Conservation Assessment of *Eucalyptus boliviana* J.B.Williams & K.D.Hill (Myrtaceae)

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***Eucalyptus boliviana* J.B.Williams & 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: Critically Endangered
Reason for change: Non-genuine change based on increased knowledge of species abundance, distribution and threats acting on the population.

Summary of Conservation Assessment

Eucalyptus boliviana was found to be eligible for listing as Critically Endangered under Criterion B1ab(iii, v). The main reasons for this species being eligible are (i) *Eucalyptus boliviana* has a highly restricted Extent of Occurrence (EOO) of 16 km^2; (ii) *Eucalyptus boliviana* is known from a single threat-defined location; and (iii) continuing decline has been observed and is projected to continue in the area, extent and quality of habitat and number of mature individuals due to the combined effects of increased frequency and duration of drought due to climate change and adverse fire regimes.

Description and Taxonomy

Eucalyptus boliviana (Bolivia Stringybark) is a conventionally accepted species (CHAH 2022) that lies phylogenetically within the clade of subgenus *Eucalyptus,* section *Eucalyptus,* series *Olsenianae* (Nicolle 2021). It is described by Williams and Hill (2001) as a "shrub or mallee to 5 m tall, sometimes a tree to 12 m. Bark persistent, long-fibrous ('stringy') with included thin scales, branches to 2 cm diam. smooth, weakly glaucous, quadrangular. Seedling leaves not seen. Juvenile leaves elliptical, dull green, glaucous, glabrous, 8–11 cm long, 3–6 cm wide, petioles 2–3 cm long. Adult leaves semi-glossy green with a bluish sheen, becoming glossy green with age, glabrous, highly coriaceous, similifacial, broad-lanceolate, acute or apiculate, oblique at base, 8–13 cm long, 2.0–5.0 cm wide; petioles 2.0–3.0 cm long, strongly flattened to quadrangular, usually several times twisted, decurrent into strong ribs on branchlets. Inflorescences axillary; umbellasters 7-flowered. Peduncles thick and broadly flattened, 4–10 mm long, to 7 mm wide. Mature buds sessile, glaucous, ovoid to rhomboid, often curved, strongly 3-4-angular, 7–10 mm long, 6–7 mm diam., calyptra as long as hypanthium. Flowers yellow. Filaments irregularly flexed, stamens all fertile, anthers reniform. Fruits sessile, tightly clustered, flattened-globular, weakly angular, distinctly flanged at top of hypanthium, glaucous, 4-(rarely 5)-locular, 7–11 mm long, 9–15 mm diam. Calyptra scar and stemonophore raised, 0.5–1 mm wide. Disc raised, 2–4 mm wide. Valves broadly triangular, obtuse, raised at a low angle, tips exserted. Seeds dark brown, semiglossy, pyramidal or D-shaped, 1.5–2 mm long; chaff similar, smaller."

Eucalyptus boliviana has no known synonyms (CHAH 2022). It is closest morphologically to *E. williamsiana* which is widespread in the district in which *E. boliviana* occurs. However the latter is distinguished by the 4-winged, glaucous stems (*c.f.* weakly ridged, non-glaucous), shorter buds and fruit, thicker peduncles, 4-valved fruits with a medial flange (*c.f.* 3-valved fruits with no flange), flowers with yellow stamens (*c.f.* white stamens), flattened, twisted petioles decurrent onto the branches (*c.f.* not twisted or decurrent), the dull, glaucous juvenile foliage (*c.f.* glossy, green juvenile foliage), and the smaller, gnarled habit (*c.f.* upright tree) (Williams and Hill 2001; Brooker and Kleinig 2006; Slee *et al.* 2020).

Distribution and Abundance

Eucalyptus boliviana is a naturally rare species endemic to the Bolivia Hill Range south of Tenterfield in northern NSW. This area lies within the New England Tablelands Bioregion (Department of Agriculture, Water and Environment 2012) on the traditional lands of the Ngarabul First Nations people (Horton 1996; NPWS 2011).

Eucalyptus boliviana is restricted to a small section of the Bolivia Hill Range around granite outcrops and slabs above 900 m elevation (OEH 2021). The species first confirmed record was in 1998 just prior to the gazettal of Bolivia Hill Nature Reserve (Williams and Hill 2001; NPWS 2011). This National Parks and Wildlife Service (NPWS) managed reserve, which contains at least 75% of the total *E. boliviana* population, was gazetted in 2000 due to the presence of *E. boliviana* in addition to high concentrations of other rare endemic plant species (NPWS 2011). The remaining ~25% of the population occurs in adjoining freehold land, which is currently under absentee ownership, uncleared and not subject to grazing (T. Soderquist pers. comm. August 2022).

