Conservation Assessment of *Boronia boliviensis* J.B.Williams & J.T.Hunter (Rutaceae)

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***Boronia boliviensis* J.B.Williams & J.T.Hunter (Rutaceae)**
Distribution: Endemic to NSW
Current EPBC Act Status: Not listed
Current NSW BC Act Status: Endangered
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

Boronia boliviensis was found to be eligible for listing as Critically Endangered under Criterion B1ab(iii,v).

The main reasons for this species being eligible for listing are (i) *Boronia boliviensis* has a highly restricted Extent of Occurrence (EOO) of 12 km^2; (ii) *B. boliviensis* 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/or quality of habitat and number of mature individuals due to the combined effects of increased frequency and duration of drought due to climate change, adverse fire regimes and browsing by feral goats.

Description and Taxonomy

Boronia boliviensis (Bolivia Hill Boronia) is a conventionally accepted species (CHAH 2008) within *Boronia* section *Valvatae* series *Erianthae* (Duretto and Ladiges 1999). It is described by Williams and Hunter (2006) as a "Much-branched shrub to 1.5 (–2.2) m tall, odoriferous; branchlets with a dense covering of very short, sessile, multi-angular yellowish stellate hairs, becoming glabrous with age. Leaves pinnate with mostly 7–11 leaflets, rarely with 1–5 leaflets on some leaves (especially on flowering branchlets); rachis 2–12 (–20) mm long, jointed, 8–15 mm wide, narrowly winged, rachis wings flat or recurved; leaflets narrow-elliptic, sessile, 3.8–9 mm long, 0.5–1.5 mm wide, apex acute to sub-obtuse, broadest above the middle, margins entire and closely revolute, rarely only recurved, upper surface deep green with a sparse indumentum of stellate hairs or ± glabrous, the surface and margin dotted with large, sunken oil glands, lower surface often hidden by revolute margins but when visible markedly paler, usually glabrous; petiole 1–3 mm long. Inflorescences axillary, 1–3-flowered; prophylls unifoliate; peduncle 1.5–2 mm long; pedicels 2–3 mm long. Calyx lobes deep red, narrow-deltate, acute or acuminate, 2.5–3.8 mm long, 1–2 mm wide, shortly stellate hairy abaxially. Petals pink, 4–9 mm long, 3–4 mm wide, valvate in bud, very shortly stellate-tomentose abaxially, glabrous or almost so with fine simple hairs

adaxially, persistent in fruit. Filaments 1–2 mm long, glandular to tuberculate; anther with erect apiculum. Style glabrous or sparsely hairy. Fruit with cocci glabrous, 4–5 mm long, 2–3 mm wide. Seed 3–4 mm long, 1–2 mm wide."

Boronia boliviensis has also been known as *Boronia* sp. J (Bolivia Hill) (Quinn *et al.* 1995), *Boronia* aff. *granitica* (Duretto and Ladiges 1999), *Boronia* aff. *granitica* (Bolivia Hill) (Duretto 1999) and *Boronia boliviensis* J.B.Williams ms. (Williams 89556) (Weston and Duretto 2002). It is closely related to *Boronia granitica* and *Boronia ruppii* within *Boronia* section *Valvatae* series *Erianthae* (Duretto and Ladiges 1999), which both also occur on the New South Wales (NSW) New England Tablelands but do not co-occur with *B. boliviensis*. *Boronia boliviensis* is distinguished from both these species by its lack of long, slender multi-angular stellate hairs on the branchlets and leaves, and the deltate red sepals (Williams and Hunter 2006).

Distribution and Abundance

Boronia boliviensis is an uncommon species endemic to the Bolivia 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; NSW NPWS 2011).

Boronia boliviensis is restricted to the higher parts of the Bolivia Range, especially around granite outcrops at 900–1200 m elevation around the floristically diverse Bolivia Hill (Williams and Hunter 2006). The species was first recorded by botanist John Williams in 1989 when Bolivia Hill was under a Crown Lands grazing lease (Williams and Hunter 2006; NSW NPWS 2011) and is still only known from this area which is now entirely within Bolivia Hill Nature Reserve. This National Parks and Wildlife Service (NPWS) managed reserve, which includes the lands of the former Crown lease, was gazetted in 2000 due to the presence of *B. boliviensis* and high concentrations of other rare endemic plant species that also occur there (NSW NPWS 2011).

