire (DPE 2023b). Areas within the Broken Back Range and Sentry Box Point subpopulations have been recorded as being burnt at a similar severity to that seen at Glen Gallic in the 2019-20 fires (DPE 2020) and so if the subpopulations here are similarly affected by another severe fire in the immediate future, then much more widespread decline may ensue, and climate predictions for the area indicate this is now a genuine threat (AdaptNSW 2023; CSIRO 2023). “High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition” is listed as a Key Threatening Process under the *NSW Biodiversity Conservation Act 2016.*

The 2017-2020 drought may also have contributed to the lack of development of an aerial seedbank, and thus seedling recruitment, by limiting coppice growth following the 2013 fire. Interactions between drought and frequent severe fire are expected to continue under future climate scenarios. Adverse fire regimes may also impact the population of *Eucalyptus fracta* if fire is kept out of the landscape for too long by reducing recruitment events that may replenish senescent stands. Like other eucalypts, *E. fracta* seeds are held within the canopy until release upon death of the supporting branch, typically after fire (Tozer and Bradstock 1997). Many eucalypts, including resprouting species, have increased germination rates following fire (Wellington and Noble 1985; Keeley 1995), with release from competition, increased light levels, and nutrient influxes provided by fire all thought to contribute to this enhancement (Etchells *et al.* 2020). Given this and the fact that little seedling

recruitment has yet been noted in stands of *E. fracta* (G. Phillips pers. obs. November 2019, November 2021), it may be possible that regular passage of lower intensity fire may be required to stimulate stronger germination to regenerate stands if they become senescent.

Land Uses Including Timber Harvesting

While the Glen Gallic and Sentry Box Point subpopulations are wholly reserved within Wollemi and Yengo National Parks respectively (Hager and Benson 2010; Bell 2019), the larger Broken Back Range subpopulation is mostly on lands reserved for other purposes, existing predominantly within Pokolbin State Forest and the Singleton Military Area (Copeland and Hunter 2005). The areas containing the plants on defence land are confined to steep areas and are managed to protect *E. fracta* and other threatened taxa found there (Copeland and Hunter 2005). Additionally, a small portion of the subpopulation within the State Forest are mapped within harvesting exclusion zones and a flora reserve (FCNSW 2023), meaning they are unlikely to be harvested in the future as they too are managed for conservation values (State Forests of NSW 1999).

A larger portion of the plants within Pokolbin State Forest, amounting to approximately 23-27% of the total known population, are mapped in a general management zone for harvesting operations (FCNSW 2023). However, there is little contemporary evidence of timber harvesting causing any loss of individuals in the stands containing *Eucalyptus fracta* (NSW Scientific Committee 1999; G. Phillips pers. obs. July 2017; November 2019, November 2021) and no surveys to date have noted timber harvesting as a threat to the species (Hunter and Copeland 2005; A. Fawcett *in litt.* September 2018). While the threat of future harvesting operations cannot be completely discounted, the likelihood of harvesting in the area is minimal given the preferred habitat of *E. fracta* is not typically included in harvesting plans and no plans are in place to recommence timber harvesting in Pokolbin State Forest in the near future (A. Ford *in litt.* April 2023; C. Slade *in litt.* April 2023). In addition, the species has been deemed adequately protected in the Coastal Integrated Forestry Operations Approval due to the protection of areas of rock outcrop and skeletal soil through mapping and exclusion of these areas from timber harvesting activities (NSW EPA 2018). As such, timber harvesting constitutes only a minor plausible future threat.

Trail Maintenance and Firewood Collection

While the collection of firewood was the only physical threat specifically mentioned when the threatened status of *Eucalyptus fracta* was previously assessed (NSW Scientific Committee 1999), this is considered to be a very minor current threat to the species. While firewood collection does occur in the portion of the Broken Back Range subpopulation within Pokolbin State Forest, areas where it occurs within the range of *E. fracta* are largely confined to locations where access tracks reach the escarpment (A. Fawcett *in litt.* September 2018). Even here, timber cutting by campers tends to focus on the smooth-barked species such as *Corymbia maculata* and not the harder to cut ironbarks (G. Phillips pers. obs. November 2019, November 2021). Additionally, firewood collection more commonly occurs in Pokolbin State Forest in post-harvest areas and is largely restricted to fallen timber remaining from forestry operations (A. Fawcett *in litt.* September 2018). The Glen Gallic and Sentry Box Point subpopulations

are unaffected by this threat as they are much harder to access and are reserved within national parks estate. This means that firewood collection is unlikely to have a widespread impact on *E. fracta*, with its effects concentrated on a minor portion of the overall population and is thus considered trivial in magnitude and not contributing to continuing decline in the population.