Early estimates of the *Eucalyptus boliviana* population suggested that there were around 1,000–1,500 individuals spread between two main stands (Hunter 2002). Since this time further surveys have been undertaken, with the population now considered to consist of five discrete stands spanning a linear distance of approximately 5 km (T. Soderquist pers. comm. August 2022, *in litt.* December 2022). However, some small stands previously identified by botanists no longer appear to be extant, having not been relocated for over two decades (OEH 2021; T. Soderquist *in litt.* December 2022). Of the extant stands, four are mostly concentrated in one area in the south of the nature reserve, separated by largely unvegetated granite slabs and densely vegetated, steep-sided gullies over distances of up to several hundred metres (G. Phillips pers. obs. October 2020; January 2021). The fifth and largest stand is separate from all the others, being 2–3 km to the northeast of the next nearest stand (T. Soderquist pers. comm. August 2022).

The separation of the northeast stand means that the *Eucalyptus boliviana* population is considered to consist of two subpopulations (Table 1), i.e., geographically or otherwise distinct groups between which there is little demographic or genetic exchange, as defined by IUCN (2022). This is due to the relatively short pollen dispersal distances reported in eucalypts (Peters *et al.* 1990; Butcher *et al.* 2005; Byrne *et al.* 2008; Jones *et al.* 2008; Breed *et al.* 2015) and highly localised seed dispersal (Booth 2017). This is supported by gas chromatography studies which have

shown differences in leaf oil chemistry between the northeast stand and all the southwestern ones which is potentially indicative of genetic differences (Collins 2017).

Table 1 – Population data for *Eucalyptus boliviana* including estimated numbers of mature individuals before the 2017-2020 drought and notes regarding declines since this time.

Subpopulation	No. of stands	Pre-2017 abundance estimate	Decline in mature individuals	Reference
Northeast	1	*c.* 1,000	10% initial mortality in 2017-2020 drought, increasing to 15% post-drought.	T. Soderquist pers. comm. August 2022, *in litt.* December 2022
Southwest	4	500–1,000	Stands showing variable mortality of 10–20% in 2017-2020 drought, with all stands remaining in very unhealthy states since and further declines likely.	G. Phillips pers. obs. October 2020, January 2021; T. Soderquist pers. comm. August 2022, *in litt.* December 2022

Typical stands in the southwestern subpopulation of *Eucalyptus boliviana* can be quite dense, often forming almost monocultures in soil pockets among the granite slabs (G. Phillips pers. obs. October 2020; January 2021). Together, the four stands in this subpopulation had a combined estimated maximum population of 500–1,000 trees prior to the 2017–2020 drought (T. Soderquist *in litt.* December 2022). The northeastern subpopulation is in an open, shrubby dry sclerophyll forest (Hunter and Metcalfe 2001), which consists of a single stand spread over a larger area of suitable habitat (T. Soderquist pers. comm. August 2022). This subpopulation was also estimated to have approximately 1,000 mature individuals prior to the 2017–2020 drought (T. Soderquist pers. comm. August 2022). Thus, the total maximum pre-drought population is estimated to have been 1,500–2,000 mature individuals.

During the 2017–2020 drought, many mature *Eucalyptus boliviana* trees suffered heavy dieback including canopy and stem death (G. Phillips pers. obs. October 2020; January 2021; DPE 2022a; J. Hunter *in litt.* July 2022). Shallow-rooted stringybark species, such as *E. boliviana*, were under significant hydraulic stress during this drought, with other local species suffering up to 60% mortality (DPE 2022a; J. Hunter *in litt.* July 2022). However, *E. boliviana* appears to have suffered relatively lower overall mortality, with 15% of mature individuals estimated to have died across both subpopulations during and following the drought (T. Soderquist *in litt.* December 2022). The stands in the southwestern subpopulation did not suffer evenly, with the majority of trees appearing very unhealthy in two patches and mortality estimated to be at least 20%, while other stands are reported to have lower losses of approximately 10% of mature individuals (G. Phillips pers. obs. October 2020, January 2021; Hunter 2022; T. Soderquist *in litt.* December 2022). Recruitment since the breaking of the drought is occurring, albeit slowly and sparsely. However, as not all unhealthy mature trees appear to be recovering the decline in mature individuals appears likely to continue at least into the immediate future (G. Phillips pers. obs. October 2020, January 2021; T. Soderquist pers. comm. August 2022; *in litt.* December 2022). Thus, the population of mature individuals is currently estimated to be 1,275–1,700, 15%

lower than pre-drought estimates. With the continuing mortality along with recruitment that may offset the loss in some stands over time, it is difficult to know if this figure will return to pre-drought numbers over time despite predictions some stands will remain stable in number (T. Soderquist *in litt.* December 2022).

