Conservation Assessment of *Darwinia glaucophylla* B.G.Briggs (Myrtaceae)

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***Darwinia glaucophylla* B.G.Briggs (Myrtaceae)**

Distribution: Endemic to NSW
Current EPBC Act Status: Not listed
Current NSW BC Act Status: Vulnerable
Proposed listing on NSW BC Act: Endangered

Reason for change: Genuine change based on decline in the species distribution, likely as a result of severe wildfire.

Summary of Conservation Assessment

Darwinia glaucophylla was found to be eligible for listing as Endangered under Criterion B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v).

The main reasons for *Darwinia glaucophylla* being eligible are: 1) it has a highly restricted geographic range with an extent of occurrence of 54-88 km^2 and an area of occupancy of 48-64 km^2; 2) it occurs at five threat defined locations; 3) there is continuing decline observed and inferred in the EOO, AOO, area, extent and quality of habitat, number of locations and subpopulations, and number of mature individuals of *D. glaucophylla* due to the combined effects of adverse fire regimes, clearing and land degradation, and increased frequency, intensity and duration of drought due to climate change.

Figure 1 - *Darwinia glaucophylla* growing near Lyre Trig, Brisbane Water National Park. Image: Gavin Phillips

Description and Taxonomy

Darwinia glaucophylla is a conventionally accepted species within the family Myrtaceae (CHAH 2023). It is described in PlantNET (2022) as: "Spreading, prostrate shrub with ascending branchlets to 15 cm high. Leaves laterally compressed, 8-17 mm long, glabrous, glaucous, and often tinged red purple. Flowers mostly in clusters of 2-4; peduncles 1-1.5 mm long; bracts leaf-like, 8-12 mm long; bracteoles oblong, 4-6 mm long, red brown. Hypanthium 7-8 mm long, 0.5-1.5 mm diam., with prominent ribs. Sepals triangular, ≤ 0.5 mm long, entire or toothed; much shorter than petals. Style straight, 12-16 mm long, white. Flowers winter and spring. Flower surrounded by red-brown bracteoles (bract like structure at base of flower)."

Darwinia glaucophylla has no known synonyms (CHAH 2023). It is closely related to *D. biflora,* which occurs south of the Hawkesbury River and is differentiated by the green leaves (*c.f.* glaucous leaves) and persistent, purple-red bracteoles (*c.f.* caducous, red-brown bracteoles). *Darwinia glaucophylla* often co-occurs with *D. fascicularis* subsp. *fascicularis* with which it has been observed to hybridise, with hybrids identified by their green leaves and much more upright habit (*c.f.* prostrate habit; OEH 2017; G. Phillips pers. obs. October 2021).

Distribution and Abundance

Darwinia glaucophylla is endemic to the New South Wales (NSW) Central Coast region. It occurs entirely within the Gosford local government area, having a small geographical range between the area of Narara and the Hawkesbury River, and extending west to Calga (Focus Flora 2018). These are the Traditional Lands of the Darkinjung people, who have lived throughout the Central Coast region from up to 40,000 years (Darkinjung LALC 2023). Evidence of the Darkinjung people in the area occupied by *D. glaucophylla* remains in rock engravings, foreshore middens and rock paintings (Darkinjung LALC 2023), suggesting they likely interacted with *D. glaucophylla* to some extent.

Within its narrow range, *Darwinia glaucophylla* has been recorded in four discrete areas (Table 1). There are two core areas with high densities of records: an area west of Mooney Mooney Creek around Calga (Mooney Mooney West), and to the east of Mooney Mooney Creek around Kariong and Somersby (Mooney Mooney East). Further afield, two smaller areas with fewer records are then known adjacent to Strickland State Forest in the north, and near to Patonga in the south (Focus Flora 2018). Currently, over 70% of the known population occurs within Brisbane Water National Park (NP) and Popran NP.

Table 1 - Population breakdown for *Darwinia glaucophylla.*

Subpopulation	Tenure	Minimum Abundance Estimate	Notes	Fire History per NSW NPWS (2022)	References
Mooney Mooney West	NPWS, Private, Crown Land, RMS	2,508	Many records without counts, 2,508 counted in Popran and Brisbane Water NPs to date	November 1979 (Wildfire) October 1988 (Wildfire) 1994 (Wildfire) October 1998 (Wildfire) January 2003 (Wildfire)	Focus Flora 2018, 2019, 2020

Mooney Mooney East	NPWS, Private, Crown Land, LALC	2,411	Many records without counts, 2,411 counted in Brisbane Water NP to date	March 1965 (Wildfire) November 1968 (Wildfire) April 1979 (Wildfire) November 1979 (Wildfire) October 1988 (Wildfire) 1994 (Wildfire) September 1999 (Prescribed) January 2003 (Wildfire) September 2013 (Prescribed) May 2018 (Prescribed)	Focus Flora 2018
Patonga	NPWS	0	Not seen since 2000 despite targeted surveys	April 1977 (Prescribed) November 1988 (Wildfire) December 1990 (Wildfire) January 2006 (Wildfire)	Focus Flora 2018, 2019, 2020
Strickland State Forest	Forestry, Crown Land, Council	270	Three discrete patches with one not re-recorded since 2000	October 1968 (Wildfire) August 2001 (Prescribed)	Focus Flora 2018; BioNet 2023
ESTIMATED MINIMUM INDIVIDUALS		**5,189**			