Track maintenance as a threat to *Eucalyptus fracta* is similarly restricted in nature. Track maintenance works only affect a small portion of the population in Pokolbin State Forest where access tracks reach the escarpment (A. Fawcett *in litt.* September 2018). Tracks reach the *E. fracta* stands at three sites in the Broken Back Range, however at each only a small number of trees are near to the track, with the majority located further afield on the steep escarpments. In the case of the largest stand, the adjacent track is an informal access with no regular formal maintenance (G. Phillips pers. obs. November 2019). A fire trail also runs through much of the known Glen Gallic subpopulation, but again only a small number of individuals are close to the trail, with many more trees located away from the track (DPE 2023b). This means that the effect of any track maintenance on the *E. fracta* population is considered to be trivial in magnitude and not contributing to continuing decline.

Assessment against IUCN Red List criteria

For this assessment it is considered that the survey of *Eucalyptus fracta* has been adequate and there is sufficient scientific evidence to support the listing outcome.

Criterion A *Population size reduction*

Assessment Outcome: Data deficient

Justification: Despite continuing decline being projected in the population of *Eucalyptus fracta* in the future due to adverse fire regimes, there is no evidence of a current or historical population reduction for *E. fracta* and future reductions are currently difficult to calculate in magnitude. Given a maximum three generation timespan of *c.* 203-312 years, a population size reduction of at least 50% for reversible and ceased causes (A1) or 30% for irreversible or continuing causes (A2, A3 and A4) has not been observed. Following repeat high severity fires in the Glen Gallic subpopulation, no mortality of stems has yet been observed, despite clear indications that stand structure is being negatively affected and regrowth and reproductive potential is being reduced (DPE 2023b). While this indicates that future, continuing reductions are highly likely given the conditions that can precipitate such severe fires are expected to increase through the 21st century (CSIRO 2023), calculating the magnitude of any reduction up to 100 years into the future cannot be undertaken with confidence. Given this, assessment under Criterion A is not able to be presently undertaken.

Criterion B *Geographic range*

Assessment Outcome: Endangered under Criterion B1ab(v)+2ab(v).

Justification: *Eucalyptus fracta* is endemic to the Broken Back and Hunter Ranges in the Hunter Valley of NSW and has a highly restricted geographic distribution. The Extent of Occurrence (EOO) of *E. fracta* has been calculated as 233 km^2, which meets

the threshold for listing as Endangered. The Area of Occupancy (AOO) has been calculated as 52 km^2, meeting the threshold for Endangered.

In addition to these thresholds, at least two of three other conditions must be met to qualify for listing under Criterion B. These conditions are:

a) The population or habitat is observed or inferred to be severely fragmented or there is 1 (CR), ≤5 (EN) or ≤10 (VU) locations.

   Assessment Outcome: Met for Endangered due to having three threat-defined locations.

   Justification: *Eucalyptus fracta* is found at three threat-defined locations when considering the most serious plausible threat of increased frequency of severe of wildfires.

   Eucalyptus fracta is not considered severely fragmented as all individuals are found in large, non-isolated subpopulations and all subpopulations are considered viable.

b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals

   Assessment Outcome: Met for continuing decline inferred for (v) number of mature individuals.

   Justification: Continuing decline is inferred in the number of individuals of *Eucalyptus fracta* due to the increasing frequency of severe wildfires. *E. fracta* stands are not known to have previously been placed under pressure from frequent and/or severe fires, with no site having been burnt by uncontrolled wildfire more than three times in the past 44 years (NPWS 2022). However, recent surveys in the Glen Gallic subpopulation have revealed that significant structural change may be underway following two severe wildfires in the space of seven years (DPE 2023b). Higher intensity wildfire can alter stand structure and understorey species competition, as well as increase mortality of dominant eucalypts (Etchells *et al.* 2020). Death of above-ground stems in a combination resprouter species like *Eucalyptus fracta* push the species to rely more on basal coppicing alone to regenerate, as larger stems capable of epicormic regrowth are eliminated in hotter fires (Zimmer *et al.* 2021). This pattern is enhanced if intense fires become more frequent, further limiting the species' ability to coppice and reducing the chance of escape from subsequent fires (Zimmer *et al.* 2021). This process appears to now be underway in the Glen Gallic subpopulation, where a significant portion of trees were observed to have been burnt at high severity in the February 2020 Kerry Ridge wildfire following a similar high severity wildfire in November 2013 (DPE 2023b). While no complete mortality was observed following the 2020 fire, approximately three years post-fire, coppicing has become the dominant response, with limited epicormic regrowth (DPE 2023b). Additionally, the coppice growth of *E. fracta* remained on average only 1-1.5 m in height, much lower than expected compared to