Early surveys of *Boronia boliviensis* noted a restricted distribution of up to 1,000 mature plants across an area of 90 ha (Quinn *et al.* 1995; Morsley and Falconer 1999). Further surveys have increased the known distribution and abundance across Bolivia Hill. The population of *Boronia boliviensis* is currently known to consist of approximately 14 discrete patches across a 5 km stretch of the Bolivia Range (T. Soderquist pers. comm. August 2022). The patches are not continuous and are often separated by areas of largely unvegetated granite slabs 200–750 m across (Morsley and Falconer 1999). A single patch, previously the largest known, is further distant, being some 3–4 km to the northeast of all other patches. Studies on other *Boronia* species have shown patches separated by such distances are often genetically distinct, with limited gene flow of less than one migrant per generation (Shapcott *et al.* 2005). Given this, the population of *B. boliviensis* is regarded as consisting of two subpopulations, with the disjunct northeast patch separate to all others in the southwest of the reserve.

Typically, patches of *Boronia boliviensis* occur at high densities, with patches as small as 400 m^2 capable of harbouring tens to hundreds of plants (Morsley and Falconer 1999; Hunter 2022). Prior to the drought of 2017-2019, the total population was

conservatively estimated to be a minimum of 8,000 mature individuals across all known patches, with the two largest patches having estimated numbers of 1,200 and 5,000 plants (T. Soderquist pers. comm. September 2022). The remaining 1,800 plants were distributed across several smaller patches of various sizes with some as small as 10 scattered plants found in more restricted soil pockets on the more exposed, open granite slabs (Hunter 2022, RBGDT 2022a).

The population of *Boronia boliviensis* appears to have long-term fluctuations in number and structure (J. Hunter *in litt.* July 2022). Episodic recruitment events which occur in seasons of increased rainfall or other climatic triggers, with little recruitment in between, are not unusual in species such as *Boronia boliviensis* (J. Hunter *in litt.* July 2022). The growth cycle of *B. boliviensis* also appears to be punctuated by sharp declines through disturbance and drought, such as that seen in 2017-2019 (J. Hunter *in litt.* July 2022; T. Soderquist pers. comm. August 2022), so estimating numbers of mature individuals in the population is difficult over time.

Despite predictions of significant seedling recruitment of *Boronia boliviensis* in the wet years of 2021 and 2022, current monitoring indicates that recruitment since 2020 has been extremely varied among the known patches. Minimal seedling recruitment has so far been observed in one of the two largest patches (T. Soderquist pers. comm. August 2022) with others showing high seedling mortality following a season of strong growth (T. Soderquist *in litt.* October 2022). However, a few smaller patches and the large northeast patch are showing significant levels of seedling growth and maturation over the same time, which should at least maintain numbers in those patches (Hunter 2022; T. Soderquist pers. comm. September 2022; *in litt.* December 2022). Given this, the population of *B. boliviensis* in this assessment is regarded as a minimum of 6,800 plants, almost all within the smaller patches within the southwest subpopulation and the large patch in the northeast subpopulation where successful recent recruitment has been recorded. A maximum figure is difficult to estimate given the vast difference in recruitment levels between the stands and lack of evidence that one of the largest stands will recover to pre-drought numbers (T. Soderquist *in litt.* August 2022, December 2022).

Area of Occupancy and Extent of Occurrence

The Area of Occupancy (AOO) of *Boronia boliviensis* was calculated using 2 x 2 km grid cells, the scale recommended by IUCN (2022) and was estimated to be 12 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 4.8 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 *B. boliviensis* is also estimated to be 12 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, *B. boliviensis* 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 *Boronia boliviensis* can be considered a single threat-defined location, as per the IUCN definition (IUCN 2022), given drought effects are likely to be consistent across the species' highly restricted range.

Ecology

Habitat

Boronia boliviensis predominantly grows in low shrublands and heaths around granite outcrops between 900–1200 m elevation on a granitic intrusion known as the Bolivia Hill leucomonzogranite (Morsley and Falconer 1999; Geoscience Australia 2022). The hill receives an average of 800–900 mm of rainfall annually (Williams and Hunter 2006). Patches commonly occur in shallow accumulations of course, sandy soils in erosional fissures and depressions among these outcrops, and on the edge of expansive granite sheeting, often in open, southeast to southwest aspects with low tree cover (Quinn *et al.* 1995; Morsley and Falconer 1999; RBGDT 2022a). It appears that the ecological niche occupied by *B. boliviensis* is characterised by soil depth, soil moisture and light levels, with mature plants tending to be found in areas near to outcrops with greater soil depths, higher levels of leaf litter, persistent drainage and partial shade (Morsley and Falconer 1999).

