Conservation Assessment of *Eucalyptus parvula* L.A.S.Johnson & K.D.Hill (Myrtaceae)

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***Eucalyptus parvula* L.A.S.Johnson & K.D.Hill (Myrtaceae)**

Distribution: Endemic to NSW
Current EPBC Act Status: Vulnerable
Current NSW BC Act Status: Endangered
Proposed listing on NSW BC Act: Vulnerable

Reason for Change: Non-genuine change based on a revised assessment using current knowledge of species ecology, distribution and threats.

Summary of Conservation Assessment

Eucalyptus parvula was found to be eligible for listing as Vulnerable under Criterion B1ab (iii, iv, v) + B2ab (iii, iv, v).

The main reasons for this species being eligible are:

i) It has a highly restricted extent of occurrence (EOO) of 560 km^2 and area of occupancy (AOO) of 92 km^2;
ii) It has seven threat-defined locations if the most serious plausible threat of inhibited recruitment due to livestock grazing is considered; and
iii) Continuing declines are inferred in area, extent and/or quality of habitat, number of locations or subpopulations and number of mature individuals due to threats including livestock grazing, changes in temperature and rainfall due to climate change, and land clearing and degradation.

In this assessment, the word subpopulation is used following the IUCN (2022) guidelines.

Description and Taxonomy

Eucalyptus parvula is described as a "tree to 15 m high; bark persistent, shedding imperfectly on lower trunk, red-brown, fibrous-flaky or platy; smooth above, grey or green, shedding in long ribbons. Juvenile leaves opposite, elliptic to obovate to broad-lanceolate, glossy green. Adult leaves disjunct or opposite, lanceolate, 4–7 cm long, 0.6–1 cm wide, green, dull, concolorous. Umbellasters 7-flowered; peduncle terete, 4–7 mm long. Buds sessile, ovoid, 3–5 mm long, 2–3 mm diam., scar present; calyptra conical, shorter than and as wide as hypanthium. Fruit cylindrical, conical or ovoid, 3–4 mm long, 3–4 mm diam.; disc raised slightly; valves enclosed or rim-level." (PlantNET 2022).

Eucalyptus parvula is in the subgenus *Symphyomyrtus* section *Maidenaria* (Brooker 2000; Slee *et al.* 2020). Brooker (2000) further classified *E. parvula* in the subsection *Obscurae*, however the most recent formal classification of section *Maidenaria* does not recognise any subsections in *Maidenaria* and places it in the series *Viminales*

(Nicolle 2021; Jones and Nicolle 2018). *E. ser. Viminales* includes 40 species which are widespread in southeastern Australia. These trees or mallees have "bark annually decorticating throughout to mostly persistent, juvenile leaves sessile or shortly petiolate, adult leaves concolorous, inflorescences 1-, 3- or 7-flowered, fruit disc level to ascending, fruit valves at or above rim level" (Jones and Nicolle 2018).

Eucalyptus parvula was previously known as *Eucalyptus parvifolia* (Cambage 1909) but was renamed *E. parvula* by Hill and Johnson (1991) as the original name had already been used for a fossil eucalypt species.

Distribution and Abundance

The geographic distribution of *Eucalyptus parvula* is highly restricted, occurring primarily between Badja to the north and Cathcart in the south (NSW Scientific Committee 2009). It was previously thought that it may extend to Tinderry where some old (1963 and undated), outlying records were georeferenced, however recent examination of the herbarium specimens associated with these records found them to be misidentifications (G. Phillips *in litt.* July 2022). Recent examination of another two old (1971, 1995) herbarium specimens associated with outlying records near Wadbilliga Trig, and the absence of known habitat at the described locality, support the conclusion that these records were most likely misidentified as well (G. Phillips *in litt.* July 2022; J. Miles *in litt.* July 2022).

The distribution of *Eucalyptus parvula* lies within the South Eastern Highlands Bioregion and may extend into the adjacent South East Corner Bioregion (Department of Climate Change, Energy, the Environment and Water 2020) on the traditional lands of the Yuin (Walbanga and Djiringanj), Thaua and Ngarigo First Nations people (Horton 1996; NSW NPWS 2019; Tindale 1940).

Approximately 27% of known individuals of *Eucalyptus parvula* occur in South East Forest National Park and Wadbilliga National Park. Previous assessments suggested that the species may also occur in Tinderry Nature Reserve, Kybeyan State Conservation Area, and Deua National Park, however re-examination of the location descriptions and herbarium specimens related to these records, and an absence of any recent records in these protected areas suggest that the georeferences, and/or species identifications were erroneous. The remaining occurrences of known individuals are on private property for which the predominant land use is cattle grazing.

The NSW Scientific Committee (2009) stated "as populations of *Eucalyptus parvula* grow mainly on flats within headwater valleys separated by low ridges, its habitat is naturally patchy in the landscape (Miles 2008). However, clearing of woodlands in this habitat for grazing may also have contributed to fragmentation of the populations (Prober *et al.* 1990)."