previous surveys, and was in overall poor health (DPE 2023b). Given the Hunter Region in which *E. fracta* occurs is predicted to become hotter, have fewer colder nights under 2°C annually, more hot days over 35°C annually and an increase in average and severe fire weather by 2079 (CSIRO and BOM 2022; AdaptNSW 2023) and that fire weather is predicted to become harsher and the time spent in drought is predicted to increase on the East Coast through the 21st century (CSIRO 2023), it is highly plausible that more frequent and/or severe fires driven by these changes in climate will impact the *E. fracta* population in the future. Other populations affected by severe wildfires in 2019/20, such as in the Broken Back Range and Sentry Box Point subpopulations, are therefore at increased risk if another severe fire occurs given the observations of lowered coppice vigour at the Glen Gallic site following the repeat severe fires there (DPE 2023b). Thus, continuing decline is inferred in the number of mature individuals of *E. fracta* given this threat is likely to continue to increase into the future, exacerbating and expanding the processes of structural change and increased mortality risk observed at Glen Gallic.

c) Extreme fluctuations.

Assessment Outcome: Not met.

Justification: *Eucalyptus fracta* is a long-lived eucalypt and is unlikely to undergo extreme fluctuations.

Criterion C Small population size and decline

Assessment Outcome: Not met.

Justification: The current estimated population for *Eucalyptus fracta* is a minimum of 3,539-3,639 mature individuals, meeting the threshold for Endangered.

At least one of two additional conditions must be met. These are:

C1. An observed, estimated or projected continuing decline of at least: 25% in 3 years or 1 generation (whichever is longer) (CR); 20% in 5 years or 2 generations (whichever is longer) (EN); or 10% in 10 years or 3 generations (whichever is longer) (VU).

Assessment Outcome: Data Deficient.

Justification: While continuing decline is inferred in the number of mature individuals of *Eucalyptus fracta*, the overall magnitude of such a decline is not able to be calculated with confidence over the period of one generation (71 years) to the maximum 100 years in the future. This is because while continuing decline is likely to occur in the future given current observations of structural change following repeat severe fires which will almost certainly result in future mortality, no direct mortality has yet been observed (DPE 2023b). Thus, assessment under Subcriterion C1 is not able to be presently undertaken.

C2. An observed, estimated, projected or inferred continuing decline in number of mature individuals.

Assessment Outcome: Not met.

Justification: Continuing decline is strongly inferred in the number of mature individuals of *Eucalyptus fracta* due to structural changes and increased mortality risk in the population resulting from increased frequency of severe wildfires.

However, at least 1 of the following 3 conditions also must be met:

a (i). Number of mature individuals in each subpopulation ≤50 (CR); ≤250 (EN) or ≤1000 (VU).

Assessment Outcome: Not met.

Justification: The largest subpopulation of *Eucalyptus fracta*, Broken Back Range, contains a conservative minimum of 3,039–3,139 plants, exceeding the thresholds for this criterion.

a (ii). % of mature individuals in one subpopulation is 90-100% (CR); 95-100% (EN) or 100% (VU)

Assessment Outcome: Not met.

Justification: Current knowledge suggests the vast bulk of mature individuals of *Eucalyptus fracta* reside within the Broken Back Range subpopulation, which contains an estimated 86% of the total population, exceeding the thresholds for this criterion.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Not met.

Justification: *Eucalyptus fracta* is a long-lived eucalypt and is unlikely to undergo extreme fluctuations.

Criterion D Very small or restricted population

Assessment Outcome: Not met.

Justification: *Eucalyptus fracta* is currently estimated to have a minimum population of at least 3,539-3,639 mature individuals.

To be listed as Vulnerable under D, a species must meet at least one of the two following conditions:

D1. Population size estimated to number fewer than 1,000 mature individuals

Assessment Outcome: Not met

Justification: *Eucalyptus fracta* is currently estimated to have a minimum population of at least 3,539-3,639 mature individuals.

D2. Restricted area of occupancy (typically <20 km^2) or number of locations (typically <5) with a plausible future threat that could drive the taxon to CR or EX in a very short time.

Assessment Outcome: Criterion not met.

Justification: *Eucalyptus fracta* occurs at only three threat-defined locations and has an estimated AOO of 52 km^2. However, it is not considered to be subject to any threats that may drive the species to extinction in a very short time period.

Criterion E Quantitative Analysis

Assessment Outcome: Data deficient.

Justification: Currently there are not enough data to undertake a quantitative analysis to determine the extinction probability of *Eucalyptus fracta.*

Conservation and Management Actions

Eucalyptus fracta is currently listed on the NSW *Biodiversity Conservation Act 2016* and a conservation project has been developed by the NSW Department of Planning and Environment under the Saving our Species program. The conservation project identifies priority locations, critical threats and required management actions to ensure the species is extant in the wild in 100 years. *Eucalyptus fracta* sits within the site-managed management stream of the SoS program.

Activities to assist this species currently recommended by the SoS program (OEH 2019; DPE 2023) include:

Habitat loss, disturbance and modification

- Minimise disturbance from fire, logging or other insensitive land uses where they occur within stands of *Eucalyptus fracta.*
- Control and minimize damage through firewood collection.

