Conservation Assessment of *Eucalyptus benthamii* Maiden & Cambage (Myrtaceae)

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***Eucalyptus benthamii* Maiden & Cambage (Myrtaceae)**
Distribution: Endemic to NSW
Current EPBC Act Status: VU
Current NSW BC Act Status: VU

Proposed change: List as Critically Endangered on BC Act.

Summary of Conservation Assessment

A preliminary determination was placed on public exhibition from the 1st July 2022 to 1st October 2022 to list *Eucalyptus benthamii* as an Endangered Species. Following consideration of advice and submissions received, the TSSC have reassessed *E benthamii* as eligible for listing as a Critically Endangered Species under Criteria A2c and A4c. The main reasons for the listing are that the species has a suspected population reduction of greater than 80% over a 3-generation period (including both past and future) and the causes of reduction may not have ceased and may not be reversible. This reduction is mainly due to extensive habitat loss and modification in the past and ongoing threats including habitat loss, altered hydrology, the effects of introduced plant and animal species, hybridisation, and an altered fire regime.

Description and Taxonomy

PlantNET (2022) describes *Eucalyptus benthamii* as a: "Tree to 40 m high; bark smooth, white, shedding in short ribbons or flakes. Juvenile leaves opposite, elliptic to ovate, dull grey-green to glaucous. Adult leaves disjunct, lanceolate, 8–12 cm long, 1.5–2 cm wide, green, dull, concolorous. Umbellasters 7-flowered; peduncle terete, 5–6 mm long; pedicels terete, 0–2 mm long. Buds ovoid or clavate, sometimes glaucous, 3–5 mm long, 2–3 mm diam., scar present, but outer calyptra not shedding cleanly; calyptra hemispherical, shorter than and narrower than or as wide as hypanthium. Fruit campanulate, 4–5 mm long, 4–5 mm diam.; disc flat or raised; valves exserted." Brooker & Kleinig (1990) note that the bark decorticates to ground level or is retained as a small stocking of imperfectly decorticated rough bark at the base. The common name for *Eucalyptus benthamii* is the Camden White Gum or Bentham's Gum (PlantNET 2022).

The type specimen for the species was collected from the banks of the Nepean River at Cobbitty (Macarthur District) in June 1913 and Maiden and Cambage (1914) described and named the species.

In this assessment, the word population is used to refer to the concept of 'subpopulation' in IUCN (2022), in keeping with the terminology used in the NSW BC Act, EPBC Act and other state/territory environmental legislation and general biological usage.

Distribution and Abundance

Eucalyptus benthamii is endemic to the Sydney Basin Bioregion (*sensu* SEWPaC 2012) and occurs within five subcatchments of the Hawkesbury-Nepean River system: the Coxs River (where the species is now considered extinct as a result of the flooding of the Cox's River and formation of Lake

Burragorang following the construction of the Warragamba Dam (Benson 1985); the Kedumba River and some of its lower tributaries (current north-western limit); the Nattai River (southern limit); the mid-lower Nepean River (eastern limit in the Camden area); and the Hawkesbury-Nepean River in the vicinity of its confluence with the Grose River (historic northern limit: now extinct,England 2016). The Nattai population and part of the Kedumba Valley population are within the Greater Blue Mountains World Heritage Area.

A review of BioNet (2021) records of this species was undertaken in 2018. A record georeferenced as occurring in Wentworth Falls was actually from Reedy Creek, a tributary of the Kedumba River. Hence, the species' known altitude maximum is approximately 300 m, in the Werriberri Creek catchment near The Oaks. The apparent altitude minimum was ~10 m near the Grose River confluence with the Hawkesbury-Nepean in the vicinity of Yarramundi.

The habitat of *Eucalyptus benthamii* has been substantially modified since European colonisation of the Sydney region. Benson (1985) notes that "The original habitat for *Eucalyptus benthamii* was to the south-west of Sydney, on the flats of the Nepean River and its tributaries, particularly Coxs River. Since the arrival of European people, most of this habitat has been cleared for agriculture or submerged beneath the waters of Warragamba Dam. Today, one small population and a number of scattered individuals occur along the Nepean River between Wallacia and Camden. Another larger population is on Kedumba Creek about 5 km upstream from the junction with the old Coxs River. The Coxs River is now flooded by Lake Burragorang". Citing Benson *et al*. (1996), Butcher *et al.* (2005) also notes that the floodplains "were largely cleared of native vegetation for agriculture by the mid-1800s." Whilst all known extant occurrences are to the west and south-west of Sydney, the existence of unrecorded historical occurrences downstream of Yarramundi, north-west of Sydney, cannot be ruled out with certainty.

The population represented by vouchered historic records of the species from the Hawkesbury-Nepean River near the Grose River confluence is regarded as extinct (e.g. England (2016), with no modern records in that area despite the region being subject to considerable but non-targeted survey effort in recent decades). England's fieldwork suggested that mining for sand and gravel until 1990 was the likely major cause in that population's demise.

Based on its historic distribution and habitat, it seems likely that the species occurred from at least the North Richmond area (the confluence of Grose and Nepean Rivers), upstream to its present north-eastern limit at Wallacia, then along the Nepean River and suitable tributaries to at least Menangle Park where suitable riverine habitat is present. Much of this area was cleared for timber and agriculture relatively early in European colonisation, with later clearing for extraction of alluvium of varying grades, and more recently for urban use. England (2016) also notes an occurrence of the species at "Cattai Creek Reserve" (apparently Cattai Bridge Reserve) near the confluence of Cattai Creek with the Hawkesbury-Nepean River, but says this is believed to be a planting. Nonetheless, there appears to be or have been potentially suitable habitat for the species on parts of the floodplains of the Hawkesbury-Nepean River and some of its tributaries, and occurrences in those areas may have been cleared before the species was documented to have occurred there.

There are vouchered historic records from the Burragorang Valley associated with what would have been the lower Coxs, Kedumba and Wollondilly Rivers and their confluences. Other than the population extant in the Kedumba Creek catchment, those occurrences are considered extinct due to permanent inundation of a large area of former habitat in and around that region through construction of Warragamba Dam. Fairley (2004) notes: "Much of the original habitat along Coxs

and lower Kedumba Creek has been submerged beneath the waters of Warragamba Dam" (*sic* Lake Burragorang). The species was reportedly common in parts of that area e.g., Coxs River flats, but absent from the Kowmung River (LAS Johnson 1951 collection notes for specimen NSW326631, NSW Herbarium). Based on its known distribution and habitat requirements, it is feasible that the species also occurred along the lower Wollondilly River and the now-submerged parts of the lower Nattai River.

Extent of Occurrence (EOO): Based on records that are known or likely to be extant, the EOO is estimated to be 1,207 km^2 using a minimum convex polygon enclosing all mapped occurrences of the species with sufficient spatial accuracy for this purpose, as recommended by IUCN (2022). The same dataset plus historic records that are known to be extinct generates an historical EOO of 1,723 km^2. This represents a minimum estimated 30% reduction in EOO since the species was first collected in the early 1900s.

Area of Occupancy (AOO): Based on records that are known or likely to be extant, the AOO is estimated to be 116 km^2 based on the species occupying 29 (2 km x 2 km) grid cells, the spatial scale of assessment recommended by IUCN (2022). When using the same dataset plus historic records that are now presumed or known to be extinct, the historical AOO was estimated as 140 km^2. This represents a minimum estimated 17% reduction in AOO since the species was first collected in the early 1900s as, in addition there may have been more areas occupied that were not recorded before the species went extinct (e.g., beneath Lake Burragorang).