<u>Extent of Occurrence and Area of Occupancy</u>

Based on the cleaned dataset, extent of occurrence (EOO) and area of occupancy (AOO) were calculated using Kew Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.* 2011). The EOO is estimated to be 560 km^2 based on a minimum convex hull polygon encompassing all cleaned records of the species as recommended by IUCN (2022). The AOO is estimated to be between 76 km^2 and 92 km^2 based on 19–23 2 x 2 km grid cells, the scale recommended for assessing AOO recommended by IUCN (2022). This encompasses the entire known historical

and extant distribution of the species. The range of values reflects exclusion or inclusion of low accuracy outlier records (see below).

Population Size

There are nine known subpopulations of *Eucalyptus parvula* with a total of c. 3,476–4,046 mature individuals (Table 1). There are also 4 outlier records which are many decades old, have very low accuracy and have not been formally surveyed. This estimate of the number of subpopulations is based on several assumptions. Firstly, the two sites of occurrence at Duck Hole Creek are most likely part of one continuous subpopulation. Secondly, given the likely pollen and seed dispersal distances, it is very unlikely that gene flow occurs regularly across distances greater than 1,000 m. And finally, the occurrence records at Badja have been assumed to represent a single subpopulation, due to the poor quality of information available from this area (old records with low spatial accuracy).

Accuracy of subpopulation counts is variable. Most stands are comprised mainly of single stemmed individuals with no evidence of resprouting, and counts are straightforward. However, the Dragons Swamp subpopulation consists primarily of resprouted stems, and accurate counts are difficult due to the presence of many multi-stemmed plants that have resprouted from lignotubers. Dense sod grass often conceals the lignotubers making it difficult to determine whether closely growing stems are multiple plants or single resprouting individuals (Miles 2017). There is, therefore, some uncertainty over the total population estimate for *E. parvula.* Furthermore, some of the subpopulations were burnt during the 2019–2020 fire season and have not been formally resurveyed since.

Dragon Swamp Creek & New Line Road

This subpopulation was formally surveyed in 1988 and 2017 (Prober *et al.* 1990; Miles 2017). Although previously referred to as two subpopulations, it is considered as one subpopulation in this assessment due to the 400 m distance between the two sites of occurrence (less than half of the conservative 1,000 m dispersal distance used to distinguish between subpopulations).

Based on the 2017 surveys this subpopulation was comprised of c. 200 juveniles and 769 mature individuals. The current structure of this subpopulation may have changed due to it being burnt by the Creewah wildfire during the 2019–2020 fire season. The Fire Extent and Severity mapping 2019/20 (FESMv3) (DPE 2022e) suggests that 15% of occurrences within this subpopulation were burnt at low severity, 55% at moderate, 24% at high and 5% at extreme. Only 1% of the subpopulation is estimated to have been unburnt. The only previous fire recorded in this area is a 1957-58 Wildfire (DPE 2022d), however Gavin Morgan's field notes from 1988 record the appearance of a recent fire (Miles 2017; J. Miles *in litt.* August 2022).

This is the most southerly confirmed extant subpopulation and it occurs within the South East Forest National Park.

Swamp area between Nunnock Swamp and Dragon Swamp Creek

This subpopulation may have previously been referred to as part of the Nunnock Swamp or Dragon Swamp Creek subpopulations. Based on a 2008 BioNet record, this subpopulation was comprised of c. 75 mature individuals (Miles 2017). Nineteen dead or dying plants were also recorded. FESMv3 (DPE 2022e) suggests that approx. 100%

of the occurrences within this subpopulation were burnt at moderate severity by the 'Creewah' wildfire during the 2019–2020 fire season. It occurs within the South East Forest National Park.

Nunnock Swamp

This subpopulation was formally surveyed in 2017 (Miles 2017). It is now thought that the subpopulation referred to as Nunnock Swamp by Prober *et al.* (1990) is most likely the Dragon Swamp Creek and New Line Road subpopulation, or the unnamed subpopulation referred to above.

Based on the 2017 survey this subpopulation was comprised of approx. 6 juveniles and 6 mature individuals of moderate health condition. FESMv3 (DPE 2022e) suggests that approx. 50% of occurrences within this subpopulation were burnt at low severity by the 'Creewah' wildfire during the 2019–2020 fire season. It occurs within the South East Forest National Park.

Steeple Flat

The Steeple Flat subpopulation was formally surveyed in 1988 (Prober *et al.* 1990) and estimated to contain 42 individuals. It has not been comprehensively surveyed since, as it occurs on private property. A partial survey of the area in 2008 recorded 23 individuals (Miles 2008) and roadside observations conducted with binoculars in 2017 and 2022 confirmed the persistence of at least five to seven individuals in paddocks (Miles 2017; Schlunke 2022). All of the plants observed in 2017 were in poor health, with two of them having resprouted from stems which likely died from drought (Miles 2017).

Based on the 1988 survey, and assuming individuals recorded as juvenile have now reached maturity, and that there has been little fatality or recruitment (due to absence of fire, no evidence of further clearing and continued grazing), this subpopulation is estimated to be comprised of c. 42 mature individuals.

