World Heritage Values and the Warragamba Dam

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Executive Summary

- The Greater Blue Mountains World Heritage Area (GBMWHA) was listed under world heritage natural criteria ii and iv for its importance for the story of the development of the megadiverse eucalypts and for the presence rare and threatened species that have remained unchanged for very long periods.
- Proposed developments in the GBMWHA, such as the raising of the Warragamba Dam, tend to be justified by the small proportion of the total area of the GBMWHA they will damage.
- Small areas that are part of a larger area that is the best expression of Outstanding Universal Values (OUV) should not be considered for development.
- Furthermore, world heritage values are not likely to be spread evenly across any world heritage area. Some places within a world heritage area may be significant disproportionate to their area.
- We determine whether eucalypt values are concentrated, particularly in the area of the Warragamba Dam.
- Using a scoring system that rewarded the joint presences of rare eucalypt species with high scores we mapped variation in values related to eucalypts.
- Twenty-two eucalypt species were recorded within 500 m of the shore of the impoundment, two of them highly rare.
- Several 5 x 5 km grid squares with high and medium scores overlapped the dam.
- Therefore, the raising of the dam will impact the OUV of the site.
- The large data set we used was mostly records that predated the 2019/2020 fires. There is a need for detailed investigations, including field studies, to determine whether the OUV related to the eucalypts have been affected by this fire.

Introduction

The outstanding universal values that have resulted in the listing of world heritage areas (WHA) under natural criteria are unlikely to be uniformly distributed within world heritage areas or confined to them. The patchiness of such values is illustrated by the distribution of range-restricted plant species within the Tasmanian Wilderness WHA (Kirkpatrick et al. 2017) and the Tasman Peninsula (Atkinson and Kirkpatrick 2020). Thus, the world heritage significance of any small part of a world heritage area is not reflected solely by the proportion of the WHA it occupies. This lack of correspondence between area and significance is outstandingly illustrated in the Greater Blue Mountains WHA by the Wollemi pine. Thus, a spatially restricted development, like the raising of the Warragamba Dam, may have disproportionate impacts on world heritage values both inside and outside the WHA boundary. In a context in which impacts on world heritage values are illegal, it is important to know where the values occur and where they are concentrated.

The Greater Blue Mountains WHA is listed under natural criteria ii and iv for its importance for the story of the development of the megadiverse eucalypts and for the presence rare and threatened palaeoendemic species (species such as Wollemi pine that have remained unchanged for very long time periods).

One means by which relative importance of species can be measured is an inverse rarity score. This score can indicate relative importance of a given area based on the sum of species and their respective range restriction. Each eucalypt is given a score that is the inverse of the number of grid squares in which it is known. The scores for all species are then added up for each grid square to give summed inverse rarity.

The present research aims to map those areas inside and adjacent to the Blue Mountains WHA that express its world heritage values related to the eucalypts to help determine the potential impact on world heritage values of an expansion of the footprint of the Warragamba Dam.

Methods

We used the Atlas of Living Australia (ALA) to compiled a list of more 220 species from the genera *Eucalyptus, Corymbia* and *Angophora* found within a 5 kilometre buffer from the Greater Blue Mountains World Heritage Area (GBMWHA). The ALA compiles observational data from herbariums across Australia and various State-level flora inventories.

Next, we downloaded all known observations of these 220 species across Australia where we determined the number of 1ºx1º cells occupied each species. Only observations with an accuracy less than 5 km were included, and only those observed within Australia (and excluding any observations with spurious locations such as in the ocean).

We also chose to exclude all iNaturalist observations as the recording of either unverified or cultivated individuals are not able to be easily excluded and single street trees can significantly expand the range of some species. For example, there are single observation of *Eucalyptus benthamii* in the Canberra CBD, which skewed the total number of 1ºx1º occupied by this species from 2 to 3.

For each species we then calculated the inverse-rarity of each species by dividing its total number of grid squares occupied (Williams et al. 1996). That is, species occurring only in a single 1x1 degree cell score 1, those occurring in 10 cells score 0.1, and so on. This measure a measure of the geographic range-restriction of each species.

We then focused exclusively on the GBMWHA where we summed inverse-rarity within 5 km grid squares (counting each unique species only once), calculating weighted-endemism (WE; Crisp et al. 2001). Then, to account for inflation in this metric by high species richness (Crisp et al. 2001, Atkinson and Kirkpatrick 2020) we divided each cells WE score by the total number of *Eucalyptus, Corymbia* and *Angophora* species known to occur within that cell to produce corrected weighted endemism scores (CWE).

We chose 5 km as the scale for mapping CWE within the GBMWHA to allow for a potential coarse collection effort given the inaccessible or infrequently surveyed regions of the World Heritage Area. However, our final dataset contained over 90,000 records of species of the target genera within the GBMWHA.

Nomenclature notes

Eucalyptus ralla is all considered as *Eucalyptus tenella* in the Australian Virtual Herbarium and the ALA which uses the Australian Plant Census as the authority on accepted scientific names, despite having two maintained profiles on PlantNET (the online NSW flora maintained by the Royal Botanic Gardens of Sydney). If treated as discrete taxa, they would both be likely to be more range-restricted. The same applies to *E. oblonga*, which is treated as within *E. globoidea* (Appendix Table A1).

Results

High scoring corrected-weighted endemism (CWE) scores were scattered across the GBMWHA (Figure 1) as were cells that scored high on richness (Figure A1). The highest scoring cells in CWE were situated around northern Nattai National Park, south of Katoomba, south Wollemi National Park, Mt Monundilla, south Yengo National Park, Mt Moruben, and Mt Wambo.