The above calculations use BioNet Atlas records with 100 m spatial accuracy or better, except for vouchered historic records that have low spatial accuracy but sufficient locational information to be useful and important for calculating historic EOO and AOO. Only a very few low spatial accuracy records for the Grose / Hawkesbury-Nepean River confluence collections and three clusters of collection records from what is now Lake Burragorang were included.

Abundance

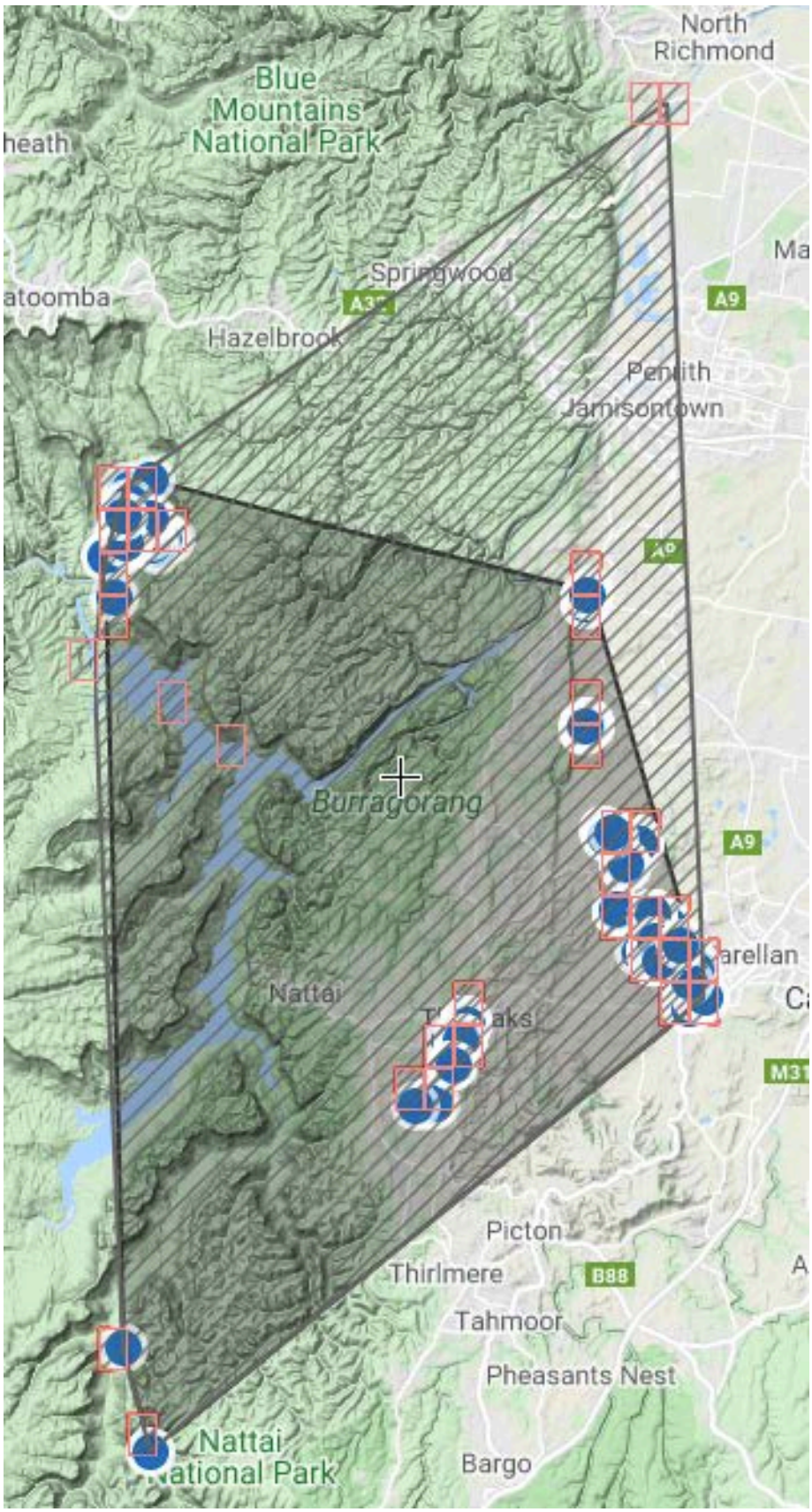
The species has not been subject to targeted survey across its whole distribution, and a total population census is not available. However, occurrences within the Nepean River system have been surveyed in detail in recent years for Greater Sydney Local Land Services (LLS) and for research undertaken by the Australian Tree Seed Centre (CSIRO) (see records in Bionet 2021). Camden Airport was part of those surveys along with several other sites within the Macarthur District and environs. The Nattai occurrences are the least well documented, and that population has not been subject to targeted survey. Table 1 provides details of the current abundance estimates.

The Kedumba population has been recorded in parts by numerous observers and collectors over many years, but most of those records do not contain population data, and only one is the source of a long-standing estimate of 'up to 10,000' (Payne 1992 (cited in NPWS 2000)). Butcher *et al*. (2005) estimate this population at 6,500. England (2016) estimates the population to be 2,000 trees. NPWS Ranger, C. Banffy (pers. comm. February 2021) estimated the number of breeding trees to be 8,000-9,000. The Environmental Impact Statement (EIS) for the proposed raising of the Warragamba Dam wall (SMEC 2021) includes a partial census of the population in areas modelled as potentially affected by that proposed project. This partial census produced a count of 3,527 trees but does not specify the proportion that are or are likely to be mature, or whether this figure is a direct total count of individuals, or an estimate based on sampling part, or all, of the population. These data suggest that Banffy's estimate of 8-9,000 mature individuals across the Kedumba subpopulation is a credible upper bound.

Most database records of the species lack a value for the number of individuals observed or estimated, however many records from the Nepean population from 2015 to 2017 are for individuals and have high spatial accuracy. Twenty records relating to twenty individuals are coded as "Vagrant or escaped animal or planted specimen" and relate to known plantings in mown parkland within Bents Basin SCA. A record from 1999 at Elizabeth Macarthur Agricultural Institute (Menangle Park) is treated as a planting based on advice that the species is well documented to have been planted there, with further plantings planned (P. Ridgeway pers. comm. February 2021). Plantings of several hundred trees are known to have occurred within the Macarthur District, the majority of which are not recorded in BioNet Atlas. It is not known if the plantings have produced viable offspring (*sensu* IUCN 2022) hence, they have not been included in any population estimates used in this assessment.

The estimated total population range for the species is around 4,500-10,200 mature individuals (Table 1). The Nepean populations are heavily dominated by adult trees with very low recruitment as there is little regeneration due to agricultural practices and competition with weeds (England 2016) along with hybridisation and lower seed viability and germination rates (Butcher *et al.* 2005). Whilst the Nattai occurrence remains largely unknown, and could be substantial, at present, a very large majority of occurrences are within a single population in the Kedumba Valley. Using the estimates in Table 1, the estimated percentage of the total abundance of *E. benthamii* in the Kedumba population is that 88% of mature individuals occur within a single population based on either population lower bounds (4,000 plants at Kedumba in an estimated total population of 4,541) or population upper bounds (9,000 plants at Kedumba in an estimated total population of 10,238).

Extreme fluctuations in population size are highly unlikely across the species' whole distribution as individual trees of the species are long-lived. Prolific germination may occur post-flooding under suitable conditions, but seedling mortality is expected to be high based on the density of adult trees seen in regenerating and mature stands.