Mowitts Swamp Creek

The Mowitts Swamp Creek subpopulation was formally surveyed in 1988 and 2017 (Prober *et al.* 1990; Miles 2017). Based on these surveys, the subpopulation is comprised of approx. 262 juveniles and 238 mature individuals. There were also fourteen individuals recorded as dead or near dead in 2017. Their deaths were attributed to the 2002–2009 drought, as the trees were more elevated from the creek, west-facing and exposed (Miles 2017).

FESMv3 (DPE 2022e) suggests that approx. 5% of occurrences within this subpopulation were burnt at low severity by the 'Badja Forest Rd, Countegany' wildfire during the 2019–2020 fire season. Gavin Moran's 1988 fieldnotes recorded evidence of a recent fire including blackened remains of small 'shrubby' individuals, blackened trunks of trees, crowns not scorched and some regrowth by lignotubers. He also recorded that a large area had been recently cleared, so it is likely that the clearing and fire were implemented by landowners, prior to it becoming part of Wadbilliga NP (J. Miles *in. litt.* August 2022). The only other fire that has been recorded in this area is a 1951-52 wildfire (DPE 2022d).

It is located in Wadbilliga National Park and adjacent private property.

Patch between Mowitts Swamp Creek site and the Kybean River

This subpopulation was surveyed in 2004 and is located on private property. An estimate of 300 individuals was recorded. Although the extent of this survey is unknown, the georeference is approx. 1.3 km west of the subpopulation referred to as Mowitts Swamp Creek and most of the land between the two sites of occurrence is cleared.

Duck Hole Creek

This subpopulation was recorded in two vegetation plots during the Eden Comprehensive Regional Assessment conducted in 2002. An herbarium specimen collected during the survey described it as occurring in 'scattered infrequent patches on rocky rises'. Although there have been no subsequent surveys of this subpopulation, Miles (2008) inferred a subpopulation size of 200 mature individuals based on subpopulation abundances and stand densities observed at other surveyed sites. Being private property, however, it is likely that the number of mature individuals is closer to the size of the grazed subpopulation at Steeple Flat (J. Miles, pers. comm. August 2022). If so, a subpopulation estimate of 50 mature individuals would be more likely. The two sites of occurrence comprising the Duck Hole Creek subpopulation are approx. 1.2 km apart, however this assessment assumes that individuals occur between the sites based on the herbarium description. There is one plausible outlying unconfirmed 1974 record between the Duck Hole Creek and Two Rivers Plain subpopulations, approx. 3.5 km from Duck Hole Creek and 1.8 km from Two Rivers Plain.

Two Rivers Plain

The Two Rivers Plain subpopulation was formally surveyed in 1988 and 2017 (Prober *et al.* 1990; Miles 2017). This is the largest subpopulation, estimated to have approx. 951 juveniles, and 1,661 mature individuals. These are lower bound estimates and true numbers of mature individuals may be up to 25% higher (c. 2073) (J. Miles, pers. comm. May 2018). Age and condition ranged from healthy saplings to mature senescing trees. Forty-three plants were resprouting from dead bases.

FESMv3 (DPE 2022e) suggests that approx. 3% of occurrences within this subpopulation may have been burnt at low severity by the 'Kydra Complex' wildfire during the 2019–2020 fire season.

Badja

The extent of the subpopulation at Badja has not been surveyed since 1988 due to its occurrence on private property, but when last counted it contained approximately 155 juveniles and 269 mature individuals (Prober *et al.* 1990; Miles 2008). Assuming individuals recorded as juvenile have now reached maturity, and that there has been little fatality or recruitment (no evidence of further clearing and continued grazing), this subpopulation could have up to 424 mature individuals (Miles 2008). As it has not been possible to survey the private property, and there is uncertainty about the location of several of the records in this area, it is not possible to determine whether the two northern-most records are linked to the main subpopulation by other plants, or whether they represent another one or two outliers or subpopulations of *E. parvula.* For the purpose of this assessment, all of the occurrences at Badja have been considered as one subpopulation.

FESMv3 (DPE 2022e) suggests that parts of this subpopulation were burnt by the 'Good Good Fire' wildfire during the 2019–2020 fire season, however the low spatial accuracy of species records here makes this fire's impacts on the Badja subpopulation difficult to gauge.

Fragmentation

The distribution of *Eucalyptus parvula* is fragmented with subpopulations separated by distances of c. 1.5–33 km. Prober *et al.* (1990) conducted a genetic analysis on *E. parvula* and estimated a medium to high level of total genetic diversity and diversity within subpopulations, which suggests its distribution across the landscape was once more continuous and that its current distribution is likely a result of naturally patchy habitat amplified by extensive land clearing across its range. The life history of *E. parvula* means that genetic transfer between subpopulations is highly unlikely, and should any subpopulations be removed or become locally extinct there is little chance they will be recolonised successfully through natural means (NSW Scientific Committee 2008). Although the species is fragmented the viability of patches is not well understood and it is unknown whether it can be considered severely fragmented under IUCN Criteria.