Boronia boliviensis commonly co-occurs with *Leucopogon neoanglicus* and *Micromyrtus sessilis* in pockets of heath among the granite slabs, but is also associated with *Boronia anethifolia, Brachyloma saxicola, Kunzea bracteolata, Leptospermum novae-angliae, L. brevipes, Melichrus urceolatus* and *Cryptandra lanosiflora* on the outcrops (Williams and Hunter 2006). When it occurs within adjacent low forest and woodland surrounding the granite slabs, it is commonly associated with *Acacia adunca, Callitris endlicheri, Eucalyptus andrewsii, E. prava and E. youmanii* (Williams and Hunter 2006). Other threatened species listed on the NSW *Biodiversity Conservation Act 2016* also associate with *B. boliviensis*, with *A. pycnostachya* (Vulnerable) commonly co-occurring and *E. boliviana* (Vulnerable) and *Homoranthus croftianus* (Endangered) co-occurring in specific patches (Hunter 2022; RBGDT 2022a). The occurrence of both *A. adunca* and *A. pycnostachya* together are regarded as reliable indicator for the presence of *B. boliviensis* (Morsley and Falconer 1999).

Based on Plant Community Type (PCT) mapping, *Boronia boliviensis* is most commonly found in New England Rockplate Shrubland (PCT 3854) with occasional occurrences in Tenterfield Plateau Stringybark Sheltered Forest (PCT 3507) (DPE 2022).

Life History

Boronia are typically either obligate seeding or facultative seeding species in response to major disturbances such as fire (NSW NPWS 2002). Despite a lack of fire response observations to date (T. Soderquist *in litt.* August 2022), *Boronia boliviensis* is currently considered an obligate seeding species as it appears to recruit primarily in flushes of seedlings when environmental conditions suit (J. Hunter *in litt.* July 2022). Some resprouting has been observed in heavily browsed plants in the past (Morsley and

Falconer 1999; T. Soderquist *in litt.* August 2022). However, this response is unlikely to be the primary regenerative strategy as is seen in other related species such as *B. rivularis*, which only resprouts after small, low-severity fires but relies on seedling recruitment for population maintenance following major disturbance events (Shapcott *et al.* 2005).

The primary juvenile period of *Boronia boliviensis* is currently unknown. *Boronia granitica*, an obligate seeding species and the closest phylogenetic relative to *B. boliviensis,* is reported to have a primary juvenile period of 3–4 years (NSW NPWS 2002), however more recent observations indicate it can be as short as two years when conditions are conducive to strong growth and flower/fruit production (G. Phillips pers. obs. November 2021). Flowering has also been observed to take place on *B. boliviensis* plants only 50 cm in height (Morsley and Falconer 1999), which would equate to at least 2–3 years of age when compared to observed growth rates in *B. granitica* (G. Phillips pers. obs. April 2021, November 2021). Given this, a primary juvenile period of approximately three years is reasonably inferred for *B. boliviensis*.

The lifespan of *Boronia boliviensis* is unknown, though generation length can be estimated using two methods. It has been postulated that *B. boliviensis* has a lifespan of greater than 15 years, but growth rates and survivorship have not been studied to confirm this inference (Morsley and Falconer 1999). *Boronia keysii*, another rare species in section *Valvatae*, has a lifespan of 15–30 years and a period from reproductive maturity to senescence of approximately 15 years (Burgman *et al.* 2001), so *B. boliviensis* can be inferred to have a similar lifespan and reproductive period. Given this data, generation length can be estimated using the age of first reproduction + *z* * length of reproductive period (IUCN 2022), where *z* is a constant between 0 and 1 calculated using survivorship and the relationship between fecundity and age. Using the above estimate of reproductive period of 15 years, a value for *z* of 0.21 comparable to other woody shrub species (Fung and Waples 2017) and an age of first reproduction of three years as estimated above, the generation length of *B. boliviensis* is therefore estimated to be approximately six to seven years. Alternatively, generation length can also be estimated using the seedbank half-life added to the primary juvenile period (IUCN 2022). If a seedbank half-life of approximately four to five years is used in line with that known for related Rutaceae taxa (Auld *et al.* 2000), then generation length is estimated to be approximately seven to eight years. Given these estimates, a generation length of approximately seven years is assumed for *B. boliviensis* in this assessment.

