Conservation Assessment of *Leionema scopulinum* B.M. Horton & Crayn (Rutaceae)

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NSW Threatened Species Scientific Committee

***Leionema scopulinum* B.M.Horton & Crayn (Rutaceae)**

Distribution: Endemic to NSW
Current EPBC Act Status: Not listed
Current NSW BC Act Status: Not listed

Proposed listing on NSW BC Act and EPBC Act: Endangered

Conservation Advice: *Leionema scopulinum* B.M. Horton & Crayn (Rutaceae)

Summary of Conservation Assessment

Leionema scopulinum was found to be eligible for listing as Endangered under Criteria B1(a)(b v) + B2(a)(b v).

The main reasons for this species being eligible for listing are:

i) it has a highly restricted geographic distribution;

ii) it occurs at two locations; and

iii) there is inferred continuing decline in the number of mature individuals of the species due to susceptibility to drought and fire, which are both becoming more severe and frequent due to the effects of anthropogenic climate change.

Description and Taxonomy

Leionema scopulinum (Rutaceae) was formally described by Horton *et al.* (2004). *Leionema scopulinum* is described by PlantNET (2022) as 'Shrub, inhabiting rocky ledges and clefts. Branchlets angled, stellate-hairy. Lamina 24–65 mm long, 4.5–10.0 mm wide, margins frequently serrulate. Inflorescence erect with 9–32 flowers. Petals valvate, 6.6–8.1 mm long, 1.5–2.0 mm wide, greenish-yellow to yellow. Fruit a schizocarp capsule; cocci 5.5–7.0 mm high, rostrate, the beak 1.5–3.0 mm long.' *Leionema scopulinum* has also been known as *Leionema* sp. 'Nullo Mountain' and *Leionema* sp. Lee Creek (PlantNET 2022).

Leionema scopulinum is similar to *Leionema ralstonii*, *L. sympetalum* and *L. viridiflorum* but can be distinguished from these species by its larger leaves and cocci and erect inflorescence (Horton *et al.* 2004). Of these species, only *L. sympetalum* overlaps in distribution with *L. scopulinum*. *Leionema sympetalum* occupies similar rocky outcrop habitat and replaces *L. scopulinum* in pagoda habitat between the main cluster of *L. scopulinum* occurences in northwest Wollemi National Park and the site southwest of Glen Davis (S. Clarke *in litt*. May 2022). The two species do not co-occur at known sites (NSW Government 2022b; Royal Botanic Gardens NSW 2022). In addition to the morphological differences outlined above, *L. sympetalum* can be distinguished from *L. scopulinum* by its tubular flowers and glabrous branchlets (Horton *et al.* 2004).

Distribution and Abundance

Leionema scopulinum is endemic to New South Wales. The species has a highly restricted geographic distribution, known only from limited areas of pagoda habitat in Wollemi National Park on the Central Tablelands of NSW. The main cluster of *L. scopulinum* localities, reported in 2004, are located in the northwest of Wollemi National Park on rocky ridges of the Lee Creek and Growee River catchment and in the vicinity of Nullo Mountain (Horton *et al.* 2004). Two additional sites were documented in 2012 and 2016, one site ~55 km to the south of the main cluster, on cliffs above the tributary of Canobla Creek southwest of Glen Davis, and the other ~11 km east of the main cluster, around Emu Creek (Royal Botanic Gardens NSW 2022). These are the Traditional Lands of the Wiradjuri, Dharug, Wonnarua and Darkinjung people (Horton 1996). The entire known population is located within Wollemi National Park, which is managed by the NSW National Parks and Wildlife Service as a protected area.

Leionema scopulinum grows in shallow sandy soil on rocky ledges and ridgetops and in clefts among sandstone pagoda formations at 660–900 m above sea level (Horton *et al.* 2004; Royal Botanic Gardens NSW 2022). Due to the nature of its rugged habitat, the localities at which *L. scopulinum* occurs are relatively inaccessible (H. Washington *in litt.* August 2018). However, the majority of potentially suitable habitat in the vicinity of known localities has been visited, and the area of the species distribution is considered well surveyed (H. Washington *in litt.* August 2018; S. Clarke *in litt*. May 2022). Extensive areas of similar pagoda habitat exist between the northern localities and the site southwest of Glen Davis (S. Clarke *in litt*. May 2022). Throughout this area *L. scopulinum* has not been detected and is replaced by *L. sympetalum* (S. Clarke *in litt*. May 2022).

Area of Occupancy and Extent of Occurrence

The area of occupancy (AOO) and extent of occurrence (EOO) of *Leionema scopulinum* were calculated in GeoCAT using all validated occurrence records drawn from the KE EMu and BioNet Atlas databases, managed by the Royal Botanic Gardens, Sydney, and the NSW Department of Planning and Environment, respectively. AOO and EOO were calculated following methods recommended by the IUCN (2022).