Number of Locations

There are seven threat-defined locations for *E. parvula* if the most serious plausible threat of inhibited recruitment due to livestock grazing is considered. This is considered the most serious plausible threat due its past and present contribution to population reduction and decline, as well as its role in reducing the species resilience to all other threats. Approximately 71% of the total population size, and five of the nine verified subpopulations, occur on private property.

Location No.	Site of Occurrence	Tenure	Abundance							
			1988 Juvenile	1988 mature	2008 mature	2017 Juveniles	2017 mature	Lower Estimate Total mature	Upper Estimate Total mature	Best Estimate of Total mature
1	Dragon Swamp Creek & New Line Road	South East Forest National Park	456	114	865	200	678	769	769	769
1	Swamp area between Nunnock Swamp and Dragon Swamp Creek	South East Forest National Park	NA	NA	75?	NA	NA	75	75	75
1	Nunnock Swamp	South East Forest National Park	NA	NA	NA	6	6	6	6	6
2	Steeple Flat	Private Property	28	14	NA	NA	NA	42	42	42
3	Mowitts Swamp Creek	Wadbilliga National Park	57	15	150	248	304	304	308	304
4	Patch between Mowitts Swamp Creek site and the Kybean River	Private Property	NA	NA	> 300	NA	NA	300	300	300
5	Duck Hole Creek	Private Property	NA	NA	50- 200?	NA	NA	50	200	50
6	Two Rivers Plain	Private Property	1607	800	NA	c. 951	c. `1,661	1,661	2,076	1,661–2,076
7	Badja	Private Property	155	269	NA	NA	NA	269	424	424
							Total	3,476	4,046	3,476–4,046

Table 1. Estimates of the number of mature and juvenile individuals in each site of occurrence surveyed during 2017 (Miles 2017), compared with mature individual estimates from 1988 (Prober *et al*. 1990) and 2008 (Miles 2008).

Ecology

The ecology of *Eucalyptus parvula* is poorly studied, with most knowledge being derived from collection data and observations by surveyors and collectors.

Habitat

The NSW Scientific Committee (2009) states "*Eucalyptus parvula* grows mainly in grassy woodlands around the edges of broad, flat headwater valleys in frost-prone areas at altitudes of 800–1200 m above sea level (Hill 2002; Miles 2008). It occurs on poorly drained humic soils derived from granite or granodiorite (Miles 2008). Associated species include *E. pauciflora* (Snow Gum), *E. stellulata* (Black Sally), and occasionally *E. viminalis* (Ribbon Gum), *E. ovata* (Swamp Gum), and *E. rubida* (Candlebark) (Miles 2008)."

Lifespan and Generation Length

Although the generation length for *E. parvula* is unknown due to insufficient data on lifespan, primary juvenile period and fecundity, it is possible to infer from conservative estimates that have been calculated for other eucalypts.

Generation length is determined as age of first reproduction + z ∗ length of reproductive period (IUCN Standards and Petitions Committee, 2022), where *z* is a constant between 0 and 1 depending on survivorship and relationship of fecundity to tree age (Fensham *et al.* 2020). A *z* value of 0.33 that was calculated for another long-lived tree species, *Araucaria cunninghamii* (Fung and Waples 2017), can be used as an approximation for the z value of *Eucalyptus*. Fensham *et al.* (2020) calculated a minimum generation length of 70 years for *Eucalypts* assuming 4 years as the minimum age of reproduction, a z value of 0.33 and 200 years as the minimum age of a large tree. If a younger age of 150 years is assumed, the minimum generation length would be 53.5 years.

Pollen Dispersal

Flowering events may be stimulated following stressful conditions such as droughts, as has been observed in other *Eucalyptus* species in the same general area. Consequently, flowering is likely to occur sporadically and asynchronously between subpopulations (NSW Scientific Committee 2008). Flowering has been recorded in January, and buds have been recorded throughout the year (RBGDT 2022; Slee *et al.* 2020). The morphologically unspecialised flowers of eucalypts are known to encourage visitation from a range of pollinators (Ford *et al.* 1979; Paton and Ford 1977). It allows them to be pollinated by birds earlier in the day (and in colder weather), then insects such as bees, flies, and beetles, later in the day (and in warmer weather), and mammals and possibly moths at night (Ford *et al.* 1979). It has been estimated that more than half of *Eucalyptus* species can be pollinated by birds, and in general, those which produce small, white or cream flowers grouped into large conflorescences are visited by birds and bats, which are capable of pollen transfer over greater distances than insects (Griffin 1980). When climate and flowering season are unpredictable, birds may be more reliable pollinators than insects (Ford *et al.* 1979).

While some dispersal studies suggest that eucalypt pollen regularly disperses over 1,000 m, most pollen is usually distributed within 200 m (Byrne *et al*. 2008; Broadhurst 2013).