Reproductive Ecology

Boronia boliviensis flowers mostly in spring from September to November but has also been recorded flowering in May, August and December (Williams and Hunter 2006). It is likely that *B. boliviensis* can flower sporadically year-round, with a peak in spring that may be extended by suitable environmental conditions (Morsley and Falconer 1999).

Pollination in *Boronia boliviensis* has not been studied, however all other species in *Boronia* section *Valvatae* are known to be self-incompatible, requiring outcrossing for successful pollination to occur (Weston *et al.* 1984). Potential pollinators recorded interacting with *Boronia* include sawflies, beetles, flies, moths, butterflies and at least

12 genera of bee, which appear to be the most common pollinators across multiple *Boronia* species (Armstrong 1979).

Seed ecology

Sclerophyllous *Boronia* species typically employ ballistic release of seeds for initial dispersal (Auld 2001). Seeds are then further dispersed by ants (myrmecochory), a common trait in species found on infertile soils such as the granite-derived substrates on Bolivia Hill (Westoby *et al.* 1990). Ants are attracted to *B. boliviensis* seeds due to the presence of a prominent lipid-rich elaiosome (Morsley and Falconer 1999). Seedlings have been recorded further than 20 m from the nearest mature plants, much further than ballistic release alone can achieve, implying ant dispersal (Morsley and Falconer 1999). *Boronia boliviensis* seeds have also been found buried at up to 15 cm depth in excavated ant nests, with *Aphaenogaster longiceps* and *Rhytidoponera nodifera*, species both known to undertake seed movement, collected and identified at Bolivia Hill (Morsley and Falconer 1999). The caching of seeds underground by ants may also reduce seed predation and contribute to dormancy breaking, germination, and seedling emergence depending on the depth of burial, and provide buffering against the effects of disturbances such as fire which may deplete the soil seedbank (Hughes and Westoby 1992; Auld 2001; NSW NPWS 2002).

Despite commonly having high seed viability rates of over 95%, *Boronia* are considered a difficult genus to germinate as their seeds possess physiological dormancy allowing persistence in the soil seedbank (Auld 2001; Mackenzie *et al.* 2016, Ma *et al.* 2018). This dormancy is overcome by various ecological processes such as heat shock, smoke or the combination of both which then allows the now non-dormant seed to await advantageous environmental cues to stimulate germination (Mackenzie *et al.* 2016, Ma *et al.* 2018). Studies have shown that the application of gibberellic acid and smoke water enhances the germination rate of *Boronia boliviensis* as opposed to the application of gibberellic acid alone (Martyn *et al.* 2009; RBGDT 2022b). However, a considerable portion of *in situ B. boliviensis* seeds appear to be able to germinate and maintain mature stand numbers in the absence of fire, with reasonable germination observed up to 20 years post-fire on several occasions (Morsley and Falconer 1999; J. Hunter *in litt.* July 2022; T. Soderquist pers. comm. September 2022). This may indicate that a substantial proportion of the soil seed bank lacks a deeper dormancy that requires breaking by fire and that stand maintenance is not strictly dependent on fire cycles but other environmental stimuli for the majority of recruitment.

Threats

The NSW Scientific Committee (2000) stated that threats to *Boronia boliviensis* include "browsing by goats and power line maintenance activities." It has become apparent in recent years that the impacts of increased frequency and duration of drought due to climate change and adverse fire regimes are also relevant threats to *B. boliviensis* (J. Hunter *in litt.* July 2022; T. Soderquist *in litt.* August 2022). Browsing by feral goats and native macropods also continues to be problematic (J. Hunter *in litt.* July 2022; T. Soderquist *in litt.* August 2022).