Area of Occupancy and Extent of Occurrence

The Area of Occupancy (AOO) of *Eucalyptus boliviana* was calculated using 2 x 2 km grid cells, the scale recommended by IUCN (2022) and was estimated to be 16 km^2. The Extent of Occurrence (EOO) is based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2022) and was estimated to be 3.3 km^2. However, where EOO is less than or equal to AOO then IUCN guidelines recommend EOO estimates be changed to be equal to AOO to ensure consistency with the definition of AOO as an area that fits within EOO (IUCN 2022). Therefore, the EOO for *E. boliviana* is also estimated to be 16 km^2 in this assessment. Both EOO and AOO were calculated using ArcGIS (Esri 2015), enclosing all confirmed survey records and cleaned spatial datasets. Based on these estimates, *E. boliviana* has a highly restricted AOO and very highly restricted EOO.

Number of Locations

When the most serious plausible threat of increased frequency and duration of drought due to climate change is considered, both subpopulations of *Eucalyptus boliviana* can be considered to be within a single threat-defined location, as per the IUCN definition (IUCN 2022), given drought effects are likely to be consistent across the full range of the species.

Ecology

Habitat
On Bolivia Hill, *Eucalyptus boliviana* grows in open shrubland, low woodland, and open forest possessing a shrubby understorey among granite outcrops above 900 m elevation (Williams and Hill 2001; OEH 2021; DPE 2022b). Bolivia Hill is a unique granitic intrusion known as the Bolivia Hill Leucomonzogranite (Geoscience Australia 2022) and receives 800–900 mm of rainfall annually (Hunter 2002). The coarse, shallow soils derived from the Leucomonzogranite are characterised by high sodium and potassium content and *E. boliviana* is predicted to especially prefer the high sodium concentrations (Bui *et al.* 2017).

Eucalyptus boliviana commonly co-occurs with *E. prava, Callitris endlicheri, Acacia adunca, Leptospermum nova-angliae, Micromyrtus sessilis* and *Leucopogon neoanglicus* (Williams and Hill 2001; Phillips 2020). In the more densely vegetated sites, *E. andrewsii, E. macrorhyncha, E. dealbata, E. caleyi* and *E. youmanii* may also contribute to the canopy (OEH 2021). Other threatened species listed on the NSW *Biodiversity Conservation Act 2016* also associate with *E. boliviana,* with *A. pycnostachya* (Vulnerable) commonly co-occurring and *Boronia boliviensis* (Endangered), and *Homoranthus croftianus* (Endangered) co-occurring in certain stands (Williams and Hill 2001; Hunter 2022; G. Phillips pers. obs. January 2021).

Eucalyptus boliviana has been recorded in the Plant Community Type (PCT) New England Rockplate Shrubland (PCT 3854) in the southwestern subpopulation (Hunter 2002; DPE 2022b). In the northeastern subpopulation, *E. boliviana* has been recorded in Northern New England Orange Gum Exposed Woodland (PCT 3711), Mole River Blackbutt Woodland (PCT 3707) and Tenterfield Plateau Stringybark Sheltered Forest (PCT 3507) (Hunter 2002; DPE 2022b, 2022c). However, the species may not be restricted to these PCTs, and it may be found in other PCTs within the area.

Life History

Eucalyptus boliviana has been recorded resprouting after fire (Hunter 2002), and this is likely to be the primary response of the species following major disturbance. Eucalypts such as *E. boliviana*, in which the mallee and stunted forms are derived due to environmental constraints, and a tree form occurs on less shallow soils, employ a combination sprouting strategy when burnt (Nicolle 2006). In combination sprouters, 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). This appears to be the case for *E. boliviana*, which has been observed to coppice from a lignotuber after major fires, and via epicormic shoots in the stems after other disturbances such as drought-induced dieback (G. Phillips pers. obs. October 2020).