Seed Dispersal and Ecology

A number of studies have found that virtually all seeds are deposited within a radius of twice the tree or canopy height (Floyd 1962; Barber 1965; Cremer 1977). Using the method developed by Cremer (1977) to estimate the distance of seed dispersal, a dispersal distance (D) of 5.3–10.6 m can be estimated for *Eucalyptus parvula.*

Eucalyptus parvula can be propagated by seed and takes 5–10 days to germinate at a temperature of 25ºC (Ollerenshaw 1983). The NSW Royal Botanic Garden conducted three separate germination trials on seed from three separate seedlots - one 2009 collection from the Two Rivers Plain subpopulation, and one February and one November 2009 collection, both from the Dragon Swamp Creek & New Line Road subpopulation. The germinability of these samples were 44%, 54% and 69% respectively. As most eucalypts have germinability ≥ 80%, the lower germinability observed for *E. parvula* indicates that a portion of the seed have a physiological dormancy (G. Phillips *in litt.* September 2022). Eucalypts growing in cold and high-altitude areas often require exposure to low temperatures to induce germination (Pryor 1957; Boden 1957; Boland *et al.* 1980) and the duration of low temperature exposure has been observed to increase the germination rates of some eucalypts (Close and Wilson 2002; Booth 2017; Battaglia 1993). Given the altitude and temperatures where *E. parvula* grows, it is reasonable to assume that it too, has a low-temperature requirement to break its seed dormancy.

Genetic Diversity and Hybridisation

A genetic study analysing the levels and distributions of allozyme diversity in *Eucalyptus parvula* was conducted by Prober *et al.* in 1990. They found high levels of total diversity, low between-stand diversity and small proportions of localised alleles which are characteristic of common and widespread eucalypt species. Their findings suggest a more continuous distribution prior to European settlement, and they concluded that fragmentation of the [sub]populations could lead to a decline in genetic diversity and reduced evolutionary potential in the future (Prober *et al.* 1990).

A low proportion of *Eucalyptus parvula* hybridises with *Eucalyptus viminalis* and *Eucalyptus rubida* (later suspected to be *Eucalyptus dalrympleana)* have been observed (Prober *et al.* 1990; Miles 2017). These mainly occur along the margins of cleared areas at Two Rivers Plain and Badja, however a small number of possible hybrids were also observed at Dragon Swamp Creek and New Line Road. “Invasion by seedlings of other tree species from surrounding forests and woodlands may lead to a decrease in the competitive advantage of *E. parvula* within its habitat and possibly an increase in the frequency of hybridisation with related Eucalyptus species (Miles 2008).” (NSW Scientific Committee 2009).

Disturbance Response

Recruitment in many eucalypts is primarily episodic, occurring in response to disturbance events. This is likely to be the case for *E. parvula,* as most stands have similarly sized plants, there are lower numbers of juvenile individuals compared to mature plants, and seedling germination and resprouting following fire and physical disturbance have been observed (NSW Scientific Committee 2008; Miles 2017).

Eucalyptus parvula tends to resprout from basal buds and the lignotuber rather than along stems (NSW Scientific Committee 2008). Exposure to bare ground, reduction in competition, increased light, seed-predator satiation and an increase in soil moisture following fire are favourable for eucalypt seedling establishment (Gill 1997).

Eucalyptus parvula seeds are not known to possess dormancy mechanisms or germination requirements that necessitate exposure to fire or physical damage. It is therefore likely that fires and physical disturbance primarily facilitate recruitment through the creation of bare ground and elimination of competitors such as grasses that may prevent the establishment of seedlings. Seeds are primarily stored in the canopy and are only dispersed a short distance and once dropped are unlikely to remain viable for more than a short period of time (NSW Scientific Committee 2008). Consequently, disturbances that result in the loss of all mature trees in a subpopulation or patch, but which do not result in successful recruitment events, are likely to lead to local extinctions of the species in the absence of recolonisation.

Soil turnover caused by a bulldozer during a land clearing event was observed to promote significant recruitment in the Two Rivers Plain subpopulation (Miles 2017). Recent incidental observations suggest that recruits have persisted at this location under the current pulse grazing regime (Armstrong, 2022, pers. comm.). Feral pigs (*Sus scrofa*) may also provide sufficient soil disturbance for recruitment and so may in some cases provide a benefit to *E. parvula* (Miles 2017).

Given the need for disturbance for recruitment, episodic recruitment events may be more likely to replace the mature plants lost to disturbance, rather than increase the total population size, especially as they are naturally thinned out by competition by the time they mature (NSW Scientific Committee 2008).

Population Structure

The population structure primarily consisted of mature individuals in 2017, with an average of about 70% of individuals being mature across the known subpopulations. The Dragons Creek Swamp subpopulation is primarily composed of coppiced, resprouting trees and most sites had a handful of dead plants and plants that looked to be in poor condition (Miles 2017). This population structure is not unusual for a species with episodic recruitment driven by disturbance. With such a large proportion of individuals occurring on private and grazed land the numbers of recruits and juveniles are likely to be maintained at lower levels due to grazing pressure.