Map 1. Plot of BioNet records showing presumed extant (blue dot) and presumed or known extinct (red square, no dot) occurrences

Table 1. Abundance estimates for *Eucalyptus benthamii*

Site	Site	Comments	Abundance
1	Kedumba Valley within Blue Mtns NP	Not censused but relatively well surveyed in part, including for the EIA related to the proposed raising of Warragamba Dam	"Up to 10,000" estimated by Payne in 1992 (cited in NPWS 2000); several hundred estimated by Benson (1985); 6,500 estimated by Butcher *et al.* (2005); 2,000 (England 2016); >6,000 (Bush *et al*. 2016); 8-9,000 mature individuals (>7 years age) by Banffy (pers. comm. 2021); 3,527 counted in partial survey of the more downstream portion of the population by SMEC (2021) but this doesn't differentiate between mature individuals and juveniles. Likely range of **4,000-9,000**.
2	The Oaks (Werriberri / Monkey Creeks) and tributaries, all outside formal reserves	Records appear over several kilometres within a largely cleared catchment in which what little vegetation remains is largely restricted to the riparian zone.	OEH (2019) refers to this population as "a further stand" and does not provide an estimate of numbers. Review of BioNet Atlas records (primarily those from GS LLS 2015) suggests **39** trees over some kilometres. Benson (1985) and some others have previously considered this population likely to be extinct. Whilst rediscovered, it is arguably not viable without intervention to boost numbers and mitigate threats.
3	Camden region (includes Council parkland such as Belgenny Reserve and Kings Bush Reserve, conservation covenanted land in the Mater Dei property, and semi-protected land within Camden Airport (Cwlth)).	Historic and recent records, including detailed recent survey for Greater Sydney LLS that provides good census data. Includes trees recorded as being on the site of a future sand mine. The context of this cluster of records is a highly modified rural, rural-residential and urbanising environment with significant habitat loss from historic and continuing mining of alluvium. Remnant vegetation is largely restricted to degraded riparian zones.	Fairley (2004) says that there are only "a number of scattered individual trees along the Nepean River between Wallacia and Camden." This is also stated by Robinson (2003) and by NPWS (2000). OEH (2019) refers to several trees being scattered along the Nepean River around Camden and Cobbitty. Review of records suggests **388** discontinuously scattered as individuals or small groups of trees over several kilometres of frequently very degraded (weedy) or managed by highly modified habitat (e.g., mown parkland).

4	Bents Basin cluster within Bents Basin SCA but also downstream for a short distance	The species has been planted in a modified part of the SCA, but the reserve is generally accepted to support at least 100 trees.	100 trees are said to survive at Bents Basin (NPWS 2000; Fairley 2004) with some remaining "unchanged since the 1880s, although fires, especially one in 1979, have adversely affected the canopies. Fire also kills young trees" (Fairley 2004). Barker (2017:15-16) estimates >100 trees in the SCA based on his partial survey. Butcher *et al*. (2005) estimate 300 at this locality (not just in SCA). Most BioNet records in the SCA are known plantings. Likely range of **100**-**300** trees
5	Wallacia cluster, relatively localised and all outside formal reserves but includes Council-managed Fowler Reserve and Blaxland's Crossing Reserve	Appears to be mainly within Council reserves and is a very small and somewhat disjunct remnant occurrence at what is now a limit of distribution.	Fairley (2004) says that there are only "a number of scattered individual trees along the Nepean River between Wallacia and Camden." This is also stated by Robinson (2003) and by NPWS (2000). Review of records suggests likely range of **9-11** trees.
6	Nattai River cluster, Nattai NP	Three records, two duplicated, are sightings only (not vouchered) but are by experienced observers who have recorded the species at other sites elsewhere that are supported by vouchers. Records are within credible habitat.	OEH (2019) refers to this site as supporting "at least five trees". This site is relatively poorly surveyed. **>5** trees but based on the area of potential habitat, it could be much larger. In the absence of good data, the likely estimate is **5-500** trees.

Ecology

Eucalyptus benthamii is a tree to 40 m high (PlantNET 2022), with diameter at breast height of ~1.5 m when mature. Flowering has been observed between March and May, but also in late September (Corringham 1988; Benson & McDougall 1998; Han *et al*. 2020). OEH (2019) state that flowering occurs in summer and autumn but may occur sporadically through the year. Longevity is estimated to be at least 250 years (Benson 1985) though other studies have shown some species of long lived eucalypts can be at least 300-400 years old (Brookhouse 2006). The primary juvenile period is not known, but thought to be around 6-10 years (Benson 1985) for some plants and probably 10-20 years for most plants (following the pattern identified in *Eucalyptus delegatensis* by Doherty *et al.* 2017). Plants can likely produce fruit for 250-350 years after the primary juvenile period. The species' altitude range is from ~300 to ~ 10 m AHD based on extant and extinct records. However, as much of its habitat was cleared before it was known to science, it may have previously occurred at higher elevation, particularly in the Nepean River catchment.

Benson and McDougall (1998) note *E. benthamii* occurs in "Tall open-forest e.g., with *Eucalyptus baueriana*, *Angophora subvelutina*, *E. elata* (in Camden White Gum Forest of Benson 1992). In flood-disturbed area (at Kedumba) regeneration with *Lomandra longifolia*, *Pteridium esculentum*, *Banksia ericifolia*, *Leptospermum flavescens* (syn. *polygalifolium*), *Gahnia aspera*, *Imperata cylindrica*, *Grevillea asplenifolia*, *G. mucronatus*, *Acacia longifolia*, *Carex appressa*, *Acacia parramattensis* (R. Paine pers. comm.). Substrate: sandy alluvial coarse deep yellow sand or brown-yellow deep sandy loam, infertile to fertile, with a mostly high-water table but moisture supply intermitted and fresh, with soil pH 5.5-6.5 (Corringham 1988). Exposure: full sun to light shade." *Eucalyptus benthamii* is likely to have been more extensive on floodplains that were cleared for timber and agriculture relatively early in European colonisation of western Sydney.

Eucalyptus benthamii occurs in the 'River-Flat Eucalypt Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions' Threatened Ecological Community (TEC) (NSW Scientific Committee 2011). Most of the area occupied by the species is or was within a relatively small portion of this TEC. River-flat Eucalypt Forest on Coastal Floodplains has been very extensively cleared and fragmented for agriculture and pastoralism, and to lesser degree for mining of alluvium, with what little remains being often severely compromised by weed invasion, along with other threats such as feral animals, water pollution (excessive nutrient and sediment loads), and changed hydrology that can lead to effects ranging from reduced flooding to increased erosion, depending on conditions (see for e.g., NSW Scientific Committee 2011; DAWE 2020; DPIE 2021).

Barker (2017), referring to his observations in Bents Basin SCA, describes the species as often dominant in riparian and near-riparian areas with deep alluvial deposits, and occurring with *Eucalyptus tereticornis* and *Casuarina cunninghamiana* within River-flat Eucalypt Forest of Coastal Floodplains TEC.

Seed is dispersed locally by wind or gravity and there is no soil-stored seedbank (Benson & McDougall 1998). Seedling recruitment follows floods or soil disturbance (including artificial disturbance per Benson 1985) and requires open sites. Benson (1985) noted that significant seedling recruitment following fire did not occur and seedlings were outcompeted by other local species including weeds. Following fire, *Eucalyptus benthamii* resprouts by producing epicormic shoots along the trunk and major branches and/or resprouting from the base of the trunk (Benson 1985). Severe fire, as seen in 1997 at Bents Basin, may lead to death of some trees of all sizes

(particularly small ones measuring <20 cm diameter at breast height) and for some larger trees, the bole may be structurally weakened (Benson 1985).