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 the specie's requirements, pushing them to their ecological limit (Noble and Diggle 2013). *Eucalyptus boliviana* can develop relatively large lignotubers (G. Phillips pers. obs. October 2020). This may be driven by the soil chemistry of its preferred habitat, with the skeletal soils being very high in sodium and potassium (Bui *et al.* 2017), as well as by the harsh conditions experienced on the rock outcrops. *Eucalyptus boliviana* lignotubers have been postulated to take at least 5 years to develop sufficient tolerance to resprout post-disturbance (T. Soderquist *in litt.* January 2023). This points to lignotuber development in *E. boliviana* being comparable to other lignotuberous species associated with skeletal soils, which can take 7–10 years to develop such tolerance (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). Based on recent observations of post-drought epicormic growth, this also appears to be true for *E. boliviana* with stems smaller than approximately 15 cm diameter not seen to be reshooting epicormically (G. Phillips pers. obs. October 2020). This points to a situation where *E. boliviana* could be driven to increased reliance on lignotuber resprouting in the case of continued events that cause stem death such as heavy drought and severe fire if stems are not afforded sufficient time to grow to a size that can support epicormic reshooting. This phenomenon 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 *Eucalyptus boliviana* is intermittent and rarely observed without disturbance, which is consistent with other eucalypts (Keeley 1995). As with other eucalypts, *E. boliviana,* like other mallee eucalypts, develops a canopy-held seed bank where seeds can be stored for several years, with seed being gradually

released over time or *en masse* following death of a stem or branch (Tozer and Bradstock 1997; G. Phillips pers. obs. October 2020). Once released, seedling establishment and survival in eucalypts is often dependent on soil moisture availability and competition for resources in nutrient poor soils (Wellington and Noble 1985; Auld *et al* 1993; Tozer and Bradstock 1997), with release from competition, increased light levels, and nutrient influxes provided by fire all being thought to bolster recruitment (Etchells *et al.* 2020). Seedling recruitment has been observed in *E. boliviana* after the breaking of the 2017–2020 drought, however, even with the now open canopy and greatly reduced competition from shrubs, this recruitment is still sparse (G. Phillips pers. obs. October 2020; T. Soderquist *in litt.* August 2022). Given this, it is considered that fire may be required to stimulate stronger germination (OEH 2021); however, data or observations are unavailable to confirm this.

Lifespan and generation length

The lifespan of *Eucalyptus boliviana* is estimated to be up to 300 years (DPE 2022a). 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), although lifespans are more commonly in the hundreds of years (Wellington and Noble 1985). Single-stemmed *E. boliviana* plants may therefore have a 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. boliviana* suspected to be at the longer end of this range given the slow observed growth rates (G. Phillips pers. obs. January 2021).

The generation length of *Eucalyptus boliviana*, 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 (Fensham *et al.* 2020). Using a maximum lifespan of 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. boliviana* is estimated at approximately 104 years.

Reproductive and Seed Ecology

Eucalyptus boliviana flowers primarily in September, although flowers have been observed in other months (Williams and Hill 2001; OEH 2021). 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 rock outcrop eucalypts with relatively large flowers have been shown to be primarily insect-pollinated (Peters *et al.* 1990). This is a common interaction in eucalypts (Byrne *et al.* 2008; Jones *et al.* 2008), though many other species are predominantly bird-pollinated, especially by honeyeaters (Breed *et al.* 2015). Given both insects and birds, including honeyeaters, have been observed visiting flowering trees (T. Soderquist *in litt.* January 2023), it is possible that *E. boliviana* is pollinated by both agents. Therefore, regular local pollen dispersal is highly likely at least between proximate stands, with occasional long-distance pollen dispersal between subpopulations possible. This in line with other low-growing eucalypts with similarly sized large flowers (Breed *et al.* 2015) and is supported by

indications of genetic differentiation between the northeast and southwest subpopulations following gas chromatography studies (Collins 2017).

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 habit of a low, stunted tree typical of *Eucalyptus boliviana*, seed dispersal is likely restricted to the area immediately around parent plants. While occasional strong winds may promote further dispersal, this is likely minimal in most instances given the large areas of unvegetated granite slabs immediately adjacent. However, rain may move seed into other pockets of suitable habitat. 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 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).