It is likely that this structure has changed since the 2019–2020 bushfires in which approximately 20% of the total occurrence records may have been burnt at moderate

to extreme severity. This would have resulted in burnt individuals resprouting from their lignotubers as well as seedling germination. There also may have been some mortality due to the compounding effect of pre-fire drought.

Threats

Livestock grazing and trampling leading to lack of recruitment

The variable recruitment observed among and within subpopulations of *Eucalyptus parvula* is likely related to variation in livestock grazing regimes. At Two Rivers Plain, where livestock have some access, recruitment was observed to be quite common in some patches, while absent in others, particularly around isolated old trees (Miles 2017). A flush of regrowth observed at one of the Two Rivers Plain properties may have resulted from a change in land ownership and a decrease in stocking rates. No evidence of recruitment has been observed in the Steeple Flat subpopulation, or the western portion of the Mowitt's Swamp Creek subpopulation, which are both grazed (Miles 2017). Whilst grazing pressure can vary over time and from property to property, the smaller and more isolated subpopulations are considered to be most threatened (Miles 2008, NSW Scientific Committee 2008). Approximately 71% of the total population size, and five of the nine verified subpopulations, occur on private property subject to livestock grazing and trampling.

A study of eucalypt regeneration in grassy dry forests and grassy woodlands of central Victoria found that a long history of agriculture and high cover of exotic annual vegetation (i.e. grasses, graminoids and forbs) reduced eucalypt regeneration, even when grazing was removed (Dorrough and Moxham 2005). This is likely to be the case for *Eucalyptus parvula*.

Native vegetation clearing

The damp frost-hollow valley floor habitat of *Eucalyptus parvula* is naturally patchy in the landscape (Miles 2017) and has been further fragmented and restricted to mainly marginal, edge habitat due to clearing of flats for grazing (Prober *et al.* 1990). While the majority of clearing events are likely in the past now, the species is still at risk from smaller clearing events eroding the remnant patches of the species on private land. One such event occurred at Two Rivers Plain in the mid 1990s, which appears to have resulted in prolific recruitment rather than a decline. This may be due to relatively low stocking rates of livestock in the area at the time (NSW Scientific Committee 2008). Should clearing coincide with high levels of grazing or drought, successful recruitment would be unlikely.

'Clearing of native vegetation' is listed as a Key Threatening Process under the Act.

Changes in temperature and rainfall due to climate change

Climate change is a threat to *Eucalyptus parvula* as its relatively narrow climatic niche makes it particularly vulnerable to changes in temperature and rainfall. The species may have limited ability to withstand short-term drying conditions, with many subpopulations observed to include plants consisting of new growth coppicing off dead trunks that are thought to have been killed by drought (Miles 2017). Longer term drought and/or greater drought frequency may cause plant death. Furthermore, capacity for eucalypts to disperse and establish in more suitable habitat under climate

projections is limited due to clearing for agriculture, grazing and reduced fire regimes (Yates and Hobbs 1997).

Germination trials conducted by the NSW Royal Botanic Garden suggest a portion of *E. parvula* seed has a physiological dormancy, and cold stratification (chilling) is likely required to break it (G. Phillips *in litt.* September 2022). Climate projections suggest an increase in mean daily minimum temperature across all occurrences and for all seasons (AdaptNSW 2022). The greatest increase for mean daily minimum temperature is projected for summer, with temperature increases up to 0.8˚C during 2020–2039 and up to 2.3˚C during 2060–2079. The minimum daily mean for winter is projected to increase by 0.4˚C during 2020–2039 and up to 1.7˚C during 2060–2079 (AdaptNSW 2022). These projected temperature increases will likely result in fewer chilling events, and therefore lower germination rates.

The projected increase in annual precipitation accumulation for the years, 2060–2079, ranges from 0.8–2.7 mm. The greatest seasonal projected increase in precipitation accumulation between 2020–2030 is predicted for autumn and ranges from 5.5–6.9 mm and the greatest seasonal projected decrease in precipitation accumulation is predicted for winter and spring, with each ranging from -1.9 –-5.8 mm. The greatest seasonal projected increase in precipitation accumulation between 2060–2079 is also predicted for autumn and ranges from 11.9–15.7 mm and the greatest seasonal projected decrease in precipitation accumulation is predicted for winter and ranges from -8.0–14.5 mm, i.e. higher precipitation in autumn and lower precipitation during winter and spring (AdaptNSW 2022).

Eucalyptus parvula is restricted to tablelands above 1,000 m (Brooker & Kleinig, 2006), often in swampy areas (Briggs, 2000, pers. comm.) and frost hollows in shallow valleys. Fogs are common and up to 100 frosts a year occur, as well as snow which may persist on the ground for several days (Pryor 1981; Approved Conservation Advice 2008). “As the habitat of *Eucalyptus parvula* is located in the coldest, wettest parts of the landscape within its range, under conditions of increased average temperatures and possibly lower effective rainfall, the viability of subpopulations could be reduced if the region becomes warmer and drier, as projected under future climate scenarios (Hennessy *et al.* 2002). Invasion by seedlings of other tree species from surrounding forests and woodlands may lead to a decrease in the competitive advantage of *Eucalyptus parvula* within its habitat and possibly an increase in the frequency of hybridisation with related *Eucalyptus* species (Miles 2008).” (Approved Conservation Advice 2008).

