Conservation Assessment of *Phebalium bifidum* P.H. Weston & M.J. Turton (Rutaceae)

Vera Wong 23/06/2022
DPIE Science, Economics and Insights Division

***Phebalium bifidum* P.H. Weston & M.J. Turton (Rutaceae)**

Distribution: Endemic to the Capertee Valley of NSW
Current EPBC Act Status: Not listed
Current NSW BC Act Status: Endangered

Proposed outcome of Conservation Assessment: Endangered.

Summary of Conservation Assessment

Phebalium bifidum was found to be eligible for listing as Endangered under Criteria B1ab(iii)(v) + B2ab(iii)(v).

The main reasons this species is eligible for listing are:

(i) it has a very highly restricted geographic range,

(ii) the species is only known from five or less locations, and

(iii) there is an estimated continuing decline in the habitat quality and number of mature individuals due to susceptibility to drought, land use changes on private land, inappropriate fire regimes and road maintenance.

Description and Taxonomy

Phebalium bifidum is a small to medium sized shrub that was only recently discovered, informally described in 1998 as *Phebalium* sp. 'Capertee'. It was formally described by Weston and Turton (2004) as "an erect shrub 0.2–1.5 m high. Branchlets erect to spreading, terete, densely covered in glossy, scale-like compound trichomes, which vary in colour when young from cream with a scattering of ferruginous scales to uniformly ferruginous, discolouring to matt grey with age; oil glands not raised, covered by scales. Leaves of sexually immature shoots ('juvenile leaves') at first cuneate, with a slightly emarginate apex, successive leaves developing a distinctly bilobed apex, the largest leaves reaching 16 mm long, 3.5 mm wide, with an apical sinus 1 mm deep, densely lepidote on abaxial surface. Leaves of sexually mature shoots ('adult leaves') spreading to erect, shortly petiolate, Y-shaped, bilobed, 3.5–14 mm long; petiole 0.3–1.0 mm long, densely covered in scales; adaxial surface of lamina dark green when fresh, fading to olive or greyish green when dried, with distinctly impressed midvein, with oil glands protruding slightly above surrounding epidermis, sparsely to moderately covered in scales when young, glabrescent with age; margins entire, revolute; abaxial surface of lamina densely covered in glossy cream scales and a scattering of ferruginous scales when young, the scales discolouring to grey with age, the midvein protruding slightly to prominently; basal part of lamina (proximal to the lobes) narrow-oblong to narrow-cuneate, 2–10 mm long, 1–1.8 mm wide, 0.5–0.85 the length of the whole lamina; lamina lobes oblong or tapering slightly to a truncate to obtuse tip, straight or laterally incurved, 0.5–3.0 mm long, 0.6–1.2 mm wide, diverging from each other at an angle of 25–90º; sinus between lobes v-shaped to u-shaped, 0.5–2.5 mm

deep, 0.5–3.5 mm wide. Inflorescences umbelliform, sessile or rarely shortly pedunculate, terminal or rarely axillary, 2–11- flowered. Pedicels c. 0.4–0.5 mm thick at base, c. 0.7–0.8 mm thick at apex, 2.5–7.5 mm long, densely covered in glossy cream scales and usually a few scattered ferruginous scales. Mature bud broadly obovoid, c. 2.5 mm long, c. 2.0 mm wide. Calyx cupulate, 0.9–1.6 mm long, 2.0–2.5 mm wide, smooth or verrucose with slightly protruding oil glands, densely lepidote with scales grading in colour from predominantly cream at the base to ferruginous at the upper margin, truncate to obtusely lobed. Petals 5, spreading, ±elliptical, 3.0–3.5 mm long, 1.4–1.8 mm wide, cream to bright lemon yellow on adaxial surface, densely lepidote on abaxial surface with glossy cream scales in the basal half and ferruginous scales in the apical half. Stamens divergently and symmetrically spreading, cream to bright lemon yellow; staminal filaments filiform, 5.0–5.5 mm long, c. 0.1 mm thick; anthers elliptical, glandular-apiculate, 0.6–1.2 mm long. Ovary subspherical, 0.9–1.1 mm high, densely covered in shiny, colourless, semi - transparent scales; style glabrous, ± equal to stamens, cream to bright lemon yellow. Fruits and seeds not known." A description of the taxon is also given in PlantNET (2022).

Phebalium bifidum has morphological differences between the north and south of its range. At the southern Capertee Valley site, the *P. bifidum* individuals grow taller with broader leaves that are not as deeply cleft; the leaves look more heart-shaped than Y-shaped (D. Coote pers. comm. December 2021; M Duretto *in litt.* December 2021). Marco Duretto (*in litt.* December 2021), Rutaceae specialist at the National Herbarium of NSW, considers that the single herbarium specimen of this species from the Glen Davis site fits the species taxonomic description, but may warrant future taxonomic investigation if more specimens could be collected from multiple similar sites.

According to Weston and Turton (2004) *Phebalium bifidum* appears most closely related to *P. obcordatum* and *P. glandulosum*, differing in several ways but most obviously in possessing Y-shaped (bifid) leaves on mature, sexually reproductive stems.