The area of occupancy is estimated to be 72 km^2, calculated by overlaying 2 km x 2 km grid cells over occurrence records. *Leionema scopulinum* occupies an estimated EOO of 450 km^2, based on a minimum convex polygon enclosing all validated records. Both AOO and EOO fall within the Endangered geographic range as defined by the IUCN (AOO <500 km^2, EOO <5,000 km^2).

Population estimates

A reliable population estimate is not available for *Leionema scopulinum*. Horton *et al.* (2004) estimated that there were <1,500 plants, including mature individuals and others, in the initial occurrences reported in 2004 (H. Washington *in litt.* July 2022). In addition, >240 plants were recorded at additional sites in 2012 and 2016 (Royal Botanic Gardens NSW 2022).

Substantial reductions in the number of mature individuals were observed during the 2017–19 drought and following the 2019–20 fires (H. Washington *in litt.* August

2018, September 2022; S Clarke *in litt.* May 2022). A ~50% reduction in plant numbers was reported at one site west of Nullo Mountain in 2018, with a second unquantified reduction observed at a separate site northwest of Nunkeri (H. Washington *in litt.* August 2018). Following the 2019–20 fires, 100% mortality was reported at one site on Spring Log Ridge, with *L. scopulinum* reduced to post-fire seedlings at this locality (S Clarke *in litt.* May 2022). Thus, the total population, defined as mature individuals only for the purposes of assessment (IUCN 2022), will remain reduced until post-fire seedlings reach maturity. Time to maturity is inferred to be 5–8 years based on other rock outcrop *Leionema* species that are seed regenerators (Clarke *et al.* 2009). With above average rainfall in 2020–22 (Australian Government Bureau of Meteorology 2022), a higher-than-average proportion of post-fire seedlings may be expected to establish (Bradstock and Myerscough 1981) if fire is excluded for appropriate intervals.

Ecology

Leionema scopulinum is very likely an obligate seed regenerator with fire-cued recruitment from a soil-stored seedbank. This fire response was observed at one site in the Spring Log Ridge area in northwest Wollemi National Park, burnt by medium–extreme severity fire in 2019–20 and visited in August 2021 (NSW Department of Planning and Environment 2020; S. Clarke *in litt.* June–September 2022). At this site all adult plants were killed and strong post-fire recruitment from soil-stored seed was reported (S. Clarke *in litt.* May 2022).

Rocky outcrop habitats typically have high proportions of obligate seed regenerators compared with surrounding habitat (Clarke *et al.* 2009; Hunter 2003). Other *Leionema* species are known to be killed by fire and regenerate from seed, e.g., *L. ambiens*, *L. dentatum* and *L. equestre* (Clarke *et al.* 2009; Davies *et al.* 2021), though others resprout after fire, e.g., *L. carruthersii* (NSW National Parks and Wildlife Service 2003). In addition to fire-cued germination, *L. equestre* also germinates following soil disturbance and, in laboratory studies, in response to smoke in combination with other treatments (Davies *et al.* 2021; Botanic Gardens of South Australia 2022). A lack of recruitment was noted for *L. scopulinum* during the 2017–19 drought (H. Washington *in litt.* August 2018). The longevity of *Leionema scopulinum* plants and their seedbank are unknown. A related species *L. ralstonii*, is reported to be relatively long-lived (NSW National Parks and Wildlife Service 2003).

Leionema scopulinum sites are discrete, scattered on ridges and pagoda formations of rocky outcrops (H. Washington *in litt.* July 2022). Rocky outcrops generally have shallow soil overlaying bedrock (Benwell 2007). With limited capacity for water storage, soil moisture is largely dependent on recent rainfall and temperature and can fluctuate widely (Benwell 2007).

Leionema scopulinum has green-yellow flowers, recorded April–September, and fruits, which mature in December (Horton *et al.* 2004). It is not known whether the flowers and fruits attract birds or other species (H. Washington *in litt.* August 2018). Various interactions are reported for other *Leionema* species, including ballistic seed dispersal, seed dispersal by ants, and bird pollination (Auld 2001). In the absence of seed dispersal between outcrops, each *L. scopulinum* site would be isolated, and the population fragmented, with minimal capacity to (re)colonise unoccupied habitat (H. Washington *in litt.* July 2022).