Until recently, *Darwinia glaucophylla* was only known from the core areas and Patonga, with the records known prior to 2003 mainly within Brisbane Water and Popran NPs (NSW Scientific Committee 2003). Knowledge of the species' distribution has changed significantly since 2003 however, with targeted surveys leading to the discovery of numerous new sites within the core areas, notably around Strickland State Forest, extending the species' known range to the north (Focus Flora 2018). Conversely, there has also been a range contraction in the southern extent over the same time, with records in the Patonga area and near Gosford Rifle Range south of Kariong unable to be relocated after targeted surveys at the recorded sites and in the broader area from 2018 to 2021 (Focus Flora 2018, 2021).

The population of *Darwinia glaucophylla* consists of four subpopulations, as defined by IUCN (2024). The four areas where *D. glaucophylla* occurs are separated by a minimum distance of 2.9 km between Strickland and Mooney Mooney East and a maximum distance of 7 km between Mooney Mooney East and Patonga. Given the movement of primary pollinators and seed dispersal distances typical of *Darwinia* (see Ecology section), there is likely to be minimal genetic exchange between these areas, meaning they constitute separate subpopulations.

Records of *Darwinia glaucophylla* in the Mooney Mooney West subpopulation, centred around Calga, are mostly found within largely continuous sections of Popran and Brisbane Water NPs separated by the M1 motorway. Substantial patches also occur on private lands to the north of Popran NP, including around the active Calga Sands

Quarry. Within the two NPs, an estimated minimum of 2,508 mature individuals have been counted during recent surveys, with many in regularly slashed electricity and gas pipeline easements (Focus Flora 2018, 2019, 2020). The numbers on private land here are unknown. This area is also relatively long unburnt, with plants west of the M1 in Popran NP being unburnt since 1994 (29 years) and east of the M1 in Brisbane Water NP being unburnt since 2003 (20 years; NSW NPWS 2022).

In the Mooney Mooney East subpopulation, which straddles the suburbs of Kariong and Somersby, *Darwinia glaucophylla* is mostly found within large tracts of intact bush spanning Brisbane Water NP, crown land, and lands owned by the Darkingjung Local Aboriginal Land Council. Significant numbers of records also exist within private land, including that now developed for the Somersby Industrial Estate. Only plants within Brisbane Water NP have been counted to date, with 2,411 estimated between the Lyre Trig, Girrakool and Rifle Range sites (Focus Flora 2018). Several more pockets exist within Brisbane Water NP and in adjoining lands however, meaning that this estimate is highly conservative. The fire history across this subpopulation is varied, with some large patches unburnt for significant periods of up to *c*. 50 years and others having been burnt as recently as May 2018 in hazard reduction activities (NSW NPWS 2022). Seedling recruitment has been observed at the more recently burnt sites approximately 12 months post-fire and beyond (Focus Flora 2019). Plants in the southernmost part of this subpopulation have not been re-recorded since 1978 despite intensive surveys in recent years (Focus Flora 2018). *Darwinia glaucophylla* has also disappeared from sites around Somersby Falls in the north of the subpopulation in recent years, which has been attributed to the lack of any type of disturbance at these sites for greater than 20 years (Focus Flora 2021). These observations suggest this subpopulation may be contracting in area.

The Patonga subpopulation is the most geographically disjunct, lying approximately 7 km south of the Mooney Mooney East subpopulation. Here, *Darwinia glaucophylla* is only known from the Van Dahl Track area of Brisbane Water NP where 150 individuals were recorded in 2000 (BioNet 2023). However, no plants have since been re-recorded in this subpopulation despite intensive survey effort in the area (Focus Flora 2018, 2019, 2020). This site was burnt in a major bushfire in 2006 (NSW NPWS 2022).

The Strickland State Forest subpopulation is the northernmost, lying approximately 2.9 km northeast of the Mooney Mooney East subpopulation, and consists of three discrete patches – one in Strickland State Forest, one on private property, and one on crown lands adjacent to the state forest. 210 individuals have been counted in Strickland State Forest (Focus Flora 2018) and 60 in the crown lands (BioNet 2023), with the numbers in the council land unknown as it has not been recently surveyed (Focus Flora 2018). This means at least 210 individuals are estimated to exist in the subpopulation. Only the patch in Strickland State Forest has records of being burnt, with wildfire last affecting it in 1968 and a hazard reduction burn occurring in 2001 (NSW NPWS 2022).