Eucalyptus benthamii has been planted at several sites within and just outside its known natural distribution and is also grown in the Australian Capital Territory and in Deniliquin NSW for seed production and conservation purposes (Han *et al*. 2020). Invasion potential has been assessed for this species in areas outside of Australia where it has been introduced and considered of moderate risk (Ziller *et al*. 2019).

Threats

The main threats to *Eucalyptus benthamii* are habitat disturbance including ongoing habitat loss and fragmentation (land clearing, urban development, proposed raising of Warragamba Dam wall and construction of other smaller dams), changed hydrology (flood mitigation and proposed raising or Warragamba Dam wall), weed invasion, inappropriate fire regimes, and inbreeding depression (Benson *et al*. 1996, cited in Butcher *et al*. 2005; Gardiner 2004; OEH 2019; DoE 2014). Remnant populations are now isolated within an extensively fragmented habitat (NSW NPWS 2000). Other threats include habitat degradation caused by feral pigs (*Sus scrofa*) at Kedumba (OEH 2019), hybridisation with manna gum (*Eucalyptus viminalis*) (Butcher *et al*. 2005), and mowing (Barker 2017). Future threats include disease, climate change and ongoing habitat loss. These threats are leading to the loss of adult plants, loss and degradation of habitat and limiting any new plant recruitment.

Habitat loss and fragmentation

The threat of direct habitat removal (vegetation clearing) has occurred in the past and is ongoing for this species. Extensive habitat loss is likely to have occurred in the past due to clearing of floodplain and riparian forest for agriculture, and later for mining of soil, sand and gravel in some areas (see for e.g., Benson 1985; Butcher *et al*. 2005; England 2016). Occurrences at The Oaks and along the Nepean River are fragmented and genetically isolated from each other, with isolation and inbreeding known to be a problem within these sites as discussed below.

"Large areas of habitat [of *E. benthamii*] were inundated by the formation of Warragamba Dam in 1960" (SMEC 2021). Further loss of habitat will occur if the Warragamba Dam wall is raised (as well as changes to hydrology - see below). Further losses are possible due to infrastructure creation associated with increasing urbanisation (e.g., additional or wider road and rail bridges, water pipelines, and aerial powerlines) and further losses are apparently likely due to continuing or expanding 'sand mining' at the locality of Elderslie (BioNet Atlas records from GS LLS 2015). Indirect habitat removal is possible through other threats such as altered hydrology that includes erosion of habitat, detrimental temporary inundation of habitat, pollution of habitat, pest species, and livestock grazing. Further urbanisation of catchments containing the species is also predicted for all but the Kedumba location, with the Nepean sites the most likely to be severely affected. Whether direct or indirect, further habitat loss would worsen what is already a severe level of habitat fragmentation.

Impact of raising the Warragamba Dam wall on *Eucalyptus benthamii*

An Environmental Impact Statement for the proposal to raise the Warragamba Dam wall by 14m was released in September 2021 (SMEC 2021). The proposed raising of the dam wall (referred to in SMEC 2021 as the 'Project') "could potentially impact the *Eucalyptus benthamii* sub-populations upstream and downstream of the dam wall" (SMEC 2021).

"Most of the known occurrence of *E. benthamii* occurs within the Upstream and Downstream study areas or in vegetation contiguous with these study areas." (SMEC 2021). *Eucalyptus benthamii* in the Kedumba, Wallacia and Bents Basin areas (sites 1, 4 and 5 of Table 1) are within the Project's study area and the Project has been assessed as having the potential to contribute to a long-term decrease in the size of the *E. benthamii* population (SMEC 2021). "The *E. benthamii* habitat in the upstream and downstream study areas has been assessed as critical habitat because it is important for dispersal, the long-term maintenance of the species and for maintaining genetic diversity. The Project could potentially adversely affect this habitat through the direct removal of vegetation, increasing the presence of invasive species, erosion and deposition, and modifying hydrology and the fire regime." (SMEC 2021). The Project could potentially reduce the area of available habitat within these areas and has the potential to further fragment the occurrence of *Eucalyptus benthamii* occurring downstream of the dam wall (SMEC 2021).

The population of *Eucalyptus benthamii* in the Kedumba Valley is the largest and least disturbed remaining population of the species and is estimated to comprise approximately 88% of the current total known population, using either the upper or lower bounds of estimated abundance data in Table 1. The Kedumba Valley is in the upstream area of the Project and 44ha of *E. benthamii* habitat is within the 'upstream impact area' of the Project (see Figure 2 in Appendix 2). The 'upstream impact area' "comprises the maximum extent of flood prone land estimated from the probable maximum precipitation and resultant inundation" and is up to 10.25 metres above the current full supply level of the dam (SMEC 2021). "The upstream impact area has been used as a means to offset the potential impacts of the Project. For the purposes of offsetting the potential impacts of the Project, it has been assumed that there would be a complete loss of values in this area. In reality, this is unlikely as sensitive areas/sites would have differing risks of impact depending on their respective locations in terms of elevation." (SMEC 2021). Annual Exceedance Probability (AEP) describes the probability of a flooding event being equalled or exceeded in a given year; and is used in SMEC (2021) as an indicator of flooding frequency associated with raising the Warragamba dam wall. "The Project could potentially impact (modify or destroy) up to 107.39 hectares of [*E. benthamii*] habitat within the upstream 1% AEP and 10.73 hectares within the 20% AEP. The modification and/or destruction of this habitat is expected to cause the population of *E. benthamii* in the upstream study area to decline." (SMEC 2021).

Effects of inundation beyond the 10.25m increase in elevation above the current full supply level of the dam are not provided in the EIS. The percentage of the Kedumba Valley population of *E. benthamii* within the upstream impact area is not provided in the EIS.

The EIS includes a proposal to increase the headwall by a further 3m in the future in anticipation of intensified rainfall under projected climate change (SMEC 2021). The further effects of the 17m headwall extension on upstream and downstream ecological values, including *E. benthamii*, are not considered in the EIS.

Altered Hydrology

Eucalyptus benthamii is thought to be reliant upon specific flood regimes to suppress competing vegetation and provide an open, freshly deposited silty medium for seedling recruitment (see for e.g., Benson 1985). All the catchments in which the species occurs have and continue to suffer from altered hydrology to varying degrees, even those in and surrounded by extensive conservation estate. The upper Kedumba River catchment contains urbanised areas of the upper Blue Mountains, though some of its tributaries have intact subcatchments. The Nattai River occurrences are surrounded by National Park, but the headwaters contain urban, commercial and rural lands in the Southern Highlands, including discharge from municipal sewerage treatment plants. All other known occurrences of the species are in primarily agricultural catchments with

localised but increasing rural-residential and urban land use. The Nepean River is further modified by having its upper catchment impounded by large potable water supply dams that significantly modify the natural flood regime. The low levels of recruitment observed in most occurrences in The Oaks and Nepean areas, especially downstream of the upper Nepean dams, are likely a result of less frequent flooding, however, severe weed invasion is also common in most such sites, and such weed invasion would also impede recruitment. It is likely that only high intensity floods can now remove sufficient vegetation (predominantly weeds) and leave an exposed area of alluvium suitable for the species' seedlings to establish. Even in that situation, competition from germinating and resprouting weeds may be so severe as to suppress or even prevent successful recruitment of *E. benthamii* in most occurrences.

Warragamba Dam has dramatically altered the hydrology of a significant portion of the species' former and current habitat, having destroyed areas in which the species was previously common (see for e.g., Benson 1985; Butcher *et al.* 2005). The species is now confined to a relatively small part of its former habitat in that region. Some of that area is now threatened by a proposal to increase the height of the dam wall (see above for separate section on this).