An increase in temperature and decrease in winter and spring precipitation could also result in general drying out of swampy flats and an increase in fire risk. Although the lignotuber provides some tolerance to drought, increases in frequency and duration combined with lack of recruitment, will likely lead to further reductions of mature individuals and suitable habitat.

‘Anthropogenic Climate Change’ is listed as a Key Threatening Process under the Act.

Hybridisation

Although natural hybridisation is widespread among plant species (Mallet 2005), it can lead to pollen swamping and dilution of the gene pool if it occurs too frequently in rare species (Rhymer and Simberloff 1996). Prober *et. al.* (1990) identified this as a potential threat to *Eucalyptus parvula*, however few instances of hybridisation were

observed in the 2017 survey and it is now thought that the low proportions of hybrids observed are unlikely to represent a threat to the viability of the species in the long term (Miles 2017).

Alteration of drainage

Evidence of an attempt to drain the wet flats by cutting a surface drain was observed on private property at Mowitts Swamp Creek during the 2017 surveys (Miles 2017). The species is known to be susceptible to drought, and the draining of wet areas is likely to exacerbate the effects of even minor periods of reduced rainfall.

'Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands' is listed as a Key Threatening Process under the Act.

Feral animals

Feral pigs (*Sus scrofa*) are present within and around *Eucalyptus parvula* subpopulations and pose a threat to juveniles by disturbing or uprooting them while digging and foraging. Pigs may also act as vectors for the spread of *Phytophthora* (Miles 2017).

Feral deer (*Cervus* spp.) are also present in the area and pose a threat to young plants, by ringbarking them. Evidence of *Eucalyptus parvula* and *E. pauciflora* saplings being ringbarked by deer was recorded during the 2017 surveys (Miles 2017). Like pigs, deer may also act as a vector for transporting *Phytophthora* into uninfected areas.

'Herbivory and environmental degradation caused by feral deer' and 'Predation, habitat degradation, competition and disease transmission by Feral Pigs, *Sus scrofa* Linnaeus 1758' are listed as Key Threatening Processes under the Act.

Phytophthora cinnamomi

The *Eucalyptus parvula* subpopulations at Dragon Swamp Creek, New Line Road and Nunnock swamp sites were all noted as having numerous unthrifty plants with dead and dying branches in 2017, with *Phytophthora cinnamomi* being considered the most likely cause (Miles 2017). Neither Mowitts Swamp Creek or Two Rivers Plain exhibited any indication of the presence of *P. cinnamomi*, however, nearby roads are considered potential sources of infection (Miles 2017).

The susceptibility of *Eucalyptus parvula* to the pathogen *Phytophthora cinnamomi* is unknown, however 33 species of *Eucalyptus* in NSW are currently known to be susceptible to *P. cinnamomi* infection, including *E. viminalis*, which is closely related to *E. parvula*. Drought and other stressors, such as the co-occurrence of other pathogens and insects, has been found to place species which are normally tolerant, at risk of disease from *P. cinnamomi* (McDougall and Liew 2020). McDougall and Liew (2020) found that poor tree health often has a cause other than *P. cinnamomi;* largely drought which has very similar symptoms to plants affected by *P. cinnamomi.* Although Eucalypts rarely die from *P. cinnamomi* infection, it can exacerbate other stressors.

'Infection of native plants by *Phytophthora cinnamomi*' is listed as a Key Threatening Process under the Act.

Weeds

Blackberry (*Rubus fruticosus* species aggregate) has been a notable threat at the New Line Road subpopulation in the past and although numbers have been reduced

through spraying, it is still present at low numbers at the site and in higher numbers nearby (Miles 2017). The tendency for blackberries to grow around the trunks of *Eucalyptus parvula* makes spraying for blackberry control potentially hazardous for these trees.

Hawthorn (*Crataegus monogyna*) occurs at Mowitts Swamp Creek and Yorkshire Fog (*Holcus lanatus*), Sweet Vernal Grass (*Anthoxanthum odoratum*) and Clover (*Trifolium repens*) are all believed to occur at the various sites. These species are likely to suppress and compete with *Eucalyptus parvula* seedlings.

'Invasion of native plant communities by exotic perennial grasses' is listed as a Key Threatening Process under the Act.

Assessment against IUCN Red List criteria

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

Criterion A *Population Size reduction*

Assessment Outcome: Data deficient

Justification: The estimated timespan of three generations is between 160 and 210 years. This timespan encompasses the extensive clearing of habitat that has occurred since European colonisation. A large population size reduction is suspected to have occurred since 1812, based on the current fragmented distribution of *Eucalyptus parvula* contrasted with its high level of genetic diversity and low level of genetic divergence between subpopulations (Prober *et al.* 1990). Furthermore, the dominant land use where *Eucalyptus parvula* occurs is livestock grazing, and it's likely that the productive flats and swamp edges were preferentially cleared relative to the wider landscape of infertile soils and challenging topography (Prober *et al.* 1990; Fensham *et al.* 2020).