Very few eucalypts maintain seed dormancies aside from a number of montane species (Close and Wilson 2002, Booth 2017). This is true for *Eucalyptus boliviana*, with germination trials indicating the species does not possess any seed dormancies and freely germinates upon release from the capsule (RBGDT 2022).

Threats

The NSW Scientific Committee (2002) stated that due to its restricted distribution and small total population size, *Eucalyptus boliviana* was threatened by stochastic events. This has proven to be the case, with increased drought impacts and adverse fire regimes currently considered to be the main causes of decline in the population. Minor, localised threats of note are browsing of seedlings by herbivores and clearing for the construction and maintenance of fences and fire trails (J. Hunter *in litt.* July 2022; T. Soderquist pers. comm. August 2022; *in litt.* December 2022).

Increased frequency and duration of drought due to climate change
Increasing frequency and duration of drought is contributing to observed continuing decline in the *Eucalyptus boliviana* population and is strongly inferred to continue into the future. Prior to the 2017–2020 drought, the total population of *E. boliviana* was estimated to be 1,500–2,000 mature individuals, with approximately 1,000 trees in the single stand in the northeast subpopulation and 500–1,000 trees spread across four discrete stands in the southwest subpopulation (T. Soderquist *in litt.* December 2022). During the drought, the number of mature individuals declined by approximately 15% across both subpopulations, with individual stands recording between 10–20% mortality (T. Soderquist *in litt.* December 2022). While there has been recruitment and reshooting in larger stems following the drought, which may maintain some stands (T. Soderquist *in litt.* December 2022), many stands still predominantly consist of very unhealthy, highly senescent trees, and mortality of established individuals is continuing (G. Phillips pers. obs. October 2020, January 2021; Hunter 2022; T. Soderquist *in litt.* August 2022). Seedling recruitment in the northeastern stand and some of the southwestern stands continues slowly and may maintain numbers in the longer-term in those stands (T. Soderquist *in litt.* December 2022). However, some of the westernmost stands in the southwest subpopulation have very little recruitment

and high levels of senescence still and population augmentation may be required to ensure their survival in coming years (G. Phillips pers. obs. October 2020, January 2021; T. Soderquist *in litt.* December 2022). Recovery may also be hampered in these stands by the regularly observed browsing of seedling foliage by feral goats and native macropods, potentially limiting the replacement rates of senescent trees (T. Soderquist *in litt.* December 2022).

Drought is likely to increase in frequency and magnitude in the future due to widely accepted projections of increased air temperatures, representing an ongoing threat to *E. boliviana* (Reichstein *et al.* 2013; Trenberth *et al.* 2013). While predicting the effects of future droughts and how they affect individual species is difficult (Cook *et al.* 2018; De Kauwe *et al.* 2020), the observed drought-induced mortality in *E. boliviana* highlights that drought has an adverse effect on the species. This is in line with increasing reports of severe drought affecting other forest and woodland eucalypts in eastern Australia, especially when coupled with heatwave conditions (Fensham *et al.* 2009; Allen *et al.* 2015; De Kauwe *et al.* 2020). As such, it can be strongly inferred that future mortality-inducing events due to prolonged and severe drought in *E. boliviana* are likely to become more common.

Under future climate scenarios, the New England region is predicted to become hotter, have fewer colder nights under 2 °C annually, and more hot days over 35 °C annually by 2079 (AdaptNSW 2022). Furthermore, under the predicted 2–3 °C warming predicted for Bolivia Hill by 2079 (AdaptNSW 2022), *E. boliviana* is expected to exist completely outside of its current climatic envelope (Gonzalez-Orozco *et al.* 2016). Given the apparent natural restriction to the sodium rich soils of the Bolivia Hill Leucomonzogranite (Bui *et al.* 2017), these factors are highly likely to make *E. boliviana* even more susceptible to drought episodes and may accelerate mortality such as that observed during and after the 2017–2020 drought. 'Anthropogenic Climate Change' is listed as a Key Threatening Process under the *NSW Biodiversity Conservation Act 2016.*

Adverse fire regimes

Adverse fire regimes may cause decline in the population of *Eucalyptus boliviana* if severe fire were to affect the population more frequently into the future. Currently, Bolivia Hill has a very infrequent fire regime, with fires impacting the *E. boliviana* stands recorded in 1964/65 (fuel reduction burn), the mid-1970s (fuel reduction burn) and October 2002 (arson ignited wildfire) (Morsley and Falconer 1999; NPWS 2022). Sporadic, localised wildfires have also occurred elsewhere in the reserve approximately once every five years (NPWS 2022). The only large-scale fires recorded across Bolivia Hill are the 1964/65 and 2002 fires (NPWS 2011). Thus, *E. boliviana* has not historically been placed under pressure from frequent fires of any intensity.