Distribution and Abundance

Phebalium bifidum is endemic to NSW. The NSW Scientific Committee (2005) state that "*Phebalium bifidum* is found in the Capertee Valley, SE of Kandos in the South Eastern Highlands bioregion in NSW (Thackway and Creswell 1995)". The committee also found that there are only two known populations, located approximately 3 km apart that occur in dry sclerophyll woodland or heath on structured loam soil (Weston and Turton 2004).

Since the Final Determination by the NSW Scientific Committee (2005), *Phebalium bifidum* had been recorded from previously unknown sites in the central Capertee Valley, increasing the number of sites with discreet clusters of individuals from two to six (Map in Appendix II). The recent discoveries inform that the species is more widespread than previously thought. Additional occurrences of this species may also exist, as there has only been a minor search effort of potential habitat (D. Coote pers. comm. December 2021; DECC 2008; S. Clarke pers. comm. December 2021; Turton and Jones 2008).

The current distribution is based on a cleaned set of 43 unique records compiled from the Atlas of Living Australia, the NSW Bionet Atlas and herbarium specimens. The georeferences of 4 records were revised based on their descriptions. An additional 35

records were included from a 2008 survey (Turton and Jones 2008), 245 records from a 2020 survey (Priday 2020) and 796 records from a 2022 survey (V. Wong and K. Wilkins pers. obs. May 2022).

Extent of occurrence (EOO) and area of occurrence (AOO)

The discovery of new sites since the 2005 Final Determination (NSW Scientific Committee 2005) has increased the known EOO from 0.3 km^2 to 59 km^2 and the AOO from 8 km^2 to 32 km^2. The AOO is based on 2 x 2 km grid cells, the scale recommended for assessing area of occupancy by IUCN (2022). The EOO is based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2022). The EOO and AOO were calculated using Kew Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.* 2011) and encompasses the entire known historical and extant distribution of the species.

The six *Phebalium bifidum* sites are located between Port Macquarie Road and Glen Davis in the Capertee Valley (Map in Appendix 1). The five northern sites, Port Macquarie Road, Glenolan, Capertee NP, Capertee River and Oakydale, have a roughly north to south linear range. Each site is separated by 1.5 to 2 km and there is 16 km separation to the southernmost site, Glen Davis. *Phebalium bifidum* has a total linear range of 23 km.

Until 2020 *Phebalium bifidum* occurred almost entirely on private land, when additions to Capertee NP included the sites at Capertee River and Capertee NP. Oakydale and Glen Davis, the largest and third largest stands, are located entirely on private property and Glenolan is located predominantly on private property. Port Macquarie Road is located partly on private property and within a local government road reserve. The private land sites occur in proximity to cleared or partially cleared habitat and are adjacent to fire trails or roads. The sites where *P. bifidum* is known to occur are connected north to south by continuous bushland that runs through connected NPWS reserves, except in the very north of its range.

Population size

The current population size estimate is 2000-2200 mature plants (assuming no seedlings are mature) to potentially 2300+ (assuming a small proportion of seedlings present survive to maturity). The population estimate for *Phebalium bifidum* can be made by combining survey data from 2022 and 2020 for five of the six sites with an estimate from 2011 for the Capertee River site (Table in Appendix 1). The methods used to derive population estimates for each site are described in detail in the following paragraphs.

In 2020, the sites at Port Macquarie Road, Glenolan, Capertee NP and Oakydale were surveyed recording a total population of 260 (15%) mature plants and 1,485 (85%) seedlings (Priday 2020). Priday (2020) considered the Oakydale site to be “substantially under surveyed” and estimated the actual population of adult plants at Oakydale to be 350, substantially higher than the survey count of 210. Priday’s revised estimate takes into account records from 2008 surveys (Turton and Jones 2008) and the apparent condition and structure of vegetation in the unsurveyed area. Using this adjustment, the estimated total population over the four 2020 survey sites is between 260-400 mature individuals, with 81-88% of the estimated adult population at the

Oakydale site. Seedling recruitment was found at all 2020 survey sites, with mass germination evident at the two northernmost sites.

Priday (2020) notes “Plants were defined as seedlings if they had both a basal stem diameter of less than 2mm and were under 20 cm tall, although on two occasions plants with only one of these characteristics were encountered. Non-seedlings are described throughout this report as ‘mature’ plants, although it is not known at what age and/or size plants reach reproductive maturity. For the sake of simplicity, a mature plant was considered one that has survived beyond the seedling stage.” Priday (2020) found that c. 87% of plants with a diameter of <5mm had no fruit production and c. 57% of plants <10 mm diameter had no fruit production. Consideration of the observations and the method used by Priday (2020) to age plants suggests that the 2020 survey result may represent an overestimate of mature individuals.

A count in 2011 at the Capertee River site, which was not surveyed in 2020, provided a rough estimate of 300-500+ flowering plants (S. Clarke pers. comm. December 2021). This site has not been revisited.

The southernmost *Phebalium bifidum* site at Glen Davis was discovered in 2008 and observed to have the largest and presumably oldest known *Phebalium bifidum* individuals, which unlike the other sites, dominated the understory (Coote *et al*. 2008). A 2022 survey observed 1315 flowering plants and 144 seedlings in two patches 60m apart (V. Wong pers. obs. May 2022).