Although a population size reduction of between 50–80% is likely to have occurred for irreversible or continuing causes (criterion A2), the likely c) decline in area of occupancy (AOO), extent of occurrence (EOO) and habitat quality due to land clearing and livestock grazing, and (e) effects of introduced taxa (inhibited recruitment due to disturbance and herbivory by livestock, pigs and deer, and competition from pasture and weeds) have not been quantified, and therefore the extent of population reduction cannot be easily calculated.

Criterion B *Geographic range*

Assessment Outcome: Vulnerable under Criterion B1ab(iii, iv, v)+ B2ab(iii, iv, v)

Justification: *E. parvula* has a restricted geographic distribution. The extent of occurrence (EOO) is 560 km^2, as measured by a minimum convex polygon containing all the cleaned records of occurrence (IUCN 2022). The area of occupancy (AOO) was estimated to be 92 km^2, based on the number of 2 x 2 km grid cells occupied by the species, the spatial scale of assessment recommended by IUCN (2022).

These estimates of EOO and AOO fall under the threshold of Endangered (<5,000 km^2 and <500 km^2 respectively).

In addition to these thresholds, at least two of three other conditions must be met - and if the species only meets a lower threat category in these sub-criteria than for the EOO and/or AOO threshold, its overall threat category for Criterion B is that lower category. 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: Subcriterion met for Vulnerable as the species has ≤10 locations

   Justification:

   There are seven threat-defined locations for *Eucalyptus parvula* if the most serious plausible threat of inhibited recruitment due to livestock grazing is considered. Seven locations is within the threshold for the Vulnerable category. *Eucalyptus parvula* is not currently considered to be severely fragmented.

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: Sub criterion met for iii), iv) and v)

   Justification: Continuing declines are inferred in the (iii) quality of habitat (iv) number of locations and or sub-populations and (v) number of mature individuals due to the current observed threats of inhibited recruitment due to livestock grazing and trampling, drought stress, and higher temperatures, fewer cool nights, higher precipitation in summer, and lower precipitation in winter due to anthropogenic climate change. As a large portion of the population occurs on private property, further clearing of the species and its habitat, and interference with drainage also pose significant threats. The senescence of mature plants without any recruitment at sites such as Steeple Road Flat, and the private property side of Mowitts Swamp Creek is evidence that these declines are currently occurring.

c) Extreme fluctuations.

   Assessment Outcome: Sub criterion not met

   Justification: As a long-lived tree, there is no evidence to suggest the species experiences extreme fluctuations.

Criterion C Small population size and decline

Assessment Outcome: Criterion not met

Justification: The total number of mature individuals is estimated to be 3,476–4,046. This falls within the threshold for Vulnerable (<10,000).

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: There is insufficient data to quantify potential declines at present.

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

Assessment Outcome: Criterion not met

Justification: Continuing declines are inferred in the number of mature individuals due to current observed threats of inhibited recruitment due to livestock grazing and trampling, drought stress, and higher temperatures, fewer cool nights, higher precipitation in summer, and lower precipitation in winter due to anthropogenic climate change. As a large portion of the population occurs on private property, further clearing of the species and its habitat, and interference with drainage also pose significant threats. The senescence of mature plants without any recruitment at sites such as Steeple Road Flat, and the private property side of Mowitts Swamp Creek is evidence that these declines are currently occurring.

In addition, at least 1 of the following 3 conditions:

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

Assessment Outcome: Sub criterion not met

Justification: The largest known population at Two Rivers Plain contains over 1,000 mature individuals.

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

Assessment Outcome: Sub criterion not met

Justification: The largest known population at Two Rivers Plain represents approximately 51% of estimated mature individuals.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Sub criterion not met

Justification: As a long-lived tree, there is no evidence to suggest the species experiences extreme fluctuations.

Criterion D Very small or restricted population

Assessment Outcome: Criterion not met

Justification: The total number of mature individuals is estimated to be 3,476–4,046.

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: Sub criterion not met

Justification: The total number of mature individuals is c. 3,476–4,046.

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: Sub criterion not met

Justification: The species distribution is not sufficiently restricted and there are no threats currently known of that could drive the taxon to CR or EX in a very short time.

Criterion E Quantitative Analysis

Assessment Outcome: Data Deficient

Justification: There is insufficient data to quantify the Extinction Risk for this species.

Conservation and management Actions

This species 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 parvula* sits within the Site-managed species management stream of the SoS program and the conservation strategy can be viewed here:
https://www.environment.nsw.gov.au/savingourspeciesapp/Project.aspx?results=c&ProfileID=10307

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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 parvula was found to be Vulnerable under Clause 4.3 (c) (d) (e iii,iv).

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: Vulnerable under Clause 4.3 (c) (d) (e iii,iv).

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.