Barker (2017) notes that between 1987 and 1988, a large dam was built on the Nepean River partly within Bents Basin SCA and that this would have "removed an unknown number of *E. benthamii* as there would have been a contiguous population into [along] the riparian area [that is] now submerged beneath the dam." It seems likely that this dam would have also modified the downstream and upstream hydrology to varying degrees.

Altered hydrology includes changed flood regimes and associated changes to erosion and deposition; potentially, modified groundwater regimes – at least those associated with streams; altered nutrient flows; etc. Banffy (pers. comm. February 2021) suggests that severe flooding after the 2019/20 fires likely resulted in losses of saplings and trees of *E. benthamii* that had recruited within the last 10 years within the high velocity zone of the Kedumba River. Flooding events in 2022 have resulted in significant soil erosion at Bents Basin SCA, exposing the roots of mature trees and washing away habitat (Sherieff *in litt.* November 2022). Changes in extremes of rainfall and in rainfall intensity leading to flooding events are envisaged under climate change (OEH 2014).

Weed Invasion

DoE (2014) note "The productive nature of alluvial flats make(s) them particularly prone to weed invasion, and the following weeds threaten the Camden white gum: honey locust (*Gleditsia triacanthos*), African olive (*Olea europaea* subsp. *cuspidata*), privet (*Ligustrum vulgare*), box elder (*Acer negundo*), cactus (*Opuntia* spp.), balloon vine (*Cardiospermum grandiflorum*), bridal creeper (*Asparagus asparagoides*), blackberry (*Rubus* spp.) and exotic grasses such as couch (*Cynodon* spp.) and *Paspalum* spp. (OEH 2013[a])". Weed species are likely to occur within suitable habitat for *E. benthamii* in the Nattai River system near the location of the two records of the species. That catchment receives runoff from urban, commercial and rural areas, and sewerage treatment plants in the Southern Highlands. The major weeds of concern are either readily bird dispersed or may be transported downstream along waterways.

The Kedumba population is considered to have relatively low levels of weed invasion (Butcher *et al.* 2005) but is nonetheless at risk given part of the valley was used for farming until it was added to the National Park in relatively recent history, and that the headwaters of the Kedumba include

urban areas of the higher Blue Mountains in which weed species are well-established. The list of weeds in OEH (2019) that are recognised as threats to *E. benthamii* is incomplete and weighted towards the worst areas of infestation in the Nepean occurrences.

The Nepean River sites are primarily in a long-established rural context with growing urban areas, and includes areas affected by alluvium extraction that entails total removal of any remnant vegetation. The Nepean River is in relatively fertile habitat, highly disturbed with abundant weeds. At Bents Basin SCA, where the species was studied by Benson (1985), 36 non-native species (about two-thirds cosmopolitan weeds of agriculture and disturbed ground, and a third being garden escapes) were reported. Barker's (2017) study of *E. benthamii* in the same reserve also notes "dense mid-storey canopy of invasive olive and privet". Barker recorded 66 weed species but reports that the majority of these were not a threat to *E. benthamii*, though "several species are ecosystem transforming species, abundant and variably dominant over much of the riparian area downstream from the Basin itself." He then lists *Olea europaea* (African Olive), *Ligustrum sinense* (Small-leaved Privet), *Ligustrum lucidum* (Large-leaved Privet), *Lantana camara* (Lantana), *Cardiospermum* spp. (Balloon Vine), *Lonicera japonica* (Japanese Honeysuckle), *Solanum seaforthianum* (Brazilian Nightshade), *Asparagus declinatus* (Bridal Veil Creeper), and *Tradescantia fluminensis* (Wandering Spiderwort). "The dense shade and competition [combined] with the sheer numbers of weeds is likely to prevent the germination of *E. benthamii* and other native River Flat Eucalypt Forest species. During this assessment, the only young *E. benthamii* was located in an open, sunny area between the heavily [intensively] maintained area of the campsite and the densely weedy area nearer the Nepean River" (Barker 2017).

Changed fire regime

Altered fire regimes may threaten the species with high severity fire known to damage the canopy and bole of the species, weakening its propensity to resprout after successive fires (Benson 1985; Fairley 2004), and to kill seedlings and saplings. Benson (1985) also suggests that frequent fire is a threat to the species.

Between 30-54% of the distribution of *E. benthamii* overlapped with the spatial extent of the 2019/2020 fires (Gallagher 2020). Banffy (pers. comm. February 2021) reported that the entire Kedumba location was burnt in the 2019/20 wildfire (this is supported by remote sensing data i.e. DPIE 2020), and whilst most mature trees survived by resprouting from epicormic buds or basal resprouts, seedlings and saplings experienced high rates of mortality. The Nattai population and associated potential habitat was also burnt (DPIE 2020). Other known populations were outside the extent of the 2019-20 wildfires and are generally subject to infrequent fire as they occur in highly modified riparian or managed parkland contexts. An exception is the plants in Bents Basin SCA where planned and unplanned fires occur, with Benson (1985) noting damage to and death of some individuals, especially where combustible flood debris had accumulated around trunk bases, leading to fire of high severity. Benson (1985) noted the relationship between altered flood regimes and excessive accumulation of flammable debris.

Fire is now absent or extremely rare in the Nepean and The Oaks sites due to extensive land clearing and rural or urban land use along with extensive mesophyll weed invasion. This may impede recruitment because fire may have been advantageous to germination by removing or thinning competing vegetation (including weeds) and providing an exposed ash bed to allow rapid seedling establishment.

Inbreeding depression and hybridisation

Inbreeding depression is recognised as a concern for *E. benthamii* in DPIE (2014), OEH (2019), Butcher *et al*. (2005) and Han *et al*. (2020) in relation to the severely depleted and fragmented Nepean and The Oaks populations. It is not currently a concern at the Kedumba population, which is much larger and more intact, but it may become an issue as much of this population and habitat is likely to be affected by flooding under the proposed raising of the Warragamba Dam wall. Inbreeding depression is unlikely to be a concern at the Nattai population because the species is probably more abundant there than currently documented.

Hybridisation, particularly with the relatively closely related *E. viminalis*, is recognised as a threat to the species, at least at Camden and Wallacia (Butcher *et al*. 2005). Greater than 20% of hybrid offspring were recorded from those sites (lower Nepean) (Han *et al.* 2020).

DPIE (2014) and Han *et al*. (2020) have suggested that augmenting genetic diversity in the Nepean and The Oaks populations may be necessary to address inbreeding depression and hybridisation resulting from each having a relatively small and fragmented population with apparently low levels of recruitment.

Feral animals and livestock grazing

DPIE (2014) lists feral pigs as a threat to the Kedumba population and specifies control actions as part of general pest species management in Blue Mountains National Park. Feral pigs are likely to destroy seedlings/saplings through digging (NSW SoS 2022) and may also promote weed invasion. Fieldwork in the Nepean location also recorded feral animals as a threat in sightings of *Eucalyptus benthamii* (GS LLS 2015; BioNet Atlas). Pigs are likely to be a problem at most occurrences of the species as they share a preference for riparian habitats (NSW SC 2004).

Feral deer and goats may also destroy seedlings and saplings by their browsing activities, which in some cases includes stripping bark from trunks, causing damage and reduced vigour, promoting disease entry, or even ring-barking the tree. Deer are noted to be abundant in Bents Basin SCA (and presumably environs) by DPIE (2014), with evidence of deer damaging trees in *Eucalyptus benthamii* habitat (Barker 2017). Rabbits (*Oryctolagus cuniculus* (Linnaeus, 1758)) and Hares (*Lepus capensis* Linnaeus, 1758) may destroy seedlings and degrade habitat (NSW SC 2002) and are present in more modified areas such as the Nepean populations (ALA 2022) .