Population trends

Since the discovery of *Phebalium bifidum* in the late 1990s adult population trends have been found to be declining at some sites and increasing or unknown at others. At the northernmost sites, Port Macquarie Road and Glenolan, anecdotal observations (N. Keck pers. comm. in Priday 2021; M. Turton pers. comm. February 2022) suggest that the number of mature plants has declined dramatically since the mid-2000s. In 2002, 195 *P. bifidum* plants from 15 cm up to 2 m tall were recorded at the Glenolan site (H. Washington pers. comm. February 2022), compared to 11 mature plants (>20 cm) recorded in 2020 (Priday 2020). Both survey methods are likely to overestimate the number of mature plants but are comparable to measure population change. In 2007, 31 mature plants were recorded at the Port Macquarie Road site (DECC 2008) compared to nine mature plants in 2020 (Priday 2020). In contrast, between 2008 and 2020, the estimated number of mature plants at the Oakydale site increased from 172 to between 210-350 (Priday 2020; Turton and Jones 2008).

It is unclear whether estimated population changes are natural fluctuations or long-term changes. The drought between 2017 and 2019 may have resulted in the loss of some *Phebalium bifidum* plants from the northern stands, reflecting natural fluctuations in the populations as old plants senesce and seedlings emerge, however it does not explain the losses that predate the drought (Priday 2020). Drought related mortality rates of mature plants at the Oakydale site, appeared to be substantially lower than losses at the northern sites (Priday 2020). This may be explained by the better condition of the bush surrounding the Oakydale site, giving *P. bifidum* more resilience to drought than at the northern sites which both adjoin cleared or partially cleared land. At the two northernmost sites, the two areas that experienced both the highest levels of mortality of mature plants and seedling germination, it is unknown

what proportion of the seedlings will survive and if the number of mature plants will recover to pre-drought levels.

Ecology

There is very little known about the biology and ecology of *Phebalium bifidum*, other than habitat descriptions of the sites within which the plants have been found. *Phebalium bifidum* flowers with actinomorphic, yellow flowers in spring, typically from August to October.

Habitat

Phebalium bifidum populations are located on the upper slopes and crests of broad ridgelines in the central Capertee Valley, only found at an altitude between 460 to 560 m, well beneath the surrounding escarpment country. The vegetation at the northern sites is shrublands characterised by a sparse tree layer, adjoining low woodlands dominated by *Eucalyptus nubilis* and *Callitris endlicheri* (Priday 2020). The vegetation at Glen Davis an overstory dominated by *E. fibrosa* and an understorey dominated by *P. bifidum*, *Bursaria spinosa*, *Lepidosperma* spp. and *Poa* spp. (Coote *et al*. 2008). The habitat of all but the Port Macquarie Road site is reported to be in very good to excellent condition with respect to floristic diversity and structure and the minimal extent to which they are affected by disturbance, including weeds (Priday 2020).

Germination and population dynamics

Soil disturbance and reduced competition from other plant species due to grazing or physical disturbance, plant mortality or skeletal, rocky soils creating gaps in the vegetation cover appears to allow for successful seedling establishment in *Phebalium bifidum*. There is no information on the influence of fire on seedling establishment.

The presence of numerous plants at the south-eastern end of the Oakydale site growing in an area that had been scraped clear of vegetation along a boundary fence suggests that removal of vegetation and physical disturbance of the soil, at least of the upper part of the profile, promotes germination of the species (Priday 2020). Jusaitis (2000) reported substantial seed germination of *Phebalium equestre* in a road verge that had been completely cleared of vegetation by grading. Soil disturbance has been suggested as a possible germination cue for the taxonomically similar *Leionema sympetalum* (NSW Government 2022). At the Port Macquarie Road site, *P. bifidum* plants were reported to be more abundant when horses grazed part of the site and declined after the horses were excluded from the site (D. Coote pers. comm. December 2021).

The fluctuations in the number of mature plants and the large recent germination event in the two northern *Phebalium bifidum* sites are similar to patterns of mortality and germination reported for other *Phebalium* species (Priday 2020). The preceding years of drought would have resulted in a significant reduction in the biomass of the vegetation at these sites allowing heating of the soil and combined with the subsequent above-median rainfall in the first half of 2020 may have provided suitable conditions for the major germination event. However, this was not found at the other sites. The southern sites have denser canopy cover which can ameliorate drought pressures, reducing plant mortality and the resulting gaps in ground cover where seedlings can establish. At Glen Davis, most seedlings were found on a thinly

vegetated, rocky slope, where seedling survivorship may be low once climatic conditions return to normal rainfall levels (V. Wong pers. obs. May 2022).

There is no information available on the frequency of germination events and survival rates for individual cohorts of *Phebalium bifidum.* Priday (2020) suggests that germination events may occur relatively consistently and that they are either much smaller in magnitude than was the case in 2020 and survival rates are moderately high, or that similar numbers of seedlings as were observed in the most recent event are consistently produced but survival rates within seedling cohorts are relatively low. Alternatively, the extensive germination event such as occurred at the Port Macquarie Road and Glenolan in 2020 may be an infrequent event but survival rates may be high enough to re-establish the mature plant population at a site.