There are currently estimated to be 6,860 mature individuals in the population of *Darwinia glaucophylla* (Focus Flora 2021). As *D. glaucophylla* often forms large dense mats, accurately determining the number of individuals present during survey efforts is difficult (Booyens 2010). As of April 2021, surveys have counted a minimum of 5,189 individuals across the population (Table 1; Focus Flora 2018, 2019, 2020). These

counts are based on transects across occupied areas with individuals counted where they can be distinguished, or otherwise counting a continuous mat as one individual (which may underestimate the true densities in some areas; Focus Flora 2018). These counts assumed an even distribution and were then converted to an occupied area of the habitat searched, with this density then extrapolated across other verified but uncounted records in areas of suitable habitat to generate the current population estimate.

Area of Occupancy and Extent of Occurrence

When including the Patonga subpopulation and sites within Mooney Mooney East that have not been recently re-recorded, *Darwinia glaucophylla* has an estimated Extent of Occurrence (EOO) of 88 km^2 based on a minimum convex polygon containing all known occurrences, the method of assessment recommended by IUCN (2024). The Area of Occupancy (AOO) in this scenario is estimated to be 64 km^2 using 2 x 2 km grid cells, the scale recommended by IUCN (2024). When the Patonga subpopulation and the sites within Mooney Mooney East that have not been recently re-recorded are excluded, the EOO is estimated to be 54 km^2, and the AOO is estimated to be 48 km^2. Both EOO and AOO were calculated using ArcGIS (Esri 2015), enclosing all confirmed survey records and cleaned spatial datasets.

Cultural Significance

This assessment is not intended to be comprehensive of the Traditional Ecological Knowledge that exists for *Darwinia glaucophylla* or to speak for Aboriginal people. Aboriginal people have a long history of biocultural knowledge, which comes from observing and being on Country, and evolves as it is tested, validated, and passed through generations (Woodward *et al*. (Eds.) 2020). Aboriginal Peoples have cared for Country for tens of thousands of years (Bowler *et al.* 2003; Clarkson *et al*. 2017). Although no specific information could be collected on *D. glaucophylla*, it is acknowledged that there is traditional ecological knowledge for all plants, animals and fungi connected within the kinship system (Woodward *et al.* (Eds.) 2020).

Ecology

Habitat

Darwinia glaucophylla inhabits friable, shallow skeletal soils on Hawkesbury Sandstones (Booyens *et al.* 2014). The species is associated with sandy heath, scrub and woodlands often associated with sandstone rock platforms or near hanging swamps. Associated vegetation communities are adapted and prone to fire (OEH 2017). *Darwinia glaucophylla* appears to grow in gaps in the canopy caused by rocky outcrops, fire, and where vegetation has been cleared and maintained for easements. It is conspicuous in areas regularly slashed such as along a gas pipeline and powerline easements within Popran and Brisbane Water NPs (Booyens 2014). It is rarely detected in adjacent unslashed habitat, or areas long undisturbed by fire or other means (Focus Flora 2020). *Darwinia glaucophylla* is considered likely to be shade intolerant and therefore will increase in abundance and density after disturbances that improve light availability (Booyens 2010, 2014).

Darwinia glaucophylla occurs within heath vegetation often associated with species such as *Banksia ericifolia, Acacia terminalis, A. oxycedrus, Angophora hispida, Hakea teretifolia,* and *Bauera rubioides* (OEH 2017). It also occurs in open woodland where

it is associated with *Corymbia gummifera, C. eximia, Eucalyptus haemastoma* and *E. punctata* (OEH 2017).

Life history and generation length

Darwinia glaucophylla is a fire sensitive obligate seeder with adults being killed by fire and germination being heat stimulated (Auld and Scott 1997, Auld and Ooi 2009). A fire-free period is therefore needed to allow seedlings to mature and replenish the soil seedbank, with a 5–10-year fire interval suggested as the minimum required for conservation for *D. glaucophylla* (Auld and Scott 1997). The primary juvenile period is 2–3 years (Briggs 1964; Auld and Scott 1997). Fecundity then increases as the plants grow, and soil seedbanks increase rapidly from 5-10 years after a fire (Auld and Scott 1997).

Obligate seeding species of shallow, rocky soils are often long-lived, have low turnover of stands, and maximise their use of limited soil resources as these traits enable competitive advantages in the dry, harsh environments in which they occur (Hunter 2003) and *Darwinia glaucophylla* is likely no different. With an expected lifespan of 20–30 years (Booyens *et al.* 2014), rare germination outside of mass disturbance events (Focus Flora 2018, 2021), and even-aged stands where it occurs (G. Phillips pers. obs. October 2021), the species is well adapted to persist in the skeletal soils it occupies. However, the soil seedbank is likely relatively short-lived, with above-ground persistence favoured. Findings in related *Darwinia* species indicate that the genus has *in situ* seedbank half-lives of less than one year, with a small portion (7–22%) of seeds remaining viable after two years (Auld *et al.* 2000). Consequently, continual seed input is required in most seasons to maintain the soil seedbank and buffer against fire effects (Auld *et al.* 2000).