Leionema scopulinum is commonly 1.5 m in height (range 0.5–3 m) (Horton *et al.* 2004). The species grows in heath under a sparse overstory characterised by *Eucalyptus oreades* and *E. sparsifolia* (Horton *et al.* 2004). Common co-occurring species include *Acacia obtusifolia*, *A. terminalis*, *A. ulicifolia, Allocasuarina distyla*, *Amperea xiphoclada*, *Boronia anemonifolia*, *B. angustisepala*, *Callitris endlicheri, Calytrix tetragona*, *Caustis pentandra*, *Coopernookia barbata*, *Dampiera adpressa, Dillwynia retorta, Eucalyptus rossii, Epacris reclinata, Exocarpos cupressiformis, Goodenia decurrens, Hibbertia monogyna, Isopogon anemonifolius, Leptospermum arachnoides, L. parvifolium, L. sphaerocarpum, Leucopogon muticus, L. setiger, Logania albiflora, Monotoca scoparia, Ochrosperma oligomerum, Persoonia linearis, Phebalium squamulosum* subsp. *gracile, Philotheca salsolifolia* subsp. *salsolifolia,* and *Pseudanthus pimeleoides* (Horton *et al.* 2004).

Threats

Adverse fire regime

As a fire-sensitive species, *Leionema scopulinum* is vulnerable to recurrent short-interval fires. Successive fires exceeding sensitivity thresholds can remove fire-killed species from impacted sites by exhausting seedbanks (Clarke *et al.* 2009). 'High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition' is a Key Threatening Process under the *Biodiversity Conservation Act 2016*.

Large areas of Wollemi National Park were burnt during the 2019–20 fire season, including approximately 56% of spatially distinct *Leionema scopulinum* occurrence records, with fire severity ranging from low to extreme (NSW Department of Planning and Environment 2020). The pagoda habitat which *L. scopulinum* occupies may shelter the species to an extent from low-severity fire (H. Washington *in litt.* July 2022). However, as an obligate seeder *L. scopulinum* is likely to be killed by 100% leaf scorch, independent of fire severity, as is the case for *Leionema equestre*, a Kangaroo Island species which grows in open sandy areas (Davies *et al.* 2021). All *L. scopulinum* plants were killed at one site, burnt by medium–extreme severity fire (NSW Department of Planning and Environment 2020). *Leionema scopulinum* is vulnerable to a return of fire at burnt sites before post-fire seedlings reach maturity and replenish the soil-stored seedbank.

<u>Minimum fire interval</u>

An appropriate minimum fire interval for *Leionema scopulinum* is unknown but can be inferred to be 11–16 years from related species in similar habitats (Burrows *et al.* 2008; Clarke *et al.* 2009). Primary juvenile period (PJP), or time to flower, is a biological indicator which can be used to estimate the minimum interval between fires required to prevent population decline (Burrows *et al.* 2008; Clarke *et al.* 2009).

Rocky outcrops are more likely to have species with longer PJPs than average across habitats, making outcrops particularly vulnerable to short interval fires (Burrows *et al.* 2008). Clarke *et al.* (2009) found that rocky outcrop woody plants have slightly longer PJPs (mean 5.1 years) than other habitats evaluated (Clarke *et al.* 2009). For two *Leionema* species that are seed regenerators the primary juvenile period is five years for *L. dentatum* and eight years for *L. rotundifolium* (Clarke *et al.* 2009). *Leionema* species in other habitats have slightly lower PJPs, e.g., *L. equestre*

flowers after four years (Jusaitis 2011), while *L. dentatum*, growing on sandstone in dry sclerophyll forest in the Illawarra, has a PJP of ~4–5 years (Kubiak 2009; PlantNET 2022). Conversely, outcrop shrub species with exceptionally long PJPs are known, e.g., *Leucopogon exolasius*, another obligate soil seeder, has a PJP >11 years (Ooi 2019).

Burrows *et al.* (2008) recommend a minimum fire interval of twice the juvenile period where there is uncertainty regarding reproductive biology and seedbank dynamics. Similarly, Gill and Nicholls (1989) suggest two to three times the PJP may be required for self-replacement (Gill and Nicholls 1989 in Bradstock *et al.* 2012). In comparison, Clarke *et al.* (2009) determine minimum fire intervals by taking PJP and allowing three years for seedbank replenishment. Extrapolating from the higher PJP of known rocky outcrop *Leionema* species (*L. rotundifolium*), the minimum fire threshold for *L. scopulinum* is estimated to be 11–16 years using these methods. This broadly aligns with the 10–15-year minimum estimate provided by Steve Clarke, an expert familiar with the species (S. Clarke *in litt.* June 2022), and with the 10–12-year thresholds given for other rocky outcrop habitats (Burrows *et al.* 2008; Clarke *et al.* 2009).