There is no information on time to maturity and longevity of *Phebalium bifidum*. Another *Phebalium*, *P. nitens*, from south-east Queensland, has been observed to have a generation length of approximately five years, based on observations of cultivated individuals in gardens (Forster 2019). Generation length is suspected to be longer in wild subpopulations (Forster 2019). If *P. bifidum* has a similar generation length, including allowing for greater longevity in the wild, then its generation length could be inferred to be around seven years, or three generations around 20 years.

Pollination, seed dispersal and gene flow

Pollination of *Phebalium* species is generally by beetles, but also by flies and bees (Armstrong 1979). Pollination can potentially occur over many kilometres, with the foraging range of honeybees (*Apis mellifera*) known to be a maximum of 11-12 km, but influenced by the locations of suitable foraging patches (Beekman and Ratnieks 2000).

The seeds of *Phebalium* spp. are very small and dispersal may occur via an ejectile mechanism, or by transport by ants, water or wind (Lynch and Appleby 1996). If self-ejectile, ants and physical forces are the dispersal agents for this species, then it is highly unlikely that seeds are transported far from any site. In sclerophyll vegetation near Sydney, ants have been found to disperse seeds between mostly less than 2 m and rarely over 4 m (Westoby *et al.* 1991).

The potential for gene exchange between *Phebalium bifidum* sites divides them into two subpopulations. The five northern *P. bifidum* sites are one subpopulation; they are separated by 1.5 and 2 kms which is within potential pollination distance. The southern Glen Davis site is the second subpopulation as it is separated by 16 km and it is highly unlikely that any gene flow occurs between this and the northern sites.

Fire ecology and fire history

There is no information on the fire ecology of this species. However, many species of *Phebalium* are known to be obligate seeders (Auld 2001) and populations of mature plants have been reported to be inversely correlated with time since fire (Carter 2010).

Fire has been found to be a germination cue for the taxonomically similar *Leionema lachnaeoides* (M. Jones pers. comm. March 2022). The specific fire-related cues for seed germination (e.g., heat, smoke, season, disturbance) are unknown for most *Phebalium* species. Studies of fire and seasonal temperature influence on germination in another Rutaceae species, *Boronia* spp., found that different species had highly variable responses, despite being closely related (MacKenzie *et al*. 2016). Seasonal

temperature (summer/winter), heat shock (related to soil heating from fire intensity) and smoke, were important cues that were different for each species studied. Seasonal timing and intensity of the hazard reduction burns may influence successful post-fire recruitment (Mackenzie *et al*. 2021).

In a study of the ecology of the Rutaceae in the Sydney region, Auld (2001) found that seed production after a fire may require three to five years, plants may be small when first mature and seed output may be low until plants grow. *Phebalium distans*, from south-east Queensland, flowers under good conditions after five years (Forster 2019). If the flowering ecology of *P. bifidum* is similar to these related species, then the minimum fire interval for species survival would be approximately seven years. In the Rutaceae of the Sydney region there is virtually no information on the longevity of seed or the nature of soil seedbanks and only a few studies on post-fire seedling survival (Auld 2001).

There are no recorded fires for any *Phebalium bifidum* sites (National Parks and Wildlife Service Fire History spatial layer 2022; Rural Fire Service Fire History spatial layer 2021). However, fire records may not be complete for this area, as until recently all known occurrences were on private land, where small fires lit for agricultural purposes may not have been recorded. The long-term absence of fire from *Phebalium bifidum* habitat coupled with historic land clearing of comparative areas of the Capertee Valley may provide one reason for the rarity of this species.

Threats

The NSW Scientific Committee (2005) state that "*Phebalium bifidum* is threatened with clearing and habitat fragmentation, and road maintenance activities. It is at risk of extinction from stochastic processes due to its very highly restricted distribution and very low population numbers." These threats are ongoing for the species and additional threats have been identified since the Final Determination (NSW Scientific Committee 2005).

Land clearing and degradation

Land clearing and land degradation on private land is an ongoing threat to *Phebalium bifidum*. Historic vegetation clearing of comparative areas of the Capertee Valley provides one explanation for the rarity of this short-range endemic species. The persistence of *P. bifidum* in the central Capertee Valley, with its very highly restricted EOO and restricted AOO, and with four of six sites located on private land, depends on favourable land management practices. There were no livestock run on private land sites when they were surveyed in 2020 and 2022 and much of the native vegetation has been retained (Priday 2020; V. Wong pers. obs. May 2022). The current favourable land use practices are reliant on the ongoing good will and education of the landowners and property managers and future changes may adversely affect the population.

Drought

The decline in the number of mature plants at the Port Macquarie Road and Glenolan sites from the species discovery in the late 1990s to the early 2000s has been, in part, attributed to prolonged drought conditions (M. Turton pers. comm. February 2022). The central Capertee Valley is in a rain shadow, which increases the susceptibility of *Phebalium bifidum* to drought. The proximity of cleared and partially-cleared land and

sparse canopy cover of the northern *P. bifidum* sites intensifies exposure to drought conditions. Increased frequency and severity of drought associated with ongoing climate change (Dai 2021; IPCC 2022) is an estimated, ongoing threat to the long-term survival of this species. 'Anthropogenic climate change' is listed as a Key Threatening Process under the BC Act.