Increased frequency and duration of drought due to climate change

Increased frequency and duration of drought has contributed to continuing decline in the population of *Boronia boliviensis* and is strongly inferred to do so into the future. Prior to the 2017-2019 drought there were at least 8,000 mature individuals in the population, including two large patches consisting of approximately 1,200 and 5,000 mature individuals (T. Soderquist pers. comm. September 2022). Post drought, surveys have recorded reasonable recovery of individuals in the smaller patches and the large northeast patch, with recruitment at least expected to maintain pre-drought numbers in these patches (Hunter 2022, T. Soderquist *in litt.* December 2022). However, there has been little to no recruitment in the second largest known patch, with this patch reduced from 1,200 to only 5–10 plants as of December 2022 (T. Soderquist *in litt.* August 2022, December 2022). As a result, the population during the 2017-2019 drought has reduced from a minimum of 8,000 mature individuals to a current estimated minimum of 6,800 mature individuals. Further recruitment to re-establish numbers in these patches may still occur, however such a recovery also depends on management of other threats such as adverse fire regimes and browsing by feral goats and native macropods.

Evidence of substantial mortality of *Boronia boliviensis* in the 2017-2019 drought highlights the ongoing and increasing threat from such events, which are predicted to increase in frequency and severity in the future. While model uncertainty affects our capacity to project future droughts and how they may affect individual species (Cook *et al.* 2018; De Kauwe *et al.* 2020), it is highly likely that future drought impacts will increase in line with widely accepted projections of increased air temperatures for Australia (Reichstein *et al.* 2013; Trenberth *et al.* 2013). Indeed, these projected changes are already becoming more consistent with increased reports of severe drought affecting forest and woodland ecosystems in eastern Australia (Fensham *et al.* 2009; Allen *et al.* 2015; De Kauwe *et al.* 2020). As such, it can be reasonably inferred that future mortality events in *B. boliviensis* due to prolonged and severe drought are likely to become more common.

Under future climate scenarios, the New England region in which *Boronia boliviensis* occurs is projected to become hotter, have fewer colder nights under 2° C annually, and have more hot days over 35° C annually by the year 2079 (AdaptNSW 2022). These shifts may not only exacerbate mortality of *B. boliviensis* in drought conditions, but also increase canopy tree mortality (Fensham *et al.* 2009; Allen *et al.* 2015), which has been extensively recorded on Bolivia Hill since the 2017-2019 drought (J. Hunter *in litt.* July 2022; T. Soderquist pers. comm. August 2022). This canopy death reduces shade cover required for retention of soil moisture in the outcrop-edge niche that *B. boliviensis* occupies and diminishes successful recruitment of seedlings and seedling growth (Morsley and Falconer 1999). This may also reduce recovery potential with each drought episode, amplifying decline. “Anthropogenic Climate Change” is listed as a Key Threatening Process under the Act.

Adverse fire regimes

Adverse fire regimes may cause decline in the population of *Boronia boliviensis,* whose soil seedbank may be depleted prior to replenishment if fire of any intensity were to become more frequent on Bolivia Hill in the future. Currently, Bolivia Hill has

a very infrequent fire regime, with fires impacting the *B. boliviensis* stands recorded in 1964/65 (fuel reduction burn), the mid-1970's (fuel reduction burn) and October 2002 (arson ignited wildfire) (Morsley and Falconer 1999; NSW NPWS 2022). Sporadic, localised wildfires have also occurred elsewhere in the reserve approximately once every five years (NSW NPWS 2022). The only large-scale fires recorded across Bolivia Hill are the 1965 and 2002 fires (NSW NPWS 2011), meaning *B. boliviensis* has not historically been placed under pressure from frequent fires.

More frequent fires may be detrimental to *Boronia bolivensis.* Studies on other rare *Boronia* species in section *Valvatae* with similar life histories to *B. boliviensis* (namely *B. keysii* and *B. rivularis*) have shown that their rarity may be directly related to their obligate-seeding fire response, rendering them much more sensitive to increasing fire frequencies than resprouting congeners (Shapcott *et al.* 2005). Shortened fire intervals have also been shown to reduce obligate-seeding *Boronia* species survival potential, with any frequency under 3–4 years potentially exhausting soil seedbanks and causing localised extinctions (Shapcott *et al.* 2005). "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 Act and "Fire regimes that cause declines in biodiversity" is listed as a Key Threatening Process under the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act).

Adverse fire regimes may also impact the population of *Boronia boliviensis* if the landscape is unburnt for too long, possibly reducing recruitment events to replenish senescent stands. *Boronia boliviensis* seeds appear to not strictly require fire and/or smoke to germinate (Martyn *et al.* 2009, RBGDT 2022b), as supported by observations of seedling recruitment in 1996 (20 years post-fire) (Morsley and Falconer 1999) and in 2021 (19 years post-fire) (Hunter 2022). However, the current lack of post-drought recruitment in some stands may be due to the remaining proportion of seeds in the soil seed bank having higher or more complex dormancy thresholds requiring fire and/or smoke to initiate germination (Auld *et al.* 2000; Liyanage and Ooi 2015), though this remains untested.