Fire risk and climate change

While rocky outcrops are less fire-prone than adjacent forests (Clarke 2002; Burrows *et al.* 2008), with fire weather predicted to become more frequent and severe, these habitats are likely to burn with greater frequency (Canadell *et al.* 2021). Conventional wisdom has held that rocky outcrops, while not fire-free, are substantially protected from fire by sparse and discontinuous fuel, and the physical disruption of the rock interface (Clarke 2002; NSW National Parks and Wildlife Service 2006; Burrows *et al.* 2008). However, outcrops generally make poor fire breaks, and some areas of this habitat will burn during any large fire in Wollemi National Park (G. Purcell *in litt.* July 2022). The pagoda formations which *L. scopulinum* occupies is particularly vulnerable to high-severity fire, which can quickly spread up inclines and cliffs and burn this habitat (G. Purcell *in litt.* July 2022). More frequent fires in outcrop habitats will in turn reduce competitive advantages for obligate seeders in outcrop habitats, enabling migration of plant species from adjacent habitat, particularly of resprouter species (Hunter 2003).

Fire risk is forecast to increase in the NSW Central Tablelands, as it is across south-eastern Australia (NSW Government Local Land Services 2016; Collins *et al.* 2022). Average fire weather, average temperatures, and aridity are all projected to increase due to the effects of climate change, placing Wollemi National Park, and thus *L. scopulinum*, at increased risk of more severe and frequent fires (NSW Government Local Land Services 2016; NSW Government 2022a; CSIRO 2022). While a harsher fire-weather climate is projected for the region with high confidence, the magnitude of this change is unclear due to variability in rainfall projections (CSIRO 2022). AdaptNSW projects a small increase in the number of high fire danger days (Forest Fire Danger Index > 50) at *L. scopulinum* sites in the near and far future, with increases of 0.1–0.2 days by 2039, and 0.5–0.8 days by 2079 (NSW Government 2022a).

Fire history analysis

Fire history mapping shows that each *Leionema scopulinum* point record has been within the burn footprint of between one and four recorded wild/prescribed fires since 1974 (NSW Department of Planning and Environment 2021). This mapping demonstrates a variable fire history across *L. scopulinum* localities, ranging from 28 records (~46%) burnt at long recurrence intervals (>11 years) to 33 records (~54%) burnt at short recurrence intervals (≤11 years), including 4 (~7%) burnt by three successive short-interval fires. Approximately 56% of *L. scopulinum* localities were burnt in 2019–20, including ~38% by high–extreme severity fire (NSW Department of Planning and Environment 2020).

While these short-interval fires may be interpreted as indicating that *Leionema scopulinum* tolerates some fire exposure exceeding minimum thresholds, fire records can give a false indication that areas exceed thresholds (NSW National Parks and Wildlife Service 2006), particularly in the absence of finer-scale fire severity data prior to 2017. Given that the pagoda habitat which *L. scopulinum* occupies shelters the species to a degree from fire (H. Washington *in litt.* July 2022), it is more likely that *L. scopulinum* plants were not killed by each recorded fire. However, with fire severity projected to increase (Canadell *et al.* 2021; CSIRO 2022), this past pattern of repeated short-interval fires suggests that *L. scopulinum* plants may be too frequently burnt in future as high-severity fire has greater capacity to encroach into pagoda habitat (G. Purcell *in litt.* July 2022).

Prescribed burns

Prescribed burns are guided by vegetation community fire tolerance thresholds (NSW Department of Planning and Environment 2021; G. Purcell *in litt.* July 2022). In general, rocky outcrops are not used as fire breaks and prescribed burns in pagoda country are allowed to meander to achieve a mosaic pattern (G. Purcell *in litt.* July 2022; M. Sharp *in litt.* August 2022). The fire interval guiding management of the rocky heath community which *Leionema scopulinum* is a part of (10–30 years; NSW National Parks and Wildlife Service 2006) is probably broadly appropriate. However, prescribed burns have contributed to the pattern of too-frequent fire at *Leionema scopulinum* sites and should be monitored to prevent interval squeeze. Long-term fire exclusion would likely to lead to population decline similar to that seen in other *Leionema* species (Davies *et al.* 2021). However, given existing fire patterns at *L. scopulinum* sites, fire exclusion is unlikely to threaten the species.

Drought

Drought is a recurrent threat, which is projected to become more frequent due to the effects of climate change (NSW Government Local Land Services 2016; CSIRO 2022). 'Anthropogenic Climate Change' is a Key Threatening Process under the *Biodiversity Conservation Act 2016*. In 2018, an estimated 50% reduction in the number of *Leionema scopulinum* plants, compared with 2003 levels, was observed at one site, with a second unquantified decline observed at a second site (H. Washington *in litt.* August–September 2018). These plant losses are likely related to drought, which impacted much of NSW, including the area of the species distribution, in 2017–19 (H. Washington *in litt.* August 2018; Australian Government Bureau of Meteorology 2020; Government Bureau of Meteorology 2022). As these observations were made mid-drought, they may not capture the full extent of *L. scopulinum* dieback.