Given the short-lived soil seedbank, the generation length of *Darwinia glaucophylla* can be estimated using the age of first reproduction + *z* * length of reproductive period, where *z* is a constant between 0 and 1 calculated using survivorship and the relationship between fecundity and age (IUCN 2024). Using the lifespan estimate of 20–30 years, a value for *z* of 0.21 to 0.33 comparable to other woody shrub species where fecundity increases with age (Fung and Waples 2017), and a primary juvenile period of 2–3 years, the generation length of *D. glaucophylla* is therefore estimated to be approximately 6–12 years.

Reproductive Ecology

Darwinia glaucophylla flowers in winter and spring with mature fruits present in October to November (Briggs 1964; Auld and Ooi 2009). The species has small, tubular flowers that occur in clusters of 2–4 and vary in colour from green to yellow to red. The flowers of *Darwinia* species are typically pollinated by small, long-beaked honeyeaters such as the New Holland honeyeater (*Phylidonyris novaehollandiae*) and the eastern spinebill (*Acanthorhynchus tenuirostris*), as well as long-tongued bees of tribe *Anthophorini* (Brewster 1915; Armstrong 1979; Slater and Beardsell 1991). The small honeyeaters that are most likely to pollinate *D. glaucophylla* are known to have typically small home ranges of <1 ha and perform occasional longer distance movements (Higgins *et al.* 2001; Phillips *et al.* 2014; Krauss *et al*. 2017). Small nomadic honeyeater species, or more mobile individuals of the aforementioned species, which travel much greater distances of 10 km or more (Higgins *et al.* 2001)

could also move between *D. glaucophylla* sites to pollinate the species, however this is likely to be rare given the low habit of the plant.

Seed ecology

The dry indehiscent fruit of *Darwinia glaucophylla* contains a single seed that has a lipid body that serves as a food attractant for ants that may move the seeds (Auld and Ooi 2009). Ants are important agents in moving seeds after they fall to the ground at maturity. Seed movement by ants is likely to be over small distances up to several metres (Auld 2009). In sclerophyll vegetation near Sydney, ants have been found to disperse seeds over distances of mostly less than two metres and sometimes up to four metres (Westoby *et al*. 1991).

Darwinia glaucophylla seeds require heat shock to germinate, most likely associated with physiological dormancy (Auld and Ooi 2009). Seeds exhibit varying levels of dormancy, with anywhere from 39%-75% of seeds in each crop displaying dormancy, meaning that a substantial portion of each season's seed crop is available for incorporation into the soil seedbank (Auld and Ooi 2009). The non-dormant portion is lost if it does not germinate soon after dispersal. Ideal temperatures for heat shock treatment to relieve dormancy in *D. glaucophylla* are typically 80–100° C, but temperatures as low as 60°C can still stimulate germination in some seed crops (Auld and Ooi 2009). These temperatures are similar to conditions found at burial depths of 1–2 cm during a bushfire (Bradstock and Auld 1995). This indicates that intermittent wildfire likely plays a key role in the recruitment cycle and maintenance of *D. glaucophylla* stands. However, hotter fires producing soil temperatures above 100° C often result in seed mortality up to 100% (Auld and Ooi 2009), and the subsequent decline or loss of stands.

Threats

Major threats to *Darwinia glaucophylla* include adverse fire regimes, particularly increased severity and frequency of wildfires, clearing and land degradation for urban development, increased frequency and duration of drought due to climate change, and infection by myrtle rust (*Austropuccinia psidii*) (OEH 2017; Focus Flora 2018; Makinson 2018). Invasion by exotic weeds is considered a minor threat that may act locally at the site level (Focus Flora 2018).

Other previously identified threats to *Darwinia glaucophylla* included trail and track maintenance, and increased sedimentation of sites and damage by recreational vehicles (NSW Scientific Committee 2003). Recent observations and surveys have deemed these threats to be very minor however and are now deemed to be only trivially affecting the species (Focus Flora 2018).

Adverse fire regimes

Adverse fire regimes contribute to continuing decline in *Darwinia glaucophylla* by way of destroying mature plants, and depleting soil seedbanks required to replace burnt stands. Short time intervals between fires in obligate seeding species can disrupt the replenishment of seed banks, which are essential to post-fire recruitment and population persistence (Gallagher *et al*. 2020). Estimates for the minimum fire return interval to maintain *D. glaucophylla* stands are 5-10 years, and it is thought that 2-3 fires in succession within this timeframe could lead to declines or complete loss of stands (Auld and Scott 1997). Additionally, severe fires with soil heating >100°C can

eliminate the soil seedbank of *D. glaucophylla* in a single event, also leading to complete stand loss (Auld and Ooi 2009).