Higher intensity wildfire can alter stand structure and understorey species competition, as well as increase mortality of dominant eucalypts (Etchells *et al.* 2020). Such increases in mortality in a combination resprouter species like *Eucalyptus boliviana* 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). Given the current state of senescence and poor health in many *E.*

boliviana stands (G. Phillips pers. obs. October 2020, January 2021; Hunter 2022; T. Soderquist *in litt.* December 2022), and the fact that a single intense wildfire event could affect the entire population, it is plausible that increased severe wildfire could result in ever higher mortality rates in mature plants with an already compromised ability to coppice (T. Soderquist *in litt.* December 2022), driving the stands to extinction. '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.*

Adverse fire regimes may also impact the population of *Eucalyptus boliviana* if fire is kept out of the landscape for too long by reducing recruitment events that may replenish senescent stands. Like other eucalypts, *E. boliviana* seeds are held within the canopy until release upon death of the supporting branch, typically after fire. 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, the current fire history of Bolivia Hill, and the observed senescence in most stands, it is thought that regular lower intensity fire may be required to stimulate stronger germination to more fully regenerate stands (OEH 2021).

Browsing by herbivores

Browsing by herbivores, in particular feral goats (*Capra hircus*) which are commonly seen on Bolivia Hill, and native macropods such as Wallaroos (*Osphranter robustus*), can completely defoliate seedlings, with both planted and natural seedlings having been observed to suffer such defoliation (T. Soderquist pers. comm. August 2022, *in litt.* December 2022). This browsing appears to be amplified during drought as other food sources become scarcer (T. Soderquist pers. comm. August 2022), which could further exacerbate existing drought-induced losses. Goats can rapidly degrade vegetation communities through over-grazing and erosion of soils (DPE 2021), especially during drought. Additionally, while macropod browsing may be considered a natural process, populations of larger macropod species can be artificially inflated in remnant bushland and conservation reserves due to surrounding agricultural land use, leading to increased browsing pressure (NPWS 2002). 'Competition and habitat degradation by feral goats (*Caprus hircus*)' is listed as a key threatening process under the NSW *Biodiversity and Conservation Act 2016*.

Construction and maintenance of infrastructure

The construction and maintenance of fences and fire trails has caused the loss of *Eucalyptus boliviana* trees in the past. Prior to reservation, a fire trail and fence line were cut through the northeast subpopulation of *E. boliviana*, resulting in the loss of tens of trees (T. Soderquist *in litt.* December 2022). There is anecdotal evidence suggesting that approximately 20% of the original population may have been historically cleared for agricultural development (Fensham *et al.* 2019). However, this is disputed given the rocky habitat required by the species remains largely uncleared on the adjoining freehold land and no large-scale clearing for development has ever been undertaken among the stands in Bolivia Hill Nature Reserve (T. Soderquist *in litt.* December 2022). Therefore, clearing is regarded as a minor threat, though the potential for future clearing remains given ~25% of the population occurs on freehold land with no conservation protection (T. Soderquist pers. comm. August 2022).

'Clearing of native vegetation' is listed as a key threatening process under the NSW *Biodiversity Conservation Act 2016.*

Assessment against IUCN Red List criteria

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

Criterion A *Population size reduction*

Assessment Outcome: Data deficient

Justification: *Eucalyptus boliviana* has suffered some loss of individuals due to the effect of increased frequency and duration of drought due to climate change and clearing associated with fence and track construction in the past three generations (312 years). However, these population reductions are only recent, and full time series data is lacking to properly assess *E. boliviana* under Criterion A. Historically, some small stands of *E. boliviana* identified by botanists no longer appear to be extant, having not been relocated for over two decades (OEH 2021; T. Soderquist *in litt.* December 2022). More recently during and after the 2017–2020 drought, a population reduction of approximately 15% of mature individuals has been observed (T. Soderquist *in litt.* December 2022). Mortality of senescent mature individuals is continuing since 2020 with some stands remaining in ill health and failing to reshoot (G. Phillips pers. obs. October 2020, January 2021; Hunter 2022; T. Soderquist *in litt.* August 2022). Future losses are also likely but are difficult to quantify as observed seedling recruitment may stabilise numbers in some stands (T. Soderquist *in litt.* December 2022). Given the most serious threat of increased frequency and duration of drought due to climate change is unlikely to abate given future climate scenarios for the New England region (AdaptNSW 2022), and recruitment is generally sparse, an effectively irreversible population reduction of at least 15% where the causes of reduction have not ceased is confirmed to have occurred in *E. boliviana* since 2017. While this reduction does not meet the Vulnerable threshold of 30%, population trends are unknown prior to 1998, and while future reductions remain likely, they of unknown magnitude across a three-generation timeframe of 312 years. This means that assessment under Criterion A cannot be undertaken at this time.