Inappropriate fire regime

The absence of fire from *Phebalium bifidum* sites for an extended period may in part explain the declines observed of this species, based on what is known of the fire ecology of other *Phebalium* and taxonomically similar species. All *P. bifidum* sites escaped the extensive summer 2019/2020 fires, which burnt extensive tracts of vegetation in the nearby reserves of the Capertee Valley (NPWS Fire History spatial layer). The large amount of cleared land to the north and east of the *P. bifidum* population provides a substantial barrier to fire spread.

Hazard reduction burns are planned by the NPWS for the two sites within Capertee NP in 2022 and 2023 (NPWS Blue Mountains Branch). If fire triggers substantial recruitment events at these sites and if *Phebalium bifidum* is a fire sensitive obligate seeder, any bushfires affecting the National Park sites within the decade following the burns would threaten local populations. A fire within the next few years would threaten the Port Macquarie Road and Glenolan sites given the recent mass gemination events. Frequent recurrent fire in a species that is killed by fire is a serious threat (Auld 2001; Ford and Duretto 2020) as it exposes the species to "interval squeeze", a narrowing of the favourable interval between fires increasing local extinction risk by disrupting the replenishment of seed banks, which are essential to post-fire recruitment and population persistence (Enright *et al.* 2015; Gallagher *et al*. 2020). 'High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition' is listed as a Key Threatening Process under the BC Act.

Disease

Phytophthora cinnamomi is likely to be a potential, ongoing threat to *Phebalium bifidum*, based on a study of susceptibility in which all the inoculated individuals died (Wan *et al*. 2019). *Phytophthora cinnamomi* is an introduced pathogen that has had a devastating effect on plant communities world-wide, causing catastrophic dieback in many species. 'Infection of native plants by *Phytophthora cinnamomi*' is listed as a Key Threatening Process on the BC Act. Hygiene to prevent pathogen spread and soil movement to the *P. bifidum* sites is vital. There is no information available on the presence of *P. cinnamomi* in the *P. bifidum* population, but as many of its known occurrence are close to roads it could be easily introduced.

Weed invasion

Competition from weeds is a potential ongoing threat to *Phebalium bifidum.* In 2022, no weeds were found at the Glen Davis site (V. Wong pers. obs. May 2022) and the 2020 surveys found that weeds were generally rare in the areas supporting *P. bifidum*, except for at the Port Macquarie Road site (Priday 2020).

The Port Macquarie Road site differs in being partly located within a road reserve, which is affected by activities typical of such environments (e.g., partial vegetation clearing, drain construction, access by vehicles, periodic disturbance from road

maintenance activities), and partly in a paddock on private property that was presumably cleared in the past for livestock grazing (although no stock has been kept in the paddock since the discovery of the species). In the latter, several species were present, though none were abundant (Priday 2020). The most noteworthy were *Opuntia stricta*, which is locally common in the broader Port Macquarie Road area but only scattered in the area of *Phebalium bifidum* and *Cineraria lyratiformis*, a species that is very widespread in the region but generally uncommon, though apparently capable of proliferating under favourable conditions.

Road maintenance/widening

Road/fire trail maintenance or alignment works are a potential, ongoing threat at the Port Macquarie Road, Glen Davis and Oakydale sites. Historically, there was an incident where *Phebalium bifidum* individuals were accidently cleared from the Port Macquarie Road site (S. Bell pers. comm. December 2021). Currently, the Port Macquarie Road threat is managed by the Lithgow City Council by surveying the roadside and marking prior to grading so no plants are impacted. There is no roadside signage indicating the presence of a threatened species.

Grazing

Feral goats and rabbits are present in the central Capertee Valley and are a potential, ongoing threat to *Phebalium bifidum*. At high densities feral herbivore grazing may have a detrimental effect on the species, especially young plants. Feral goats are the target of ongoing NPWS control programs in Capertee and other nearby National Parks (A. Bryce pers. comm. December 2021). In both 2022 and 2020 surveys there was no evidence of grazing of *P. bifidum*, by either native or introduced herbivores (Priday 2020). Some *Phebalium* spp. are known to be affected periodically by browsing, although most species appear to be able to respond to intermittent removal of most leaves (Jusaitis 2000).

In some circumstances, grazing may benefit the species by reducing competition from other plants. Historic grazing by horses at the Port Macquarie Road site appeared to stimulate seedling germination and the number of mature plants has declined since horses were excluded (D. Coote pers. comm. December 2021).

Assessment against IUCN Red List criteria

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

Criterion A *Population size reduction*

Assessment Outcome: Vulnerable A2(a)(c)

Justification: The current estimated population size of *Phebalium bifidum* is 2000-2300+ mature individuals, assuming that some of the current seedlings mature. Generation length can be inferred from another *Phebalium*, *P. nitens*, from south-east Queensland, which has been observed to have a generation length of approximately five years, based on observations of cultivated individuals in gardens (Forster 2019). The generation time in the wild is suspected to be longer. If *P. bifidum* has a similar generation length, including allowing for greater longevity in the wild, then its generation length could be inferred to be around seven years, or three generations around 20 years.

The two northernmost *Phebalium bifidum* sites, Port Macquarie Road and Glenolan, are suspected to have declined as a result of drought, habitat disturbance and long-term absence of fire since the mid-2000s. The decline in mature plants at the Glenolan site was from 195 to 11, or 94%, in the 20 years 2002 to 2020. At the Port Macquarie Road site, the population declined from 31 to nine, a 66% decline in the 13 years 2007 to 2020. In contrast, the Oakydale population increased from 162 to 172 in the six years from 2002 and 2008 and further increased to between an estimated 210-310 in the next 12 years to 2020, a 30-90% increase in 18 years.