Historically, most sites of *Darwinia glaucophylla* are within the suggested fire return thresholds and have not experienced fire frequent enough to yet cause notable declines through this mechanism (Table 1; Focus Flora 2018; NSW NPWS 2022). However, the Patonga subpopulation was burnt in an extreme fire event in January 2006 that was hot enough to damage road infrastructure and destroy homes in neighbouring urban areas (NSW NPWS 2006), and *D. glaucophylla* has not been re-recorded in this subpopulation since this fire (Focus Flora 2018, 2019, 2020). The relatively small size of the subpopulation pre-fire, which was recorded as having approximately 150 individuals in 2000 (BioNet 2023), and the severity of the 2006 fire following on from several years of intense drought across eastern Australia (BOM 2023), may have resulted in the loss of this subpopulation. Additionally, the southern edge of the Mooney Mooney East subpopulation was affected by an equally severe fire in 2003 (NSW NPWS 2006, 2022) and the historical records in this area that have not been recently recorded (Focus Flora 2018) may also have been lost through a similar process.

The Central Coast Region in which *Darwinia glaucophylla* occurs is projected to become hotter, have fewer colder nights under 2°C annually, more hot days over 35°C annually and an increase in average and severe fire weather by 2079 (CSIRO and BOM 2022; AdaptNSW 2023). Additionally, fire weather is predicted to become harsher, and the time spent in drought is predicted to increase on the East Coast through the 21st century (CSIRO 2023). Therefore, it is highly plausible that more frequent severe fires driven by these changes in climate which result in extreme heating of the shallow soils that *D. glaucophylla* inhabits will affect the species in the future. This may result in further extirpation of patches and/or subpopulations as has been observed at Patonga, or decline in mature individuals over time in cases where fires become frequent enough to reduce maturation times and soil seedbank development.

Conversely, the exclusion of appropriate fire from the landscape for too long may also induce decline in the *Darwinia glaucophylla* population. Currently, an upper bound for the return fire interval of approximately 30–40 years is recommended in order to prevent the suppression of recruitment through overshading and leaf litter build up, which results in the loss of mature individuals without replacement over time (Auld and Scott 1997; Focus Flora 2018). Several sites are currently near this upper limit, including the Somersby Falls site in the Mooney Mooney East subpopulation, where a decline in mature individuals is inferred to have occurred through the development of dense vegetation as a result of fire exclusion (Focus Flora 2018).

'High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition' and 'Anthropogenic climate change' are listed as Key Threatening Processes under the *NSW Biodiversity Conservation Act 2016.* 'Fire regimes that cause declines in biodiversity' and 'Loss of climatic habitat caused by anthropogenic emissions of greenhouse gases' are listed as Key Threatening Processes under the *Environment Protection and Biodiversity Conservation Act 1999*.

Clearing and land degradation due to urban development

Clearing and land degradation due to urban development has caused decline in the population of *Darwinia glaucophylla*, especially around the Somersby Industrial Park, the edge of the Kariong suburban area and rural lands in the Mooney Mooney East subpopulation, and around active quarries in the Mooney Mooney West subpopulation. While clearing for development around Kariong and the Calga Sand Quarry will almost certainly have historically caused decline in the distribution and abundance of *D. glaucophylla,* the area in and around the Somersby Industrial Park has been more recently developed (Connell Wagner 2005; DPE 2022) and decline is much more confidently inferred in this area. Given the patchy distribution of *D. glaucophylla* in small, degraded remnants within the Somersby Industrial Park, and the presence of valid records that are now within heavily developed lots (BioNet 2023), it is likely that the recent development in this area has caused the direct loss of individuals and habitat. Additionally, areas to the north of the Somersby Industrial Park and around Kariong are earmarked for further development for industry and housing, including on land where *D. glaucophylla* is known to occur (DPE 2022; Umwelt 2022). This means that the threat of land clearing for urban development is likely to remain high into the future and result in further losses of mature individuals and habitat for the species.

It is also inferred that continuing decline in the quality of remaining habitat in remnant patches of *Darwinia glaucophylla* is occurring due to the degradation of these remnants due to urbanisation. Within the Somersby Industrial Park, *D. glaucophylla* often occurs in small, degraded remnants (Connell Wagner 2005) which may be prone to the effects of rubbish dumping, weed incursion and pollution from surrounding land uses. This is resulting in reduced habitat quality for the species in this area, which may in time see these small remnants decline in abundance even if they are not directly cleared.

'Clearing of Native Vegetation' is listed as a Key Threatening Process under the *Biodiversity Conservation Act 2016.* 'Land Clearance' is listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999*.

Increased frequency, intensity and severity of drought

Increased frequency, intensity and duration of drought is inferred to be contributing to continuing decline in the *Darwinia glaucophylla* population and is strongly inferred to do so into the future. There has been observed die back of adult *D. glaucophylla* cover at several sites during surveys between 2018 and 2021 that is likely attributable to the acute drought conditions experienced across the Central Coast between August 2017 and September 2019 (Focus Flora 2020). Patches occurring on exposed rock platforms with shallow soils suffered much more decline in overall plant cover during the drought, with these plants more likely to have been affected by relatively low soil moisture over a prolonged period (Focus Flora 2020). This reduction in mature plant cover would have a concomitant reduction in seed output during the drought, which is problematic for an obligate seeding species with a relatively short-lived soil seedbank that requires constant input to the seedbank to buffer against disturbances such as fire (Auld *et al.* 2000). Seedling recruitment post-fire could also be hindered by drought conditions, and this could partly explain the lower-than-expected recruitment observed after hazard reduction burns in 2018 and 2019 (Focus Flora 2020).