Criterion B *Geographic range*

Assessment Outcome: Critically Endangered under Criterion B1ab(iii, v).

Justification: *Eucalyptus boliviana* is endemic to a small area of the Bolivia Range on the NSW Northern Tablelands and has a very highly restricted geographic distribution. The Area of Occupancy (AOO) has been calculated as 16 km^2, meeting the threshold for listing as Endangered. The Extent of Occurrence (EOO) has been calculated as 3.3 km^2; however, where EOO is less than or equal to AOO then IUCN guidelines recommend EOO estimates be changed to be equal to AOO to ensure consistency with the definition of AOO as an area that fits within EOO (IUCN 2022). Therefore, EOO is also calculated as 16 km^2, meeting the threshold for listing as Critically 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 Critically Endangered due to having one threat-defined location.

Justification: *Eucalyptus boliviana* is found at one threat-defined location when considering the most serious plausible threat of increased frequency and duration of drought due to climate change.

Eucalyptus boliviana is not considered severely fragmented as all individuals are found in large, non-isolated subpopulations and these 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 observed, inferred and projected for (iii) area, extent and/or quality of habitat and (v) number of mature individuals.

Justification: Decline has been observed and is strongly inferred to continue in the area, extent and quality of habitat and number of mature individuals of *Eucalyptus boliviana* due to the combined effects of increased frequency and duration of drought due to climate change, together with adverse fire regimes. Historically, some small stands of *E. boliviana* identified by botanists no longer appear to be extant, having not been relocated for over two decades (OEH 2021; T. Soderquist *in litt.* December 2022). Additionally, during and following the 2017–2020 drought, substantial mortality has occurred in the *E. boliviana* population, with the number of mature individuals estimated to have declined by approximately 15% (T. Soderquist *in litt.* December 2022). While limited seedling recruitment observed in some stands may sustain and stabilise numbers in those stands, recruitment in other stands is very limited (T. Soderquist *in litt.* August 2022, December 2022). Additionally, the overall health of mature trees remains poor despite substantial rainfall since 2020, with limited to no reshooting and senescent individuals still in decline (G. Phillips pers. obs. October 2020, January 2021; Hunter 2022; T. Soderquist *in litt.* August 2022, December 2022). Under projected future climate conditions for the region, drought is expected to increase in frequency and duration (Reichstein *et al.* 2013; Trenberth *et al.* 2013; Allen *et al.* 2015; AdaptNSW 2022). Therefore, it can be reasonably inferred that future drought-induced mortality events in *E. boliviana,* such as that seen in 2017-2020, will become more common, exacerbating observed declines. Adverse fire regimes may also contribute to decline by the elimination of stems capable of resprouting and increased mortality of mature individuals if severe fires were to become more frequent, as seen in other eucalypts (Etchells *et al.* 2020; Zimmer *et al.* 2021). Conversely, too infrequent fire may limit recruitment episodes required to replenish senescent stands (Keeley 1995; OEH 2021). These threats mean that the quality and availability of habitat and number of mature individuals of *E. boliviana* are likely to remain under

pressure, with currently observed declines strongly inferred to continue into the future.

c) Extreme fluctuations.

Assessment Outcome: Not met.

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

Criterion C Small population size and decline

Assessment Outcome: Vulnerable under Criterion C1 and C2a(i)

Justification: The current estimated population for *Eucalyptus boliviana* is 1,275–1,700 mature individuals, meeting the threshold for Endangered.

In addition to this threshold, one of at least two other conditions must be met to qualify for listing under Criterion C. These conditions 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: Met for Vulnerable.