Browsing by herbivores

Under favourable conditions, *Boronia boliviensis* appears to not to be preferentially browsed by herbivores (J. Hunter *in litt.* July 2022; T. Soderquist pers. comm. September 2022). The adverse impact of herbivores such as feral goats and native macropods increases significantly in drought as other food decreases and *B. boliviensis* comes under higher grazing pressure, particularly on juvenile plants and seedlings (T. Soderquist pers. comm. August 2022). *Boronia boliviensis* appears to be more palatable than more common co-occurring *Boronia* species, and thus at greater risk once it does come under browsing pressure in drought. Stands of co-occurring *B. anethifolia* appeared to remain non-preferred in the 2017-2019 drought while *B. boliviensis* was comparably heavily impacted as other species were defoliated (G. Phillips pers. obs. October 2020; T. Soderquist pers. comm. September 2022). Heavily browsed, drought affected mature plants also appear to lose the ability to resprout and so recovery post-drought in surviving mature plants is also compromised by increased browsing, conferring competitive advantages to other less palatable species such as

B. anethifolia in the recovery phase (G. Phillips pers. obs. January 2021; T. Soderquist *in litt.* August 2022, pers. comm. September 2022).

Feral goats (*Capra hircus*) are active on Bolivia Hill and have been regularly recorded browsing on *Boronia boliviensis* (Morsley and Falconer 1999; T. Soderquist pers. comm. August 2022). Goats can rapidly degrade vegetation communities through over-grazing and erosion of soils (NSW DPE 2021), especially during droughts. Regular control of feral goats is undertaken in the Bolivia Hill Nature Reserve (NSW NPWS 2011), but if control were to cease, goat browsing will limit recruitment and ongoing stand maintenance, causing decline in the population (T. Soderquist pers. comm. August 2022). Stands that existed in areas grazed by sheep prior to reservation of Bolivia Hill showed that mature plants can be stunted by constant browsing and that seedling recruitment is highly diminished by the presence of the sheep (Morsley and Falconer 1999). It is likely that goat browsing maintains similar pressure on seedling recruitment and so it is inferred that their continued presence is suppressing recruitment and the proportion of seedlings that reach reproductive maturity. This contributes to continuing decline in the habitat and population of *B. boliviensis.* "Competition and habitat degradation by feral goats (*Capra hircus*)" is listed as a Key Threatening Process under the Act and "Competition and land degradation by unmanaged goats" is listed as a Key Threatening Process under the EPBC Act.

Native macropods such as Eastern Grey Kangaroos (*Macropus giganteus*) and Swamp Wallabies (*Wallabia bicolor*) have also been observed browsing on *Boronia boliviensis* (T. Soderquist pers. comm. August 2022), in line with observations of heavy macropod browsing in populations of related *B. granitica* (NSW NPWS 2002). 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 uses, leading to increased browsing pressure (NSW NPWS 2002). Macropod browsing may also be amplified in drought as other more palatable species are defoliated (NSW NPWS 2002; T. Soderquist pers. comm. September 2022), and this may limit post-drought recovery of *B. boliviensis,* along with browsing from feral goats.

Infrastructure maintenance

Part of the population of *Boronia boliviensis* occurs within a 132 kV powerline easement and vegetation management is regularly undertaken (lopping of trees, application of herbicide) to maintain access (NSW NPWS 2011). Power companies have been alerted, and educated about the presence of threatened flora including *B. boliviensis* in these easements in the past (Morsley and Falconer 1999). NPWS also continues to liaise with the power companies to prevent damage to the threatened flora during maintenance activities (NSW NPWS 2011). This threat is therefore considered minor and is not currently contributing to decline, however given approximately 15% of the known pre-drought population occurred within or near the easement (T. Soderquist pers. comm. September 2022), it remains possible that future maintenance work may impact on the species.