Drought is likely to increase in frequency, intensity and duration in the future in areas occupied by *Darwinia glaucophylla*, representing an ongoing threat (Reichstein *et al.* 2013; Trenberth *et al.* 2013; Ukkola *et al.* 2020). While predicting the effects of future droughts and how they affect individual species is difficult (Cook *et al.* 2018; De Kauwe *et al.* 2020), the observed drought-induced dieback in *D. glaucophylla* highlights that drought has an adverse effect on the species. Indeed, these projected changes are already becoming more consistent with increased reports of severe drought affecting forest and woodland ecosystems across eastern Australia (Fensham *et al.* 2009; Allen *et al.* 2015; De Kauwe *et al.* 2020; Nolan *et al.* 2021). As such, it can be reasonably inferred that future dieback and mortality events in *D. glaucophylla* due to prolonged and severe drought are likely to become more common.

Infection by myrtle rust

Darwinia glaucophylla has the potential to be susceptible to infection by myrtle rust (*Austropuccinia psidii*). Myrtle rust is an exotic fungus that affects a wide range of species in the family Myrtaceae, damaging or killing new growth and foliage in susceptible species (Makinson 2018). This progressive defoliation can increase plant stress and in turn limit reproductive success or kill plants outright (Makinson 2018). The whole Central Coast region, including the full known distribution of *D. glaucophylla* is within the zone of full myrtle rust naturalisation, with the Australian outbreak first being recorded in this area in 2010 (Makinson 2018).

Darwinia glaucophylla is known as a host species for myrtle rust following inoculation trials, although to date there have been no wild infection reports specifically for *D. glaucophylla* (B. Makinson *in litt.* May 2018; Focus Flora 2018). However, less obvious effects of myrtle rust have been recorded on post-fire regrowth and seedlings in other known host species where mature plants may appear resilient (Makinson 2018), and so the threat of myrtle rust cannot be dismissed for *D. glaucophylla.* This threat is therefore currently not considered to be contributing to continuing decline in *D. glaucophylla* as future effects are not confidently projected, though it remains a plausible future threat that may cause rapid decline in the species once it becomes apparent.

'Introduction and establishment of exotic rust fungi of the order Pucciniales pathogenic on plants of the family Myrtaceae' is listed as a Key Threatening Process under the *Biodiversity Conservation Act 2016.*

Invasion by exotic weeds

Exotic weeds have been noted within patches of *Darwinia glaucophylla*, particularly in areas on the urban interface and along disturbed track edges (Focus Flora 2018). Small patches of exotic grasses, primarily *Andropogon virginicus* (whisky grass) and *Eragrostis curvula* (African lovegrass) were observed within slashed pipeline easements and track edges within Popran and Brisbane Water NPs. However, recent annual surveys have failed to note any direct adverse effects on the *D. glaucophylla* plants in these areas, and exotic grasses are currently effectively managed by the slashing regime that occurs in the easements (Focus Flora 2018).

A low abundance of exotic pine trees (*Pinus* sp.) also occurs near the northeast section of a site within Brisbane Water NP. Exotic pine trees have the potential to impact on *Darwinia glaucophylla* through shading and suppression. While no *D. glaucophylla* individuals have been observed to be directly affected to date, there is potential for

exotic pine trees to increase in abundance and affect nearby populations in the absence of active management (Focus Flora 2018). This means that exotic weeds could plausibly cause decline in the area, extent and quality of habitat for *D. glaucophylla* in the future, however these effects are likely to be localised in nature across the species' population.

Number of Locations

When the threats of adverse fire regimes, in particular more frequent and severe wildfires, and fragmentation and clearing due to development are considered, the population of *Darwinia glaucophylla* can be treated as 5-6 threat-defined locations. This is due to an increase of severe wildfire occurrences being the most serious plausible threat that results in the lowest number of locations for patches that exist within intact bushland, while clearing and land degradation for urban development is the most serious plausible threat for those patches occurring within and immediately adjacent to the urban matrix.

The individual threat-defined locations are defined as follows:

1. All of the Mooney Mooney West subpopulation and records within National Parks estate west and north of Kariong in the Mooney Mooney East subpopulation. This area has come under threat from singular wildfires several times in the past (NSW NPWS 2022) and is mainly within conservation estate.

2. Records in the Mooney Mooney East subpopulation south and east of Kariong. This area is subject to a fire history of more frequent small-scale fires (NSW NPWS 2022) and is predominantly within conservation estate.

3. The Patonga subpopulation. Being geographically isolated and wholly within Brisbane Water NP, wildfires affecting this location have historically not reached other locations (NSW NPWS 2022). This location may however no longer contain an extant subpopulation, and its loss would reduce the number of locations to five.

a) Records within Strickland State Forest and adjoining intact bushland in the Strickland subpopulation. This location is separated from others by large tracts of developed land over which fires are not known to have historically crossed (NSW NPWS 2022), it is not under development pressure, and timber harvesting operations are no longer scheduled within Strickland State Forest (Focus Flora 2018).