The estimated total population from the Port Macquarie Road, Glenolan and Oakydale sites was 398 in 2002 and 230 to 320 in 2020, which gives an overall population size reduction in 18 years of 20-42%. Hence, the estimated *P. bifidum* population size reduction from the last three generations from these three sites is from 20-42%. There is no time series data available for the populations at the other three *P. bifidum* sites, estimated to be over 70% of the total population size, however taking a precautionary approach the decline estimated at the sites where data is available can be inferred across the entire population to assess this Criteria. A population size reduction of 20-42% meets the threshold for Vulnerable taking the precautionary approach of using the greater population size reduction when there is a range of values as recommended in the IUCN Guidelines (2022). A decline in habitat quality has occurred with drought, absence of fire and roadside disturbance.

Criterion B Geographic range

Assessment Outcome: Endangered under Criterion B1(iii)(v) + B2ab(iii)(v).

Justification: The extent of occurrence (EOO) is 59 km^2 and falls under the threshold for Critically Endangered (<100 km^2). The EOO is based on a convex hull polygon fitted around all known records as per IUCN Guidelines (2022). The area of occurrence (AOO) is 32 km^2 and falls under the threshold for Endangered (<500 km^2). The AOO is estimated using a 2 x 2 km grid as per IUCN Guidelines (2022). In addition to these thresholds, at least two of three other conditions must be met. 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: There are five or less locations, which meets the threshold for the category of Endangered. The species is not severely fragmented.

   Justification: There are six clusters of records in the Capertee Valley, with five of these clusters separated by varying distances of approximately 1.5-2km and the southernmost site 16 km away.

   If inappropriate fire regime is the threat used to determine the number of locations of this species, the total *Phebalium bifidum* population could be considered as one location which meets the threshold for this criterion for Critically Endangered. The entire species distribution is within a highly restricted EOO and connected by continuous bushland giving it the potential to be burnt in a single fire. The *P. bifidum* sites were not burnt in the extensive 2019/20 summer fires, however, the distance of fire spread seen under the severe fire conditions in nearby reserves is indicative of the potential of fire spread in the central Capertee Valley. Ongoing climate change is predicted

to result in increased fire frequency and size of wildfire in south-eastern Australian, which can threaten the persistence of fire sensitive obligate seeders.

The geographical separation of the Glen Davis subpopulation of 16 km from the nearest plants could divide the population into two locations under the threat of inappropriate fire regime which meets the threshold for this criterion for Endangered. The Capertee to Glen Davis Road provides a major barrier to fires travelling between north and south and a logical containment line for hazard reduction or back burn operations. The extensive cleared land to the east and south of the northern *Phebalium bifidum* sites also acts as a barrier to fire from the east, and between the northern and southern sites.

If the threat of land clearing and other land use changes is used to define the number of locations, then the *Phebalium bifidum* population can be divided into five locations which meets the threshold for this criterion for Endangered. The four sites on private land can be considered separate locations as they are on different properties. The two sites in Capertee NP are one location as they are protected in the reserve.

The species is not severely fragmented as only the two northern sites could be considered smaller than could be required to support a viable population which is <50% of its total area of occupancy.

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

Assessment Outcome: Subcriterion met for (iii)(v).

Justification: There is a continuing decline estimated since the mid-2000s at the two northernmost *Phebalium bifidum* sites, Port Macquarie Road and Glenolan, as a result of drought, habitat disturbance from road maintenance and inappropriate fire regime. These two *P. bifidum* sites are estimated to be more suspectable to drought than the other sites as they have sparse canopy cover and are in close proximity to cleared or partially cleared land.

The decline in mature plants at the Glenolan site was from 195 to 11, or 94%, in the 20 years 2002 to 2020. At the Port Macquarie Road site, the population declined from 31 to nine, a 66% decline in the 13 years 2007 to 2020. Both sites experienced large recruitment events in 2021, however seedling survivorship rates are unknown for this species and it is not known if the number of mature plants at these sites will recover to previously recorded levels.

Increased frequency and severity of drought associated with ongoing climate change, land use changes on private land and fire before seedlings mature and seedbanks replenish threaten both habitat quality and the number of mature plants at the Port Macquarie Rd and Glenolan sites.

c) Extreme fluctuations

Assessment Outcome: Data deficient.

Justification: It is unknown if *Phebalium bifidum* has extreme fluctuations and more information about the ecology of the species is required before this can be determined.

Criterion C Small population size and decline

Assessment Outcome: Criterion not met

Justification: The total population estimate for *Phebalium bifidum* is between 2000-2300, assuming that some of the current seedlings mature, which meets the threshold for listing as Endangered (≤2500 mature individuals).

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: The generation length, as explained in Criterion A, can be inferred to be around seven years, or two generations around 14 years. Monitoring data for the last 14 years is only available from two *Phebalium bifidum* sites. At the Port Macquarie Road site, there was an observed population declined from 31 to nine, a 66% decline in the 13 years 2007 to 2020. In contrast, the estimated Oakydale population increased 172 to between an estimated 210-310 in the 12 years to 2020, a 30-90% increase. There is no trend data available from the last 14 years for the other four sites four sites, which is estimated to be more than 70% of the total population.