A similarly pronounced drought-induced dieback was documented for a different rocky outcrop community at Bald Knob Mountain, NSW (Benwell 2007). In this habitat, ~56% of shrubs died during a period of relatively low-intensity drought in 2000, with mortality ranging from 12–100% depending on the species (Benwell 2007). Drought tolerance varies among *Leionema* species. Three years of severe drought in Kangaroo Island, between 2006–2008, resulted in 75–100% declines in translocated *L. equestre* populations, after 13 years of population stability (Jusaitis 2011). In contrast, *L. ralstonii* is described as uncommonly drought tolerant, with little mortality reported during a dry spell in 1997 (NSW National Parks and Wildlife Service 2003).

Rocky outcrop vegetation is more desiccation-prone than other habitats due to its characteristic shallow soil overlaying rock, which retains water poorly (Benwell 2007). In addition to desiccation and plant death, under warmer drier conditions woody plants on average produce fewer seeds, impacting seedbank maintenance, and experience reduced seedling survival (Benwell 2007; Enright *et al.* 2014, 2015). Furthermore, increasing aridity reduces micro-climate differences between outcrops and adjacent habitat, which over time may result in greater homogeneity between outcrop and adjacent vegetation, and outcrop-restricted species becoming less abundant (McGann 2002; Hunter 2003).

While there is variability in rainfall projections for the region, time spent in drought is projected to increase in Eastern Australia over the course of the century (NSW Government Local Land Services 2016; CSIRO 2022). As *L. scopulinum* grows towards the highest altitudes in the area, and appears to have low dispersal ability, the species has no capacity to retreat to higher ground to mitigate drought impacts (H. Washington *in litt.* August 2018).

Drought is a recurrent feature in eastern Australia and *L. scopulinum* has persisted through numerous previous droughts. However, the high mortality observed in 2018, during what was a historically severe but relatively short drought, suggests that drought will continue to be a threat and may contribute to species decline by exacerbating impacts from fire, reducing resilience and seedbank maintenance prior to fire, and reducing seedling establishment if occurring post-fire.

Combined fire-drought impacts

Drought may have a particularly severe impact on *Leionema scopulinum* if it extends after or follows fire. The 2017–19 drought, though historic in its severity, was followed by fire and an extended period of above-average rainfall, both of which promoted *L. scopulinum* regeneration (Australian Government Bureau of Meteorology 2020, 2022). Overlapping disturbance events, including fire, drought, and heatwaves, can negatively impact recruitment, seedling establishment, post-fire flowering, seedbank restoration, and seed quality (Nolan *et al.* 2021). For *L. scopulinum*, if drought were to extend after fire, these impacts may severely compromise recovery and lead to population decline.

Similar to *Leionema scopulinum*, *L. equestre*, another fire-killed species, shows a pattern of recruitment following fire and decline during drought (Davies *et al.* 2021). After quickly recruiting from seed following the 2020 Kangaroo Island bushfire, seedling survival declined by 50% between late 2020–April 2021 due to dry weather and macropod browsing (Davies *et al.* 2021). Similarly, in rocky outcrops at Bald

Knob Mountain, NSW, a relatively low-intensity drought reduced survival in ~1.5-year-old post-fire seedlings by 75% over six months (Benwell 2007). Shrub seedlings density was lower in outcrops subjected to fire + drought than in areas subjected to drought alone, despite the fire treated group having a far higher seedling density response than the unburnt group prior to the drought (Benwell 2007).

Recruitment mainly occurs in the initial year after fire and may be poor or fail entirely if such years are very dry (Enright *et al.* 2014, 2015). Post-fire winter rainfall influences seed germination and early seedling establishment, while summer rainfall is a determinant of over-summer survival (Enright *et al.* 2014). In a study of shrub species in southwestern Australian shrublands, Enright *et al.* (2014) estimated that a 20% reduction in post-fire winter rainfall would increase the minimum fire-free interval required for self-replacement by 50%, placing many species at risk of decline.

Grazing by feral goats

Feral goats may negatively impact *Leionema scopulinum* through herbivory if not managed appropriately. Outcrop-restricted flora in eastern Australia are highly susceptible to impacts from feral browsers compared with surrounding vegetation (Hunter 2003). In other *Leionema* species grazing is reported to reduce flowering and seed production, and decrease post-fire seedling survival and growth (NSW National Parks and Wildlife Service 2003; Davies *et al.* 2021). When describing the species, Horton *et al.* (2004) observed that the relatively inaccessible habitat of *L. scopulinum* appeared to provide shelter from feral browsers. However, this pagoda habitat does not shelter *L. scopulinum* entirely, as is evident from the grazing impacts observed at one site in 2003 (Royal Botanic Gardens NSW 2022), and is more likely to deter deer than goats (G. Purcell *in litt.* July 2022).