Livestock grazing is also recognised as a threat in field notes generated during the 2015 surveys for Greater Sydney Local Land Services and that are cited in Han *et al.* (2020). Cattle and horses are likely to destroy seedlings, damage bark of saplings and mature trees and cause soil compaction, reducing habitat suitability for the tree species.

Mowing/slashing of habitat

Several remnant populations or parts thereof occur in parklands managed by Councils and within the NPWS-managed Bents Basin SCA. Barker (2017) reported detrimental effects of mowing and slashing in planted and some natural occurrences within part of Bents Basin SCA. This included recurrent scalping of surface roots; compaction of soil underneath tree canopies; and erosion beneath canopies in other areas. Mowing or slashing in those areas is very likely to prevent recruitment of the species, and to reduce its area of functional habitat to parts of those sites that are not mown e.g., steeper stream banks. Mowing or slashing is also likely to be common on parts

of rural and rural-residential properties that support the species and may also prevent or limit the extent of recruitment, and increasingly confine the species to unmown areas such as riparian zones.

Disease

Myrtle Rust, a plant disease caused by the introduced fungal pathogen *Austropuccinia psidii,* affects a number of eucalypts but it is unknown if it affects *Eucalyptus benthamii.* Climate warming may worsen this threat by potentially creating warmer and wetter conditions which are associated with greater rates of infection, extending the conditions suitable for the pathogen to reproduce and spread (Makinson *et al.* 2020). However, Ridgeway (pers. comm. March 2021) has not observed this pathogen in wild trees of this species.

Dieback has been observed in the population at Camden Airport in 2017-18 and was determined to be caused by over-abundant *Cardiaspina* psyllids, likely due to Bell Miner Assisted Dieback (BMAD) (P. Ridgeway pers. comm. March 2021). Affected trees were treated with the insecticide, Movento, and have regained good health, with BMAD reduced by removal of large infestations of *Ligustrum lucidum* (Large-leaved Privet), *Ligustrum sinense* (Small-leaved Privet) and *Olea europaea* (African Olive) (in that order). The reduction in BMAD symptoms in treated areas has persisted for more than 5 years (P. Ridgeway pers. comm. March 2021; April 2022).

Barker (2017) also suspected BMAD as the cause of *E. benthamii* decline and death at Bents Basin SCA, linking this to the presence of Bell Miner's along with dense woody weed infestation.

Climate change

Anthropogenic climate change is likely to affect the species negatively through factors including: reduced rainfall; increased evapotranspiration; altered seasonal distribution of rainfall; reduced groundwater discharge to streams and to floodplain habitats as a result of medium to long-term reduction in groundwater recharge; increased temperatures causing moisture stress, canopy decline and potential mortality; increased likelihood of high severity fire and increased likelihood of death if affected by fire when combined with moisture stress from drought and/or reduced groundwater supply; with intensification of rainfall and flooding potentially being beneficial in some sites, but damaging in others depending on each event and effects on flood regimes (see for e.g. OEH 2014).

Locations (*sensu* IUCN 2022)

The main threat to *Eucalyptus benthamii* is ongoing habitat loss and degradation (the latter due to interactions between changed hydrological regimes, competition from weeds, browsing pressure, habitat disturbance and changed fire regimes), with these threats resulting in ongoing tree mortality and limited effective recruitment. In total there are considered to be 3-4 locations.

The primary threatening process for *Eucalyptus benthamii* over the next generation is habitat loss. This will mainly occur in the Kedumba Valley population if the raising of the Warragamba Wall project goes ahead. The Kedumba Valley site is considered to comprise two locations with regard to this threat (if raising the Warragamba Dam wall proceeds, only a proportion of the population is likely to be impacted by the increased inundation levels in the area, although ongoing recruitment across the whole site may be impacted by weeds).

IUCN (2022) note that "where the most serious plausible threat does not affect all of the taxon's distribution, other threats can be used to define and count locations in those areas not affected by

the most serious plausible threat." At the other *E. benthamii* sites, the main threats are those causing habitat degradation as listed above. Weeds limit recruitment of *E. benthamii* and associated habitat species and affect ongoing plant survival. The major weeds of concern are either readily bird dispersed or may be transported downstream along waterways. These weeds are widespread across all remaining sites, and as a consequence, recruitment of the species is poor or absent. Hence, these sites can be considered one location (or at most two locations if weed impacts are considered less in Nattai NP).

Assessment against IUCN Red List criteria

It is considered that whilst incomplete, surveys of *Eucalyptus benthamii* are adequate for the purpose of this assessment, and there is sufficient scientific evidence to support the listing outcome.

Criterion A Population size reduction

Assessment outcome: Critically Endangered under Criterion A2c and A4c.

Justification: The generation length of *E. benthamii* has been estimated to be approximately 70 years (Fensham *et al.* 2019), assuming a generalised minimum age of first reproduction of 4 years and a 200 year reproductive period for all eucalypts (Fensham *et al*. 2020). However, long lived eucalypts can be at least 300-400 years old (Brookhouse 2006) and continue to flower into old age. *Eucalyptus benthamii* is a long-lived tree estimated to grow for at least 250 years (Benson 1985). An estimate of generation length appropriate to *E. benthamii* can be made using IUCN (2022) age of first reproduction + [*z* * (length of the reproductive period)], where *z* is a number between 0 and 1; *z* is usually <0.5, depending on survivorship and the relative fecundity of young vs. old individuals in the population. Fung and Waples (2017) examined *z* estimates for a number of plants, including the long-lived tree *Araucaria cunninghamii* with a z value of 0.33. Z values are higher where there are ongoing high reproductive outputs in older plants, and this can be expected in long lived trees such as *E. benthamii* that develop large canopies relative to saplings and 'poleform' young adults. For *E. benthamii*, age of first reproduction is likely to be at least 5-10 years for some plants and probably 10-20 years for most plants (following the pattern identified in *Eucalyptus delegatensis* by Doherty *et al.* (2017). Plants can likely produce fruit for 250-350 years beyond that. Using 0.33 as a minimum estimate for z, generation length in *E. benthamii* would be between 87.5-92.5 and 120.5-125.5 years, with 3 generations ranging from 263 to 376 years. Hence, 3 generations in the past would include all habitat loss and modification from European settlement. Very long generation lengths (≥100 years) have been suggested for some long-lived trees, e.g., *Albies nebrodensis* Thomas (2017), *Fitzroya cupressoides* (Patagonian Cypress) Premoli *et al*. **(**2013), *Sequoiadendron giganteum* (Giant Sequoia) Schmid and Farjon (2013). With higher z values generation length would be even longer for *E. benthamii*.