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

Assessment Outcome: Subcriterion not met

Justification: There is a continuing decline estimated since the mid-2000s at the two northernmost *Phebalium bifidum* sites, Port Macquarie Road and Glenolan, as a result of drought, habitat disturbance from road maintenance and inappropriate fire regime. These two *P. bifidum* sites are estimated to be more suspectable to drought than the other sites as they have sparse canopy cover and are in close proximity to cleared or partially cleared land.

The decline in mature plants at the Glenolan site was from 195 to 11, or 94%, in the 20 years 2002 to 2020. At the Port Macquarie Road site, the population declined from 31 to nine, a 66% decline in the 13 years 2007 to 2020. Both sites experienced large recruitment events in 2021, however seedling survivorship rates are unknown for this species and it is not known if the number of mature plants at these sites will recover to previously recorded levels.

Increased frequency and severity of drought associated with ongoing climate change, land use changes on private land and fire before seedlings mature

and seedbanks replenish threaten the number of mature plants at the Port Macquarie Rd and Glenolan sites.

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: Subcriterion not met.

Justification: The population of *Phebalium bifidum* can be considered to have two subpopulations. The five northern sites are all within 1.5-2 km, well within the foraging range of their bee pollinators, which makes them of one subpopulation. The southern site at Glen Davis is the second subpopulation, located 16km form the northern sites and with morphological differences in leaf shape and growth habit suggesting genetic isolation.

The number of mature individuals in the northern population is estimated to be 650 to c.1000. The number of mature individuals in the southern population is c. 1300, which exceeds the threshold for this Subcriterion.

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

Assessment Outcome: Subcriterion not met.

Justification: 30-40% of mature *Phebalium bifidum* plants are in the northern subpopulation and 60-70% are in in the southern population.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Data deficient

Justification: It is unknown if *Phebalium bifidum* has extreme fluctuations and more information about the ecology of the species is required before this can be determined.

Criterion D Very small or restricted population

Assessment Outcome: Criterion not met.

Justification: The lower estimate of population size of *Phebalium bifidum* is 2000, which falls above the thresholds for this category. *Phebalium bifidum* meets the threshold for number of locations ≤5 for D2. However, there is no plausible future threat that could drive this taxon to extinction 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: Subcriterion not met

Justification: The lower estimate of population size for *Phebalium bifidum* is 2000, which falls above the thresholds for this category.

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: Subcriterion not met.

Justification: The AOO of *Phebalium bifidum* of 32 km^2 exceeds that suggested threshold of <20 km^2 but meets the threshold for number of locations ≤5. However, there is no plausible future threat that could drive this taxon to extinction in a very short time.

Criterion E Quantitative Analysis

Assessment Outcome: Data deficient

Justification: No quantitative analysis has been carried out to assess the probability of extinction in this taxon.

Conservation and Management Actions

This species is currently listed on the NSW BC Act and a conservation project has been developed by the NSW Department of Planning and Environment under the Saving our Species program. The conservation project identifies priority locations, critical threats and required management actions to ensure the species is extant in the wild in 100 years. *Phebalium bifidum* sits within the Site-managed species stream of the SoS program and the conservation project can be viewed here: https://www.environment.nsw.gov.au/savingourspeciesapp/project.aspx?ProfileID=20038.

References

Armstrong JA (1979) Biotic pollination mechanisms in the Australian flora — a review.
New Zealand Journal of Botany, **17(4)**, 467-508.

Auld TC (2001) The ecology of the Rutaceae in the Sydney region of south-eastern Australia: Poorly known ecology of a neglected family. *Cunninghamia* **7(2)**, 213–239.

Bachman S, Moat J, Hill AW, de la Torre J, Scott B (2011) Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool, in Smith

V & Penev L (eds) e-Infrastructures for data publishing in biodiversity science. *ZooKeys* **150**, 117–126. (Version BETA)

Beekman M, Ratnieks FLW (2000) Long-range foraging by the honey-bee, *Apis mellifera* L. *Functional Ecology*, **14(4)**, 490–496.

IPCC (2022) Intergovernmental Panel on Climate Change. Available at https://www.ipcc.ch/ (accessed 11.02.2022)

Dai AG (2012) Increasing drought under global warming in observations and models. *Nature Climate Change* **3**, 52–58.

Carter O (2010) National Recovery Plan for the Lowan Phebalium *Phebalium lowanense*. Department of Sustainability and Environment, Melbourne.

Coote D, Armstrong R, Noble N (2008) Discovery of a New Population of the Endangered Scrub *Phebalium bifidum* in the Capertee Valley, New South Wales.

Department of Environment and Climate Change (2008) Identifying and managing priority threatened flora sites in the north-west Hawkesbury Nepean Catchment. Part I. NSW Department of Environment and Climate Change, Dubbo.

Enright NJ, Fontaine JB, Bowman DMJS, Bradstock RA, Williams RJ (2015) Interval squeeze: Altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes. *Frontiers in Ecology and the Environment* **13(5)**, 265–272.