Herds of 20–40 goats were not uncommon in the vicinity of Nullo Mountain in the late 1980s (M. Sharp *in litt.* August 2022). However, goat numbers around Nullo and in Wollemi National Park generally are currently very low and stable due to control programs on park and on surrounding private property, as well as hunting on private property (G. Purcell *in litt.* July 2022; M. Sharp *in litt.* August 2022).

The presence of feral animals can compromise post-fire flora recovery and contribute to species decline (Davies *et al.* 2021; Gallagher *et al.* 2022). This is unlikely to be the case for *Leionema scopulinum* as goat impacts were diminishing in years leading to 2018, and only low numbers of goats were removed from Wollemi National Park following the 2019–20 fires (NSW National Parks and Wildlife Service 2018, 2021). No evidence of goat impacts was noted during a post-fire visit to one *L. scopulinum* site (S. Clarke *in litt.* June 2022).

Assessment against IUCN Red List criteria

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

Criterion A *Population Size reduction*

Assessment Outcome: Data Deficient

Justification: There is insufficient data on historic and current population size and life history to assess *Leionema scopulinum* under Criterion A. An estimated 50% reduction in the number of *L. scopulinum* plants was observed at one site in 2018, compared with 2003 levels, as well an unquantified reduction at a second site, most likely due to drought (H. Washington *in litt.* May–September 2022). All mature individuals were killed during the 2019–20 fires at a separate site, with a strong post-fire recruitment response observed (S. Clarke *in litt.* May 2022). While the population is currently substantially reduced following drought and fire, the population will increase as post-fire seedlings reach maturity in coming years. However, a return of fire at burn sites within the 11–16-year minimum fire interval, estimated based on other rocky outcrop *Leionema* species, is likely to drive further reductions (Burrows *et al.* 2008; Clarke *et al.* 2009).

Criterion A requires population size reduction to be measured over the longer of 10 years or three generations. The generation length for *Leionema scopulinum* is unknown but exceeds the primary juvenile period, which is estimated to be 5–8 years based on other rocky outcrop *Leionema* species (Burrows *et al.* 2008; Clarke *et al.* 2009). Determining population size and monitoring for population reductions, particularly during and following drought and fire, are recommended conservation management actions.

Criterion B Geographic range

Assessment Outcome: Endangered under Criterion B1(a)(b v) + B2(a)(b v)

Justification: *Leionema scopulinum* has a highly restricted geographic distribution. The area of occupancy (AOO) is estimated to be 72 km^2, calculated by overlaying 2 km x 2 km grid cells over validated occurrence records, as recommended by IUCN (2022). The extent of occurrence (EOO) is estimated to be 450 km^2, based on a minimum convex polygon enclosing all validated records, as recommended by IUCN (2022). The geographic range of *L. scopulinum* falls within the Endangered threshold for both AOO (<500 km^2) and EOO (<5,000 km^2).

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

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

   Assessment Outcome: Met for Endangered (2 locations)

   Justification: There are two locations based on the most serious plausible threat of recurring fires at less than the minimum fire interval for the species, estimated to be 11–16 years based on other rocky outcrop *Leionema* species (Burrows *et al.* 2008; Clarke *et al.* 2009). Fire history records indicate the minimum fire threshold for *Leionema scopulinum* (11 years) has been exceeded at least once since 1974 at ~54% of spatially distinct records, with ~7% of records shown as burnt by three successive short-interval (<11 years) wild or prescribed fires in this time.

   Two fires impacted *Leionema scopulinum* sites in the 2019–20 fire season: the Kerry Ridge fire impacted the majority of the northern localities, while

the Gospers Mountain fire impacted the southern site (NSW Department of Planning and Environment 2021). These fires burnt areas of approximately 479,514 ha and 183,647 ha, respectively (NSW Department of Planning and Environment 2021). While the footprint of a future fire could plausibly cover all *L. scopulinum* localities, it is unlikely that all plants would be burnt due to the patchy nature of bushfire, as is evident from 2019–20 fire extent severity mapping (NSW Department of Planning and Environment 2020). Hence there are two locations. There is insufficient information to determine whether the *Leionema scopulinum* is severely fragmented.