4. Records within and adjoining the Somersby Industrial Park. These records are unlikely to be impacted by widespread fire as many exist only within small, degraded remnants within the industrial area (Connell Wagner 2005). Much of this land has been heavily developed in recent decades, and remnant vegetation here remains under pressure from future industrial development (DPE 2022).

5. Records in other private and unreserved lands within the Mooney Mooney East and Strickland subpopulations. These records tend to be in areas already cleared or zoned for agricultural development, are less degraded than remnants in the industrial sites and less at risk of fire than records in the conservation estate. However, they remain at risk from future clearing given proposed

residential and other urban developments in the area, including on land parcels where *D. glaucophylla* is known to occur (DPE 2022; Umwelt 2022).

Assessment against IUCN Red List criteria

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

Criterion A *Population Size reduction*

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

(a) direct observation *[except A3]*

(b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

(e) effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

Outcome

Darwinia glaucophylla is data deficient under Criterion A.

Population reductions

The three-generation timespan in *Darwinia glaucophylla* is estimated to be 18–36 years. *Darwinia glaucophylla* has suffered a population reduction within this timespan based on the loss of the Patonga subpopulation, and apparent reduction in area of the Mooney Mooney East subpopulation, likely due to the effects of severe wildfire. While reductions over time in the total abundance of *D. glaucophylla* have occurred including the loss of 150 plants in the Patonga subpopulation, this loss represents only a small portion (<3%) of the total population. An overall magnitude of decline in individuals across the full population is also difficult to quantify given the inherent difficulty in counting individual plants, and the lack of statistical support and variation in trends observed in plots monitored since 2008 (Badcock 2020; Focus Flora 2021). Therefore, while the decline of the Patonga subpopulation and contraction to the southern extent of the Mooney Mooney subpopulation have seen the Extent of Occurrence (EOO) reduce from 88 km^2 to 54 km^2, a reduction of approximately 38%, this reduction in EOO may not reflect a population reduction of >30%, meaning Criterion A is considered data deficient.

Criterion B *Geographic range*

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)			
	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented OR Number of locations	= 1	≤ 5	≤ 10
(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			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			

Outcome

Darwinia glaucophylla is Endangered under Criterion B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v).

EOO and AOO

Darwinia glaucophylla has a very highly restricted geographic distribution. The extent of occurrence (EOO) has been calculated as 54-88 km^2, meeting the threshold for Critically Endangered. The area of occupancy (AOO) has been calculated as 48-64 km^2.

Number of threat-defined locations

Darwinia glaucophylla is found at 5-6 threat-defined locations when considering the most serious plausible threats of adverse fire regimes, in particular more frequent and severe wildfires, and fragmentation and clearing due to development. This is due to an increase of severe wildfire occurrences being the most serious plausible threat that results in the lowest number of locations for patches that exist within intact bushland, while clearing and land degradation for urban development is the most serious plausible threat for those patches occurring within and immediately adjacent to the urban matrix. Given 5-6 locations give a result of either Endangered or Vulnerable, the higher threat category is used in this assessment as the loss of the Patonga location results in the lower number of locations (5) being most appropriate.

Severely fragmented

Darwinia glaucophylla is not considered severely fragmented as most individuals are found in large, non-isolated subpopulations and the subpopulations are considered viable.

Continuing decline

Continuing decline has been observed and is inferred to continue in the EOO, AOO, area, extent and quality of habitat, number of locations and subpopulations and number of mature individuals of *Darwinia glaucophylla* due to the combined effects of adverse fire regimes, clearing and land degradation, and increased frequency, intensity and duration of drought due to climate change. *Darwinia glaucophylla* appears to have suffered a large contraction in the south of its range since 2000, with the Patonga subpopulation (150 mature individuals) and records on the southern edge of the Mooney Mooney East subpopulation not having been re-recorded since this time despite substantial survey effort (Focus Flora 2018, 2019, 2020, 2021). These

areas were affected by high severity fire in 2003 (Mooney Mooney East) and 2006 (Patonga; NSW NPWS 2006, 2022), following on from several years of intense drought (BOM 2023), and it is highly plausible that these events resulted in the loss of the Patonga subpopulation/location and the southern edge of the Mooney Mooney subpopulation.