Ford AJ, Duretto M (2020) *Phebalium cicatricatum* (Rutaceae), a newly described and Critically Endangered species from north-eastern Queensland, Australia. *Journal of Plant Systematics* **23**, 131–136.

Forster PI (2019) Nomination form to change the conservation class of *Phebalium distans* in Queensland.

Gallagher RV, Allen S, Mackenzie BD, Yates CJ, Gosper CR, Keith DA, Auld T D (2021) High fire frequency and the impact of the 2019–2020 megafires on Australian plant diversity. *Diversity and Distributions* ***27(7)***, 1166–1179.

IUCN Standards and Petitions Subcommittee (2022) Guidelines for Using the IUCN Red List Categories and Criteria. Version 15. https://nc.iucnredlist.org/redlist/content/attachment_files/RedListGuidelines.pdf.

Jusaitis M (2000) The Ecology, Biology and Conservation of Threatened *Phebalium* Species in South Australia. Department for Environment and Heritage, South Australia.

Lynch AJJ, Appleby MWA (1996) *Phebalium daviesii* Recovery Plan. Department of Primary Industries, Water and Environment.

Mackenzie BD, Auld TD, Keith DA, Ooi MK (2016) How fire and seasonal temperatures influence the germination of many plant species: Insights from 'Boronia' (Rutaceae). *Australasian Plant Conservation: Journal of the Australian Network for Plant Conservation* **25(2)**, 5–7.

Mackenzie BD, Auld TD, Keith DA, Ooi MK (2021) Fire Seasonality, Seasonal Temperature Cues, Dormancy Cycling, and Moisture Availability Mediate Post-fire Germination of Species With Physiological Dormancy. *Frontiers in plant science*, **12**, 795711

NSW Government (2022) Rylstone Bell – profile. Available at https://www.environment.nsw.gov.au/threatenedSpeciesApp/profile.aspx?id=10458 (accessed 23.02.2022)

NSW Scientific Committee (2005) Final determination to list the shrub *Phebalium bifidum* P.H. Weston & M Turton as an Endangered species [WWW Document]. Available at: https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/2004-2007/phebalium-bifidum-a-shrub-endangered-species-listing (accessed 24.11.2021)

PlantNET (The NSW Plant Information Network System) Royal Botanic Gardens and Domain Trust, Sydney. http://plantnet.rbgsyd.nsw.gov.au (accessed 28 February 2022). Available at: https://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Phebalium~bifidum

Priday S (2020) Surveys of *Phebalium bifidum* in the Capertee Valley, NSW. PSP Ecological Consulting, Queensland.

Turton M, Jones W (2008) Targeted survey for *Grevillea obtusiflora subsp. fecunda* and *Phebalium bifidum* in the Capertee Valley. Epacris Environmental Consultants Pty Ltd.

Wan JS, McDougall KL, Liew EC (2019) The susceptibility of rare and threatened NSW species to the root-rot pathogen *Phytophthora cinnamomi*: 1. Initial testing and identification of key research questions. *Australian Journal of Botany* **67(7),** 510–516.

Westoby M, French K, Hughes L, Rice B, Rodgerson L (1991) Why do more plant species use ants for dispersal on infertile compared with fertile soils? *Australian Journal of Ecology*, **16(4)**, 445–455

Weston PH, Turton M (2004) *Phebalium bifidum* (Rutaceae), a new species from the Capertee Valley, New South Wales. *Telopea* **10**, 4.

Expert Communications

Sarah Bell, Ecosystems and Threatened Species, Biodiversity and Conservation, Department Planning Industry and Environment. Species Project Coordinator.

Adam Bryce, Ranger, NPWS, Mudgee Area.

Steve Clarke, species expert.

David Coote, Senior Team Leader, Ecosystems and Threatened Species, Biodiversity and Conservation. Former species coordinator.

Marco Duretto, Manager Plant Diversity, National Herbarium of New South Wales, Australian Institute of Botanical Science, Royal Botanic Gardens & Domain Trust.

Margaret Turton, species expert.

Hayden Washington, species expert.

APPENDIX 1

Assessment against *Biodiversity Conservation Regulation 2017* criteria
The Clauses used for assessment are listed below for reference.

Overall Assessment Outcome:
Phebalium bifidum was found to be eligible for listing as Endangered under Clause 4.3(b)(e)(i)(iii)

Clause 4.2 – Reduction in population size of species
(Equivalent to IUCN criterion A)
Assessment Outcome: Vulnerable under Clause 4.2(1)(c)(2)(b)(c)

(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)(e)(i)(iii)

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

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

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

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

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

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

Clause 4.7 - Very highly restricted geographic distribution of species– vulnerable species (Equivalent to IUCN criterion D2)
Assessment Outcome: Clause 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.

Table 1. *Phebalium bifidum* survey results

Site	Survey year (Adults/Seedlings)											
	2002			2007/2008			2010			2020 and 2022(Glen Davis only)		
	A	S	Total	A	S	Total	A	S	Total	A	S	Total
Port Macquarie Rd				31		31				9	401	410
Glenolan	195		195							11	930	941
Capertee NP										30	101	131
Capertee River							300-500		300-500			
Oakydale			162	172	14	186				210 *(est. 350)	53	263 *(est. 400)
Glen Davis										1,315	166	1,481

*undersurveyed, estimated number of mature plants