Ex situ conservation

- Collect seed from each subpopulation of *Eucalyptus fracta* for incorporation into conservation seedbanks.

Survey and monitoring

- Monitor for the impacts of direct disturbance on *Eucalyptus fracta* resulting from forestry operations or too frequent fire.
- Assess general population condition, flowering and recruitment every five years.
- Monitor condition and recruitment immediately post-fire in the case of a fire event impacting stands of *Eucalyptus fracta.*
- Accurate mapping of stands to assist with identifying areas where roadside management is required when track maintenance is undertaken.
- Survey potential habitat for new locations in Yengo and Wollemi National Parks.

Information and stakeholder liaison

- Liaise with Forestry Corporation of NSW and Department of Defence to ensure potential disturbance from land use activities is minimised on lands they manage containing *Eucalyptus fracta.*

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APPENDIX 1

Assessment against *Biodiversity Conservation Regulation 2017* criteria
The Clauses used for assessment are listed below for reference.

Overall Assessment Outcome: *Eucalyptus fracta* was found to be Endangered under Clause 4.3(b)(d)(e i).

Clause 4.2 – Reduction in population size of species
(Equivalent to IUCN criterion A)
Assessment Outcome: Data deficient

(1) - The species has undergone or is likely to undergo within a time frame appropriate to the life cycle and habitat characteristics of the taxon:			
	(a)	for critically endangered species	a very large reduction in population size, or
	(b)	for endangered species	a large reduction in population size, or
	(c)	for vulnerable species	a moderate reduction in population size.
(2) - The determination of that criteria is to be based on any of the following:			
	(a)	direct observation,	
	(b)	an index of abundance appropriate to the taxon,	
	(c)	a decline in the geographic distribution or habitat quality,	
	(d)	the actual or potential levels of exploitation of the species,	
	(e)	the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.	

Clause 4.3 - Restricted geographic distribution of species and other conditions
(Equivalent to IUCN criterion B)
Assessment Outcome: Endangered under Clause 4.3(b)(d)(e i)

The geographic distribution of the species is:			
	(a)	for critically endangered species	very highly restricted, or
	(b)	for endangered species	highly restricted, or
	(c)	for vulnerable species	moderately restricted,
and at least 2 of the following 3 conditions apply:			

	(d)	the population or habitat of the species is severely fragmented or nearly all the mature individuals of the species occur within a small number of locations,	
	(e)	there is a projected or continuing decline in any of the following:	
		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	habitat area, extent or quality,
		(iv)	the number of locations in which the species occurs or of populations of the species,
	(f)	extreme fluctuations occur in any of the following:	
		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	the number of locations in which the species occur or of populations of the species.

Clause 4.4 - Low numbers of mature individuals of species and other conditions
(Equivalent to IUCN criterion C)
Assessment Outcome: Not met

The estimated total number of mature individuals of the species is:						
	(a)	for critically endangered species			very low, or	
	(b)	for endangered species			low, or	
	(c)	for vulnerable species			moderately low,	
and either of the following 2 conditions apply:						
	(d)	a continuing decline in the number of mature individuals that is (according to an index of abundance appropriate to the species):				
		(i)	for critically endangered species		very large, or	
		(ii)	for endangered species		large, or	
		(iii)	for vulnerable species		moderate,	
	(e)	both of the following apply:				
		(i)	a continuing decline in the number of mature individuals (according to an index of abundance appropriate to the species), and			
		(ii)	at least one of the following applies:			
			(A)	the number of individuals in each population of the species is:		
				(I)	for critically endangered species	extremely low, or
				(II)	for endangered species	very low, or
				(III)	for vulnerable species	low,
			(B)	all or nearly all mature individuals of the species occur within one population,		
			(C)	extreme fluctuations occur in an index of abundance appropriate to the species.		

Clause 4.5 - Low total numbers of mature individuals of species

(Equivalent to IUCN criterion D)
Assessment Outcome: Not met

The total number of mature individuals of the species is:			
	(a)	for critically endangered species	extremely low, or
	(b)	for endangered species	very low, or
	(c)	for vulnerable species	low.

Clause 4.6 - Quantitative analysis of extinction probability
(Equivalent to IUCN criterion E)
Assessment Outcome: Data deficient

The probability of extinction of the species is estimated to be:			
	(a)	for critically endangered species	extremely high, or
	(b)	for endangered species	very high, or
	(c)	for vulnerable species	high.

Clause 4.7 - Very highly restricted geographic distribution of species– vulnerable species
(Equivalent to IUCN criterion D2)
Assessment Outcome: Not met

For vulnerable species,	the geographic distribution of the species or the number of locations of the species is very highly restricted such that the species is prone to the effects of human activities or stochastic events within a very short time period.