Assessment against IUCN Red List criteria

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

Criterion A *Population size reduction*

Assessment Outcome: Criterion not met

Justification: *Boronia boliviensis* has suffered some loss of individuals due to the combined effects of increased frequency and duration of drought due to climate change and browsing by feral goats in the past three generations, however this loss is not significant enough to meet the thresholds for listing under Criterion A. Over the course of the 2017-2019 drought, a population reduction was observed from a minimum of 8,000 mature individuals to a minimum of 6,800 mature individuals in the population within Bolivia Hill Nature Reserve, mostly through direct death from the drought or the result of increased browsing pressure from feral goats as other food sources became scarce (T. Soderquist *in litt.* August 2022, December 2022). Natural recovery in the most heavily affected stands, one of which reduced from approximately 1,200 individuals to 5-10 plants by August 2022, is now considered increasingly unlikely (T. Soderquist *in litt.* August 2022) and 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). Therefore, an effectively irreversible population reduction of at least 15% where the causes of reduction have not ceased has occurred in *B. boliviensis* since 2017, well within the three-generation timeframe of 21 years for the species, but not large enough to meet the threshold of 30% for listing under Criterion A.

Criterion B *Geographic range*

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

Justification: *Boronia boliviensis* 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 12 km^2, meeting the threshold for listing as Endangered. The Extent of Occurrence (EOO) has been calculated as 4.8 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 12 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: Subcriterion met for Critically Endangered due to having one threat-defined location.

   Justification: *Boronia boliviensis* 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.

Boronia boliviensis 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: Subcriterion 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/or quality of habitat and number of mature individuals of *Boronia boliviensis* due to the combined effects of increased frequency and duration of drought due to climate change, adverse fire regimes and browsing by feral goats. Since the 2017-2019 drought, substantial mortality has occurred in the population of *B. boliviensis*, with a previous minimum population of 8,000 mature individuals reducing to approximately 6,800 mature individuals (Hunter 2022; T. Soderquist pers. comm. August 2022; *in litt.* December 2022). While recovery is underway with seedling recruitment in some patches looking to be sufficient to replenish those stands (Hunter 2022, T. Soderquist *in litt.* August 2022, December 2022), recruitment in other stands appears to be much reduced with little recruitment observed in one of the largest stands in recent surveys (T. Soderquist *in litt.* August 2022). Projections of future climate conditions indicate an increased frequency and duration of droughts when they occur in the region (Reichstein *et al.* 2013; Trenberth *et al.* 2013; Allen *et al.* 2015; AdaptNSW 2022). Therefore, it can be reasonably inferred that future mortality events in *B. boliviensis* such as that seen in 2017-2019 will become more common, exacerbating observed declines. Seedling recruitment is also impacted by continuing browsing by feral goats and macropods (Morsley and Falconer 1999; T. Soderquist *in litt.* August 2022) as well as tree canopy death resulting from drought reducing the niche habitat available for seedlings to successfully establish in (Morsley and Falconer 1999; Allen *et al.* 2015, T. Soderquist pers. comm. August 2022). Adverse fire regimes may also contribute to decline by the exhaustion of soil seedbanks if fires become more frequent (Shapcott *et al.* 2005) or conversely by limiting recruitment episodes required to replenish senescent stands if fire is excluded for too long (Auld *et al.* 2000; Shapcott *et al.* 2005). These threats mean that the quality and availability of habitat and number of mature individuals of *B. boliviensis* are likely to remain under pressure and currently observed declines are strongly inferred to continue into the future.

c) Extreme fluctuations.

Assessment Outcome: Subcriterion not met.

Justification: *Boronia boliviensis* appears to be a reasonably long-lived shrub and is unlikely to undergo extreme fluctuations. Sharp fluctuations in the population are expected at times given observed mass recruitment and

mortality events in the past (J. Hunter *in litt.* July 2022, T. Soderquist *in litt.* August 2022). However, stands appear to be maintained over significant periods without such regeneration (Morsley and Falconer 1999; T. Soderquist pers. comm. August 2022) and germination data indicate that these fluctuations are more likely to be part of long-term regeneration cycles (Martyn *et al.* 2009; RBGDT 2022b) and so do not constitute extreme fluctuations as per IUCN (2022).

Criterion C Small population size and decline

Assessment Outcome: Vulnerable under Criterion C1

Justification: The current estimated population for *Boronia boliviensis* is a minimum of 6,800 mature individuals, meeting the threshold for Vulnerable. 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: Subcriterion met for Vulnerable.