Using IUCN criterion A2, past habitat loss can be inferred from estimates of loss of vegetation communities that *E. benthamii* occurs within, assuming that the rate of loss of such vegetation communities is the same for those areas occupied by *E. benthamii* as for areas where this species does not occur. Clearing of riparian habitat in western Sydney was evident in the early 1800s, while much of the urbanisation of the area occurred in the past 140 years (Benson and Howell 1990). *Eucalyptus benthamii* occurs within the NSW BC Act listed 'River-Flat Eucalypt Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions' threatened ecological community (NSW Scientific Committee 2011) and the Commonwealth EPBC Act listed 'River-flat eucalypt forest on coastal floodplains of southern New South Wales

and eastern Victoria' (DAWE 2020). Whilst these communities contain *E. benthamii* in parts of their range, they also occur beyond the range of the species. Focussing solely on the loss of these vegetation communities within the Sydney Basin, OEH (2013b) provide an estimate of decline since European settlement for two component vegetation types within River-Flat Eucalypt Forest on Coastal Floodplains that are likely to contain *E. benthamii* in parts of their range. They estimate declines across the Sydney Basin of 80-95% for Cumberland Riverflat Forest and 75-95% for Cumberland Swamp Oak Riparian Forest. Tozer (2003) found *E. benthamii* was positively associated with Riparian Forest (Map unit 12) on the Cumberland Plain and estimates that 76 (±5%) of this vegetation community had been cleared. Further, Tozer *et al*. (2010) estimates 80-95% loss of the Cumberland River Flat Forest vegetation unit (a map unit that includes Riparian Forest of Tozer 2003). These habitat loss estimates provide an index of reduction for *E. benthamii* with declines estimated to be >80%. Assuming that *E. benthamii* underwent declines similar to those experienced by the vegetation types with which it is associated, there is a suspected population reduction of greater than 80% over a 3-generation period in the past based on habitat quality and the causes of reduction may not have ceased and may not be reversible.

Using IUCN criterion A4, the extent of suspected population decline over a 3-generation period (including both the past and future) includes two components, historical habitat loss since 1780 (240 years) and future decline in the next 20-50 years, given 3 generations of at least 260 years (see above). Firstly, there is a suspected loss of at least around 80% based on estimates of clearing of vegetation communities within which *E. benthamii* occurs (see A2 above). Secondly, future decline from tree mortality, loss of habitat and habitat degradation across the species range due to increased urbanisation and weed impacts, in addition to the declines that would result from the proposed raising of the Warragamba Dam wall, is projected in the next 20-50 years. Note that some 88% of the remaining total population for the species occurs in the Kedumba Valley where inundation will occur if the Warragamba dam wall is raised, and that SMEC (2021) estimated potential impacts from the proposed 14m dam wall extension. "The Project could potentially impact (modify or destroy) up to 107.39 hectares of [*E. benthamii*] habitat within the upstream 1% AEP and 10.73 hectares within the 20% AEP. The modification and/or destruction of this habitat is expected to cause the population of *E. benthamii* in the upstream study area to decline." NSW DPIE (2021) suggest that "approximately 33% of the [Atlas Bionet] records in the Kedumba Valley are within the upstream impact area and over two thirds are within the PMF [probable maximum flood]. If the species proves sensitive to temporary inundation, impacts are likely to be significant and important in terms of local and regional conservation of the species." Additional effects of a proposed 17m extension that is envisaged in the future are not provided by SMEC (2021) but are likely to exceed impacts from a 14m dam wall extension. When combined, past habitat loss and future reduction is >80% over 3 generations. Consequently, there is a suspected population reduction of greater than 80% over a 3-generation period (including both past and future) based on habitat quality and the causes of reduction may not have ceased and may not be reversible.

Criterion B Geographic range

Assessment outcome: Endangered under Criterion B1ab(i,ii,iii,iv,v), B2ab(i,ii,iii,iv,v).

Justification: The extant Extent of Occurrence is estimated to be 1207 km^2 using a minimum convex polygon enclosing all mapped occurrences of the species with sufficient spatial accuracy for this purpose, as recommended by IUCN (2022). To be listed as Endangered under Criterion B1, a species must have an EOO of <5000 km^2. *Eucalyptus benthamii* meets the EOO threshold for Endangered under Criterion B1.

The Area of Occupancy is estimated to be 116 km^2 based on the species occupying 29 (2 km x 2 km) grid cells, the spatial scale of assessment recommended by IUCN (2022). To be listed as Endangered under Criterion B2 a species must have an AOO of <500 km^2. *Eucalyptus benthamii* meets the AOO threshold for Endangered under Criterion B2. In addition to this threshold, 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: met at Endangered.

Justification: The species' known or inferred distribution is severely fragmented primarily because of extensive land clearing and habitat degradation, with permanent inundation having destroyed former occurrences in the Burragorang Valley. More than 50% of the AOO for the species comprises small to very small and apparently unviable remnant populations. There is extensive and often severe degradation of a large proportion of remaining habitat. It is uncertain, given the threats (past and future) to the species, if any remaining sites are viable. The limiting effects of threatening processes are such that recolonisation of former habitat is unlikely.

There are estimated to be three to four locations with the main threat of habitat loss at the Kedumba Valley site and weeds at all remaining sites. The Kedumba Valley site is considered to comprise two locations with regard to the threat of habitat loss (if raising the Warragamba Dam wall proceeds, only a proportion of the population is likely to be impacted by the increased inundation levels in the area, although ongoing recruitment across the whole site may be impacted by weeds). IUCN (2022) note that "where the most serious plausible threat does not affect all of the taxon's distribution, other threats can be used to define and count locations in those areas not affected by the most serious plausible threat." At the other *E. benthamii* sites, the main threats are those causing habitat degradation (due to interactions between changed hydrological regimes, competition from weeds, browsing pressure, habitat disturbance and changed fire regimes). Weeds limit recruitment of *E. benthamii* and associated habitat species and affect ongoing plant survival. The major weeds of concern are either readily bird dispersed or may be transported downstream along waterways. These weeds are widespread across all remaining sites, and as a consequence, recruitment of the species is poor or absent. Hence, these sites can be considered one location (or at most two locations if weed impacts are considered less in Nattai NP).

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

Assessment Outcome: met for i, ii, iii, iv, v.

Justification: Continuing decline is estimated, inferred and projected for the geographic distribution of the species; habitat area, extent and quality; the number of locations and populations of the species and the number of mature individuals. This decline is based on the continuing effects of historic and on-going habitat loss and fragmentation, degradation of habitat and associated threats (altered hydrology,

weeds, inappropriate fire, habitat disturbance, inbreeding depression) (see threats section for details). Only one relatively large occurrence is known within the Blue Mountains National Park, with another of unknown size within Nattai National Park, and a small occurrence in Bents Basin State Conservation Area. However, most records and habitat are in highly vulnerable situations facing multiple threats in the short, medium and long-term. The proposed raising of Warragamba Dam poses a very significant threat to the species and its habitat through loss of individuals, habitat loss and a changed hydrological regime.

c) Extreme fluctuations.

Assessment Outcome: Not met.

Justification: The species is not known to experience extreme fluctuations in its geographic distribution, number of locations or populations or number of mature individuals.

Criterion C Small population size and decline

Assessment Outcome: Vulnerable under Criterion C1

Justification: To be listed as Vulnerable under Criterion C, a species must have a population of <10,000 mature individuals. The total number of mature plants of *Eucalyptus benthamii* is estimated to be 4500-10,200.

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

C1. An observed, estimated or projected continuing decline (up to a max. of 100 years in future).

Assessment Outcome: Vulnerable

Justification: To meet Vulnerable, an estimated decline of 10% over the next 100 years is required. A significant decline of more than 30% is projected to occur in the remaining populations of *E. benthamii* in the next 100 years as a result of several threats. Future decline from tree mortality, loss of habitat and habitat degradation due to the proposed raising of the Warragamba Dam wall, increased urbanisation and weed impacts are likely. The future loss of individuals and habitat due to flooding from the proposed raising of the Warragamba Dam wall is likely to be greater than 30% (and potentially much more) of the remaining total population for the species, noting that some 88% of the remaining total population for the species occurs in the Kedumba Valley where the inundation will occur. NSW DPIE (2021) suggest that "approximately 33% of the records in the Kedumba Valley are within the upstream impact area and over two thirds are within the PMF [probable maximum flood]. If the species proves sensitive to temporary inundation, impacts are likely to be significant and important in terms of local and regional conservation of the species." In addition, decline is predicted in the Nepean and The Oaks populations due to their well-documented low population size, severe fragmentation and associated genetic isolation, and the effects of other threats, particularly weeds and ongoing habitat degradation.