There was observed die back of adult *Darwinia glaucophylla* cover at several sites during surveys between 2018 and 2021 that is likely attributable to the acute drought conditions experienced across the Central Coast between August 2017 and September 2019 (Focus Flora 2020). The Central Coast Region is projected to become hotter, have fewer colder nights under 2°C annually, more hot days over 35°C annually and an increase in average and severe fire weather by 2079 (CSIRO and BOM 2022; AdaptNSW 2023). Additionally, fire weather is predicted to become harsher, and the time spent in drought is predicted to increase on the East Coast through the 21st century (CSIRO 2023). This may result in further extirpation of patches and/or subpopulations as has been observed at Patonga or decline in mature individuals over time in cases where fires and/or drought become frequent enough to reduce plant cover, maturation times, and soil seed bank development. Inferred decline in habitat area and quality from clearing and land degradation due to urban development is also apparent. The loss of a number of records within the development footprint of the Somersby Industrial Park (BioNet 2023), remaining plants in the industrial area existing in small, degraded remnants (Connell Wagner 2005) and the threat of further development within the distribution of *D. glaucophylla* (DPE 2022; Umwelt 2022) is resulting in declines in habitat quality and mature individuals. This and other aforementioned threats indicate that the EOO, AOO, area, extent and quality of habitat, number of locations and subpopulations and number of mature individuals of *D. glaucophylla* are likely to remain under pressure, and observed declines are inferred to continue into the future.

Extreme fluctuations

Darwinia glaucophylla is a relatively long-lived shrub and maintains a soil seedbank that can be stimulated by the passage of fire which can replace mature plants lost in such a disturbance event. Therefore, the species does not meet the definition for extreme fluctuations as per IUCN (2024).

Conclusion

While the EOO of *Darwinia glaucophylla* meets the threshold for listing as Critically Endangered and the AOO meets the threshold for listing as Endangered, the highest level that *D. glaucophylla* is eligible to be listed under Criterion B is Endangered. This is because the number of threat-defined locations is five and continuing decline in the EOO, AOO, area, extent and quality of habitat, number of locations and subpopulations, and the number of mature individuals is observed and inferred due to the combined effects of adverse fire regimes, clearing and land degradation, and increased frequency, intensity and duration of drought due to climate change.

Criterion C Small population size and decline

C. Small population size and decline				
		Critically Endangered	Endangered	Vulnerable
Number of mature individuals		< 250	< 2,500	< 10,000
AND at least one of C1 or C2				
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):		25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:				
(a)	(i) Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
	(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals				

Outcome

Darwinia glaucophylla is not eligible to be listed under Criterion C.

Number of mature individuals

The current total population size for *Darwinia glaucophylla* is estimated to be a minimum of 5,189 mature individuals (Focus Flora 2021).

Continuing decline

While continuing decline in the number of mature individuals of *Darwinia glaucophylla* is apparent at least since 2000 (within a three-generation timeframe of 18-36 years), the magnitude of known declines resulting from the loss of the Patonga subpopulation is currently <3% of the total population, and loss of individuals across other subpopulations cannot be quantified due to inherent difficulties in counting individual plants and variation in the results of plot monitoring across sites (Focus Flora 2021).

Mature individuals in each subpopulation

The largest subpopulations at Mooney Mooney East and Mooney Mooney West contain a minimum of 2,411 and 2,508 mature individuals respectively.

% of mature individuals in a single subpopulation

The largest subpopulation of *Darwinia glaucophylla* is Mooney Mooney West, containing approximately 48% of the total population.

Extreme fluctuations

Darwinia glaucophylla is a relatively long-lived shrub and maintains a soil seedbank that can be stimulated by the passage of fire which can replace mature plants lost in such a disturbance event. Therefore, the species does not meet the definition for extreme fluctuations as per IUCN (2024).

Conclusion

While *Darwinia glaucophylla* has a minimum of 5,189 mature individuals (meeting the threshold for listing as Vulnerable) and continuing decline is inferred in the number of mature individuals, the species is not eligible for listing under Criterion C. This is because the magnitude of any decline cannot be estimated or projected over a 1-, 2- or 3-generation period, the number of mature individuals in the largest subpopulations exceeds 1,000, and one subpopulation does not contain 100% of mature individuals.

Criterion D Very small or restricted population

D. Very small or restricted population			
	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	D1. < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	D2. typically: AOO < 20 km^2 or number of locations ≤ 5

Outcome

Darwinia glaucophylla is not eligible to be listed under Criterion D.

Number of mature individuals

Darwinia glaucophylla is currently estimated to have a minimum population of 5,189 mature individuals (Focus Flora 2021).

Risk of future extinction in a very short amount of time

Darwinia glaucophylla has an AOO of 48-64 km^2 and occurs at 5-6 threat-defined locations, and based on current evidence, no plausible threat is known that could rapidly drive the species to Critically Endangered or even Extinct in a very short time.

Criterion E Quantitative Analysis

E. Quantitative Analysis			
	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

Outcome

Darwinia glaucophylla is data deficient under Criterion E.

Probability of extinction

Currently there are not enough data to undertake a quantitative analysis to determine the extinction probability of *Darwinia glaucophylla.*

Conservation and Management Actions

This species is currently listed on the NSW *Biodiversity Conservation Act 2016* and a conservation project has been developed by the NSW Department of Climate Change, Energy, the Environment and Water under the Saving our Species (SoS) 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. *Darwinia glaucophylla* sits within the Site-managed species stream of the SoS program, and the conservation project can be viewed here.

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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:
Darwinia glaucophylla was found to be Endangered under Clause 4.3(b)(d)(e i,ii,iii,iv).

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

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

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

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

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

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

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

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

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

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

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

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

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