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

Assessment Outcome: Met for (v)

Justification: Decline in the number of mature individuals has been observed and is inferred to continue for *Leionema scopulinum* due to combined impacts from increasing fire and drought frequency and severity due to the effects of climate change (CSIRO 2022). Both the 2017–19 drought and 2019–20 fires were observed to cause substantial losses of mature *Leionema scopulinum* individuals, with reductions of ~50% and 100% at impacted sites, respectively (H. Washington *in litt.* August 2018; S Clarke *in litt.* May 2022). The strong post-fire recruitment observed in 2021 (S Clarke *in litt.* May 2022) suggests that *L. scopulinum* tolerated this instance of drought and fire, despite the historical severity of both events (Australian Government Bureau of Meteorology 2020; Canadell *et al.* 2021). However, these disturbances were preceded and followed by conditions which promoted regeneration. All but three burnt localities had extended fire-free periods (≥17 years) to accumulate seed, including many years of average and above average rainfall prior to the 2017–19 drought (NSW Department of Planning and Environment 2021; Australian Government Bureau of Meteorology 2022). The site where recruitment was observed had been unburnt for 25 years. Similarly, the 2019–20 fires were followed by an extended period of above-average rainfall, promoting recruitment and seedling establishment (Bradstock and Myerscough 1981; Australian Government Bureau of Meteorology 2022).

However, with the risk of fire and drought projected to increase for the region (NSW Government Local Land Services 2016; NSW Government 2022*a*; CSIRO 2022), *Leionema scopulinum* is likely to be subjected to higher-frequency and overlapping disturbance events increasingly in future. The existing pattern of too frequent fire at ~54% of *Leionema scopulinum* localities , together with projected increases in fire severity (Canadell *et al.* 2021), which is more likely to encroach into pagoda habitat (G. Purcell *in litt.* July 2022), means it can be reasonably inferred that *L. scopulinum* plants will burn too frequently in future. Fire history records suggest that a proportion of the ~56% of localities burnt in 2019–20 will be re-exposed to fire within the minimum fire interval (i.e., prior to 2030). Repeated high-severity fires at <11-year intervals would severely compromise the species'

capacity to recruit and recover, resulting in a decline in the number of mature individuals, and potentially to localised removal from impacted sites if seedbanks are exhausted (Clarke *et al.* 2009). As *L. scopulinum* appears to have limited ability to disperse, it is unclear whether the species could recolonise lost habitat.

With the risk of drought increasing in the region (NSW Government Local Land Services 2016; CSIRO 2022), drought-induced dieback is expected to exacerbate fire-caused decline by reducing the resilience of *Leionema scopulinum* to fire. Drought is likely to decrease seed production and seedbank viability prior to fire, and compromise recruitment and seedling establishment if occurring or extending after fire (Benwell 2007; Enright *et al.* 2014, 2015; NSW Government Local Land Services 2016). The combined impact of these threats, which have both been observed to result in decline and are projected to increase into the future, indicate that *L. scopulinum* will remain under pressure, and thus, continuing decline is inferred for the *L. scopulinum* population.

c) Extreme fluctuations.

Assessment Outcome: Data Deficient

Justification: It is likely *Leionema scopulinum* undergoes natural fluctuations, with numbers fluctuating as a result of disturbance events such as drought and fire. There is no data to determine if fluctuations are extreme, i.e., varying by an order of magnitude.

Criterion C *Small population size and decline*

Assessment Outcome: Data Deficient

Justification: *Leionema scopulinum* is likely naturally rare and may have a population that falls within the vulnerable range (2500–9,999). Surveys are needed to validate this. Based on location notes >1700 plants (including mature individuals and others) were estimated by causal count between 2003–2016 (H. Washington *in litt.* July 2022). This is an approximate estimate as not all occurrence records include plant counts, and counts were made in different years at different sites and are not restricted to mature individuals. The population declined during the 2017–19 drought, and further declined following the 2019–20 fires (H. Washington *in litt.* August 2018; S Clarke *in litt.* May 2022). With above average rainfall in 2020–22 (Australian Government Bureau of Meteorology 2022), the population will increase in coming years as post-fire seedlings reach maturity so long as fire is excluded for appropriate intervals (>11 years). However, repeat exposure to fire before post-fire seedlings mature, flower, and replenish the soil-stored seedbank would be detrimental to the species.

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

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

Assessment Outcome: Data Deficient

Justification: There is insufficient data on historic and current population size and life history to estimate generation length and quantify decline.

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

Assessment Outcome: Data Deficient

Justification: Continuing decline is inferred for the *Leionema scopulinum* population due to the combined impacts of increasing fire and drought. However, there is insufficient data to determine the number of mature individuals and subpopulations, or to determine whether the species undergoes extreme fluctuations.

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

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

Assessment Outcome: Data deficient

Justification: Plant counts are not available for all occurrence records. Counts of mature individuals only are not available.

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

Assessment Outcome: Data deficient

Justification: The number of subpopulations is unknown. *Leionema scopulinum* sites are discrete, scattered on ridges and pagodas, and mechanisms for seed dispersal and pollination unknown (H. Washington *in litt.* July 2022). In the absence of seed dispersal between outcrops, each *L. scopulinum* site would be isolated, with minimal capacity to (re)colonise unoccupied habitat (H. Washington *in litt.* July 2022).