C2. An observed, estimated, projected or inferred continuing decline.

Assessment Outcome: Not met as while continuing decline is met, none of the subcriteria are met.

Justification: A continued decline in the number of mature individuals is inferred because of the continuing effects of historic, recent and on-going habitat removal and degradation, other threats such as weeds, feral animals, localised disturbances and inappropriate fire and hydrologic regimes, and the potential for significant loss and degradation of the Kedumba population arising from the proposed raising of Warragamba Dam (see threats section for details).

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: Not met.

Justification: Whilst most populations of *Eucalyptus benthamii* contain <=50 mature individuals (the Nepean and The Oaks sites), one population (Kedumba) is known to contain >1000 mature individuals.

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

Assessment Outcome: Not met.

Justification: Approximately 88% of known mature individuals of the species occur in the Kedumba population, using either upper or lower bounds for total population estimates. However, this subcriteria is not met as the percentage of mature individuals in the one subpopulation is required to be 100% for Vulnerable.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Not met.

Justification: Extreme fluctuations in the number of mature individuals is not known or likely in this species.

Criterion D Very small or restricted population

Assessment Outcome: Not met.

Justification: The number of mature individuals is known to exceed 1000.

To be listed as Vulnerable, a species must meet at least one of the two following conditions:

D1. Population size estimated to number fewer than 1000 mature individuals

Assessment Outcome: Not met.

Justification: The number of mature individuals exceeds 1000.

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: Data Deficient.

Justification: *Eucalyptus benthamii* has a small number of locations (3-4). The most plausible future threat that could possibly drive the taxon to CR is the impact of the proposed raising of the Warragamba Dam wall on the largest population of the species. However, it is unclear from the EIS (SMEC 2021) what proportion of the Kedumba Valley population of *E. benthamii* will be impacted.

Criterion E Quantitative Analysis

Assessment Outcome: Data Deficient.

Justification: A quantitative analysis of extinction probability is not currently available for this species.

Conservation and management priorities

The Saving our Species (SoS) plan for *Eucalyptus benthamii* (DPIE 2014) designates it as "site-managed" and specifies three "priority management sites": Kedumba, Bent's Basin, and Camden Airport. Threats, objectives and actions at each site are specified. The 'Approved Conservation Advice for *Eucalyptus benthamii* (Camden white gum)' (DOE 2014) lists local priority recovery and threat abatement actions that can be done to support the recovery of the Camden white gum.

The following points are derived from the threat information and can be utilised along with the current SoS program and the Commonwealth advice (DOE 2014) to prioritise, develop and update management actions across the whole distribution of the species.

Habitat loss disturbance and modifications

- Ensure sites near roads, tracks and trails are managed to exclude detrimental habitat disturbance and loss.
- Limit further habitat loss by protecting remaining intact habitat.

Fire

- Develop and implement an appropriate fire regime across the species' range.
- Avoid burning at high fire frequencies and high fire severities. The current recommended fire interval for the species is no fire more than once every 15-20 years to allow establishment, growth and survival of juvenile plants and adult recovery after fire. This means excluding fire from known sites burnt in 2019/2020 until at least 2035.
- Avoid use of any fire retardants in habitat of the species.
- Manage threats post-fire that may affect recruitment (particularly weeds and feral grazers).

Hydrology regime

- Develop and implement the best practicable hydrological regimes across the species' range, including mitigating existing damaging regimes. Engage with WaterNSW to minimise the impacts of the Warragamba Dam raising project on the species.

Invasive species

- Control at least the major weeds at all sites and in surrounding habitat, particularly following fire, flood or storm damage.
- Weed control in all NSW NPWS estate (Kedumba Valley, Nattai NP and Bent's Basin) should be undertaken to allow ongoing recruitment of the species in these habitats.
- Minimise adverse impacts on populations, particularly the effects of nutrient enrichment and weed propagules from all sources.

- Develop and implement a management plan for the control of feral pigs in habitat areas for the species.
- Assess impacts and develop management plans for introduced herbivores such as deer, stock, rabbits and hares.

Breeding, seed collection, propagation and other *ex situ* recovery action

- Develop and implement a targeted seed collection program for *ex situ* seed banking, with sampling across the full range of the species, following best-practice guidelines (Martyn Yenson *et al.* 2021).
- Implement national translocation protocols (Commander *et al*. 2018) if establishing additional populations or enhancing populations is considered necessary and feasible.
- Investigate ways to supplement genetic variation in populations where inbreeding depression is occurring. Refer to Butcher *et al.* (2005) for advice on regeneration programs and the importance of maintaining genetic diversity by conserving all populations of *Eucalyptus benthamii* across its range.

Stakeholder engagement/community engagement

- Inform land owners and managers of sites where there are known populations and consult with these groups regarding options for conservation management and protection of the species.
- Engage with private landholders and public land managers responsible for the land on which populations occur and encourage these key stakeholders to contribute to the implementation of conservation management actions.

Survey and monitoring priorities

- Survey the Kedumba population to better understand the likely impacts on the species of the proposed raising of the Warragamba Dam wall. Survey the population size and extent of habitat along the Kedumba River and Reedy Creek, documenting GPS coordinates and elevation information for *E. benthamii* individuals. Assess the impact of inundation on the Kedumba Valley population of *E. benthamii* due to the proposed raising of the dam wall.
- Conduct targeted population surveys to determine the number of individuals and impacts of 2019/2020 fires across the species range.
- Survey the Nattai population to better understand its size, health, age structure and extent of threats from weeds, feral animals, fire and changed hydrology.

Maintain a monitoring program to:

- Monitor the species' recruitment and plant health after fire events (including sites burnt in the 2019–20 bushfires) and major floods.
- Determine trends in population size and tree health.
- Monitor levels of seed production and recruitment.
- Document recovery after fires, floods or major storm damage.
- Monitor for habitat degradation by recreational activities or other site disturbances.
- Monitor for any adverse herbivory impacts, especially on seedling recruitment.
- Monitor threats including weeds, damage by deer, wild horses, pigs, and any infection by Myrtle Rust.
- Monitor stream erosion at known sites.

Information and research priorities

- Conduct research into the life history and ecology of the species. This includes determining plant longevity, pollinators, recruitment, seed bank viability and dynamics and seed dispersal.
- Continue monitoring post-2019/2020 fires and examine seedling survivorship, growth, time to maturity, magnitude of fecundity over time once mature, plant longevity, seed viability and seed dispersal.
- Determine likely extent of the proposed raising of the Warragamba Dam wall (both 14 and 17m extensions) on plants and habitat within the Kedumba population and downstream.

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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: *Eucalyptus benthamii* was found to be Critically Endangered under Clause 4.2 (1)(a)(2)(c).

Clause 4.2 – Reduction in population size of species
(Equivalent to IUCN criterion A)
Assessment Outcome: Critically Endangered under Clause 4.2 (1)(a)(2)(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) (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 Clause C)
Assessment Outcome: Vulnerable under Clause 4.4 (c) (d, iii)

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

Clause 4.5 – Low total numbers of mature individuals of species (Equivalent to IUCN criterion D)
Assessment Outcome: Clause 4.5 is 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 4.7 is data deficient.

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.