Justification: *Eucalyptus boliviana* is undergoing continuing decline due to the combined effects of increased frequency and duration of drought due to climate change and adverse fire regimes. Historically, smaller stands of *E. boliviana* identified by botanists no longer appear to be extant, having not been relocated for over two decades (OEH 2021; T. Soderquist *in litt.* December 2022). Additionally, a 15% decline of mature individuals has been observed since the start of the 2017-2020 drought (T. Soderquist *in litt.* December 2022). Given these known declines constitute a loss of greater than 10% within three generations (312 years) for the species, and the uncertain nature of the magnitude of any future declines means that further declines are data deficient, the Vulnerable threshold is met.

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

Assessment Outcome: Met for Vulnerable.

Justification: Decline has been observed and is strongly inferred to continue in the number of mature individuals of *Eucalyptus boliviana* due to the combined effects of increased frequency and duration of drought due to climate change, and adverse fire regimes, 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: Met for Vulnerable.

Justification: The population of *Eucalyptus boliviana* consists of two subpopulations with maximum pre-drought numbers estimated to be approximately 1,000 and 500–1000, respectively (T. Soderquist *in litt.* December 2022). Given drought-induced losses of approximately 15% since 2017 in both subpopulations, this means that both now have between 425 and 750 individuals (T. Soderquist *in litt.* December 2022), meeting the threshold for Vulnerable.

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

Assessment Outcome: Not met.

Justification: The population of *Eucalyptus boliviana* consists of two subpopulations with the largest currently estimated to contain 50-60% of known mature individuals (T. Soderquist *in litt.* December 2022).

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Not met.

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

Criterion D Very small or restricted population

Assessment Outcome: Criterion D2 is met for Vulnerable.

Justification: *Eucalyptus boliviana* is currently estimated to have a population of 1,250–1,700 mature individuals, with numbers unlikely to be below 1,000 based on recent survey data (T. Soderquist *in litt.* December 2022). Additionally, despite having a restricted AOO and only one location, it is subject to ongoing threats and continuing decline and therefore cannot be assessed under D2.

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 boliviana* is currently estimated to have a population of 1,250–1,700 mature individuals, with numbers unlikely to be below 1,000 based on recent survey data (T. Soderquist *in litt.* December 2022).

D2. Population with a very restricted area of occupancy (typically less than 20 km^2) or number of locations (typically five or fewer) such that it is prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and is thus capable of becoming CR or even EX in a very short time period.

Assessment Outcome: Criterion D2 is met for Vulnerable.

Justification: *Eucalyptus boliviana* has an estimated AOO of 16 km^2 and only occurs at a single threat-defined location. The combined effects of increased frequency and duration of drought due to climate change and adverse fire regimes are both plausible threats that may lead *E. boliviana* to become Critically Endangered or Extinct in a very short time period.

Criterion E Quantitative Analysis

Assessment Outcome: Data deficient.

Justification: Currently there is insufficient data to undertake a quantitative analysis to determine the extinction probability of *Eucalyptus boliviana.*

Conservation and Management Actions

Eucalyptus boliviana 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 boliviana* sits within the site-managed management stream of the SoS program.

Activities to assist this species currently recommended by the SoS program (DPE 2022a) include:

Habitat loss, disturbance and modification

- Ensure 15-year minimum fire return interval to allow for sustainable recruitment.
- Conduct hazard reduction burning to reduce incidences of wildfire entering Bolivia Hill Nature Reserve.
- Ensure fire trail maintenance is undertaken in a manner sensitive to the species.
- Ensure boundary easement maintenance is conducted in order to protect trees.
- Control feral goats in order to allow seedling establishment.

Ex situ conservation

- Identify suitable translocation sites and establish a new viable population to buffer against extinction.
- Collect seed for seedbanking and investigate seed viability, germination and longevity.
- Establish *ex situ* plantings at appropriate botanic gardens.

Survey and monitoring

- Undertake further surveys in suitable habitat.
- In the event of a fire impacting the species, monitor recruitment and adult condition immediately post-fire and at 6-month intervals thereafter.
- Conduct census of stands, using quadrats to assess stand density, condition and recruitment.

Information and stakeholder liaison

- Liaise with neighbours to protect trees in properties adjacent to Bolivia Hill Nature Reserve.

- Notify appropriate agencies of roadside, rail and powerline easement locations for protection during maintenance activities.

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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: Critically Endangered under Clause 4.3 (a) (d) (e i, iii).

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: Critically Endangered under Clause 4.3 (a) (d) (e i,iii)

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: Vulnerable under Clause 4.4 (c) (d iii) (e i,ii (A)(III)) .

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: 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.