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Data deficient

Justification: It is likely *Leionema scopulinum* undergoes natural fluctuations, with numbers fluctuating as a result of disturbance events such as drought and fire. There is no data to determine if fluctuations are extreme, i.e., varying by an order of magnitude.

Criterion D Very small or restricted population

Assessment Outcome: Not met

Justification: Although *Leionema scopulinum* has <5 locations, the species is subject to ongoing threats and continuing decline and therefore cannot be assessed under D2. There is no known plausible future threat that could drive *Leionema scopulinum* to Critically Endangered or Extinct in a very short time.

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: Data deficient

Justification: Counts of mature plants are not available for all *Leionema scopulinum* localities. The population may be reduced to <1,000 following the 2019–20 fire; however, there is low confidence about the total population size and this will increase as post-fire recruits reach maturity in coming years.

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

Assessment Outcome: Not met

Justification: Although *Leionema scopulinum* has <5 locations, the species is subject to ongoing threats and continuing decline and therefore cannot be assessed under D2.

Criterion E Quantitative Analysis

Assessment Outcome: Data Deficient

Justification: There is insufficient data to quantify extinction risk for this species.

Conservation and Management Actions

There is no National Recovery Plan and no NSW Saving our Species (SoS) program for *Leionema scopulinum*. The following actions are derived from the threat information above and do not represent a comprehensive management plan, which would need to consider many interrelated actions.

Habitat loss, disturbance and modification

- Maintain fire-free intervals of at least 11–16 years in the rocky outcrop pagoda habitat that *Leionema scopulinum* occupies.
- Exclude wild and prescribed fire from *Leionema scopulinum* sites burnt during the 2019–20 fires to allow sufficient time for replenishment of the soil-stored seedbank.

Invasive species

- Control feral goats to minimise negative impacts from grazing.

Ex situ conservation

- Develop a targeted seed collection program for ex situ seed banking and propagation. There are currently no plants in horticulture.

Stakeholders

- Inform NPWS of the estimated minimum fire interval for *Leionema scopulinum* (11–16 years) to guide any changes to fire management in the Wollemi National Park rocky heath community which *L. scopulinum* is a part of.

Traditional owners

- Consult with Traditional Owners to seek Traditional Ecological Knowledge for the species and its habitat. The Wiradjuri, Dharug, Wonnarua and Darkinjung people are the Traditional Owners of the Wollemi National Park area.

Survey and Monitoring priorities

- Monitor the species recovery and seedling establishment following the 2019–20 fires.
- Monitor species at unburnt sites to determine whether drought-induced decline is ongoing.
- Survey *Leionema scopulinum* to confirm whether fire-cued recruitment is the only recruitment mechanism for the species.
- Monitor the species during drought, and in particular, if drought follows fire monitor seedling survival and establishment.

Information and Research priorities

- Determine the current population size and demographics.
- Determine seed dispersal and pollination mechanisms.
- Determine primary juvenile period and minimum fire interval with greater confidence.

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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: *Leionema scopulinum* is Endangered under Clause 4.3 (b) (d) (e i)

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

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

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

The geographic distribution of the species is:			
	(a)	for critically endangered species	very highly restricted, or
	(b)	for endangered species	highly restricted, or
	(c)	for vulnerable species	moderately restricted,
and at least 2 of the following 3 conditions apply:			
	(d)	the population or habitat of the species is severely fragmented or nearly all the mature individuals of the species occur within a small number of locations,	
	(e)	there is a projected or continuing decline in any of the following:	
		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	habitat area, extent or quality,
		(iv)	the number of locations in which the species occurs or of populations of the species,

	(f)	extreme fluctuations occur in any of the following:				
		(i)	an index of abundance appropriate to the taxon,			
		(ii)	the geographic distribution of the species,			
		(iii)	the number of locations in which the species occur or of populations of the species.			

Clause 4.4 - Low numbers of mature individuals of species and other conditions
(Equivalent to IUCN criterion C)
Assessment Outcome: Data Deficient

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

Clause 4.5 - Low total numbers of mature individuals of species
(Equivalent to IUCN criterion D)
Assessment Outcome: Not met

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

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

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

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

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

APPENDIX 2 *Leionema scopulinum* photographs

Figure 2. *Leionema scopulinum* plant in flower in situ. Credit: Steve Clarke June 2004.

Figure 3. *Leionema scopulinum* plant in flower in situ. Credit: Steve Clarke July 2004.

Figure 4. *Leionema scopulinum* plant in flower. Cultivated specimen. Credit: Steve Clarke November 2004.

Figure 5. *Leionema scopulinum* plant in flower. Cultivated specimen. Credit: Steve Clarke August 2011.