Justification: *Boronia boliviensis* is undergoing continuing decline due to the combined effects of increased frequency and duration of drought due to climate change, adverse fire regimes and browsing by feral goats. Since the start of the 2017-2019 drought, an observed decline of 15% of mature individuals has occurred, with the population reducing from a minimum of 8,000 mature individuals to 6,800 individuals (T. Soderquist *in litt.* August 2022, December 2022). Given this constitutes a loss of greater than 10% within three generations (21 years) for the species, the Vulnerable threshold is met.

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

Assessment Outcome: Subcriterion not met.

Justification: Decline has been observed and is strongly inferred to continue in the number of mature individuals of *Boronia boliviensis* due to the combined effects of increased frequency and duration of drought due to climate change, adverse fire regimes and browsing by feral goats and macropods, 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: Subcriterion not met.

Justification: The population of *Boronia boliviensis* consists of two subpopulations with a current minimum of 5,000 mature individuals in the largest currently surveyed (T. Soderquist *in litt.* December 2022).

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

Assessment Outcome: Subcriterion not met.

Justification: The population of *Boronia boliviensis* consists of two subpopulations with one currently estimated to contain between 74% of known mature individuals and the other estimated to contain 26% following surveys since the 2017-2019 drought (T. Soderquist *in litt.* December 2022).

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Subcriterion not met.

Justification: *Boronia boliviensis* appears to be a reasonably long-lived shrub and is unlikely to undergo extreme fluctuations. Sharp fluctuations in the population are expected at times given observed mass recruitment and mortality events in the past (J. Hunter *in litt.* July 2022, T. Soderquist *in litt.* August 2022). However, stands appear to be maintained over significant periods without such regeneration (Morsley and Falconer 1999; T. Soderquist pers. comm. August 2022) and germination data indicate that these fluctuations are more likely to be part of long-term regeneration cycles (Martyn *et al.* 2009; RBGDT 2022b) and so do not constitute extreme fluctuations as per IUCN (2022).

Criterion D Very small or restricted population

Assessment Outcome: Criterion D2 is met for Vulnerable.

Justification: *Boronia boliviensis* is currently estimated to have a minimum population of at least 6,800 mature individuals. However, it also has a very restricted AOO of 12 km^2 and occurs at a single threat-defined location, rendering it prone to the effects of human activities and stochastic events that may rapidly drive the species to extinction in a very short time period.

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: Criterion not met

Justification: *Boronia boliviensis* is currently estimated to have a minimum population of at least 6,800 mature individuals.

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: *Boronia boliviensis* has a very restricted AOO (estimated to be 12 km^2) and only occurs at a single threat-defined location. Repeated drought episodes in combination with grazing pressure from feral goats and the increased likelihood of frequent fires, are likely at this location and are a plausible threat that may lead *B. boliviensis* to become Critically Endangered or even Extinct in a very short time period.

Criterion E Quantitative Analysis
Assessment Outcome: Data deficient.

Justification: Currently there is not enough data to undertake a quantitative analysis to determine the extinction probability of *Boronia boliviensis.*

Conservation and Management Actions

Boronia boliviensis 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. *B. boliviensis* sits within the site-managed management stream of the SoS program.

Activities to assist this species currently recommended by the SoS program (NSW OEH 2014, 2021) include:

Habitat loss, disturbance and modification

- Continue control of feral goats within Bolivia Hill Nature Reserve.
- Protect areas of rocky heathland and shrubby open forest from frequent fire
- Conduct strategic hazard reduction burns adjacent to reserve to reduce likelihood of fire entering Bolivia Hill Nature Reserve.
- Manage fire frequency and intensity so that development and maintenance of a soil seedbank is not inhibited.
- Protect trackside and easement populations during maintenance work.

Ex situ conservation

- Collect seed for incorporation into NSW Seedbank and investigate seed germination, dormancy and longevity.
- Develop an *ex situ* program of cultivating the species as a custodial collection in the event of collapse/loss of subpopulations.

Survey and monitoring

- Identify and map all known populations.
- Monitor efficiency of feral goat control programs.
- Monitor known populations, particularly following fire or other disturbances, to determine viability, threats and response to management.

Information and stakeholder liaison

- Provide landowners and managers with appropriate management guidelines.
- Notify appropriate agencies of roadside, rail and power easement locations for protection during roadside and easement maintenance activities.

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Expert Communications

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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:

Boronia boliviensis was found to be 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: Clause not met.

(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).

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: Clause 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: Clause 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.