The proposed Warragamba dam expansion intersects three moderate-high scoring cells in CWE and a number of moderate scoring cells (Figure 2). The highest scoring cells in the dam expansion footprint are those containing *Eucalyptus hypostomatica* and *Eucalyptus benthamii*, which are the most concentrated in their distributions of the many eucalypt species that are known to occur close to the dam (Table 1, Table A1, Figure A1). One cell is data deficient but is situated within a mosaic of low to high scoring regions.

Table 1. *Eucalyptus*, *Corymbia*, and *Angophora* species known within are within 500 m of the Warrangamba dam expansion footprint.

Species	Inverse rarity
Angophora bakeri	0.053
Angophora costata	0.016
Angophora floribunda	0.013
Corymbia gummifera	0.024
Eucalyptus agglomerata	0.032
Eucalyptus benthamii	0.500
Eucalyptus consideniana	0.038
Eucalyptus crebra	0.008
Eucalyptus deanei	0.048
Eucalyptus eugenioides	0.022
Eucalyptus fibrosa	0.019
Eucalyptus glaucina	0.091
Eucalyptus hypostomatica	0.200
Eucalyptus melliodora	0.010
Eucalyptus moluccana	0.013
Eucalyptus notabilis	0.067
Eucalyptus piperita	0.056
Eucalyptus punctata	0.024
Eucalyptus tenella (incl. *E. ralla*)	0.111
Eucalyptus rossii	0.033
Eucalyptus sparsifolia	0.063
Eucalyptus tereticornis	0.009

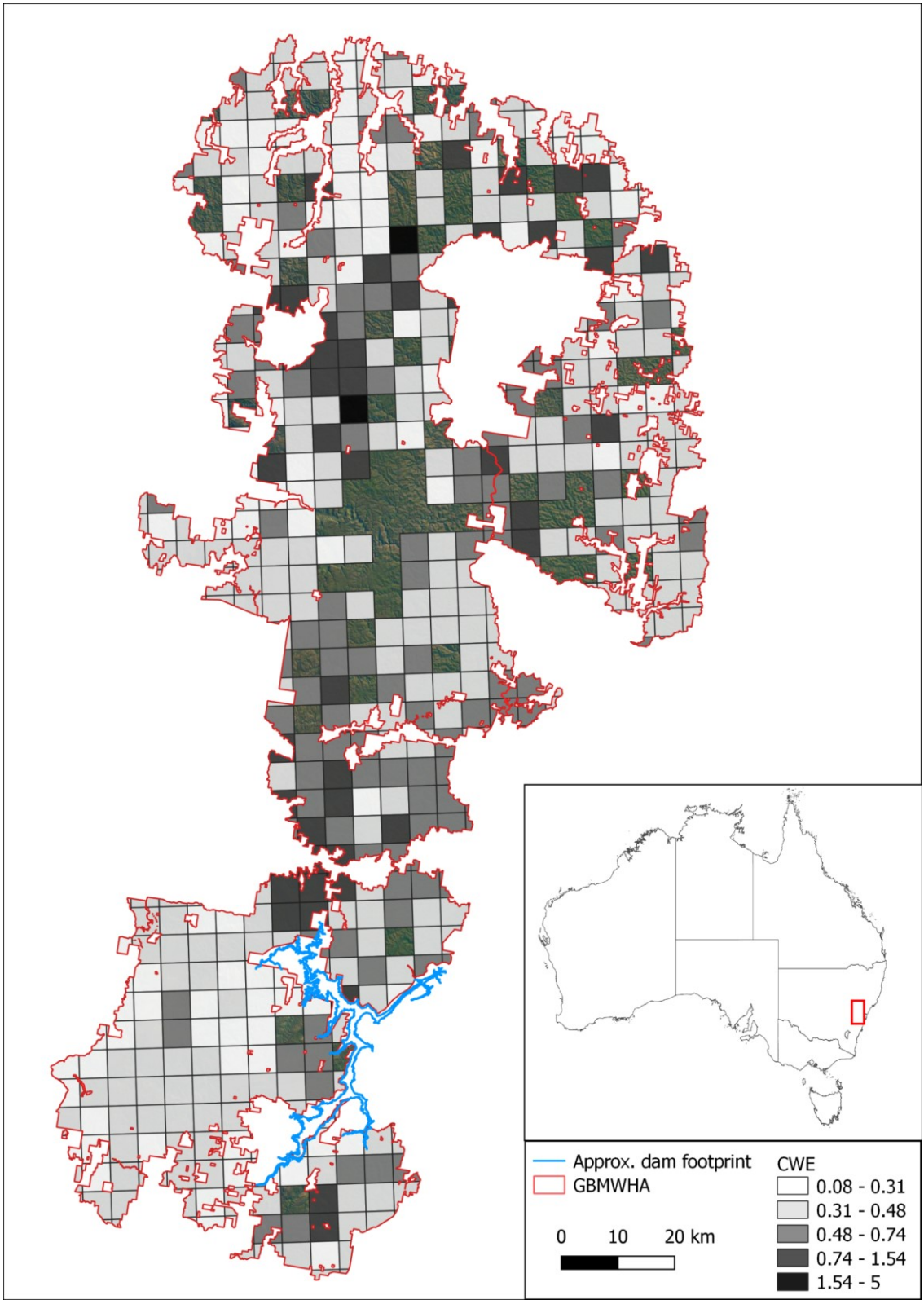

Figure 1. Corrected-weighted endemism (CWE) of *Eucalyptus, Angophora* and *Corymbia* species in the Greater Blue Mountains World Heritage Area (GBMWHA). Estimated footprint of dam expansion provided by the Colong Foundation. Hollow cells are data deficient. Detail on overlap between the expansion and GBMWHA cells are shown in greater detail in Figure 2. CWE scores are multiplied by 10 to make numbers more readable.

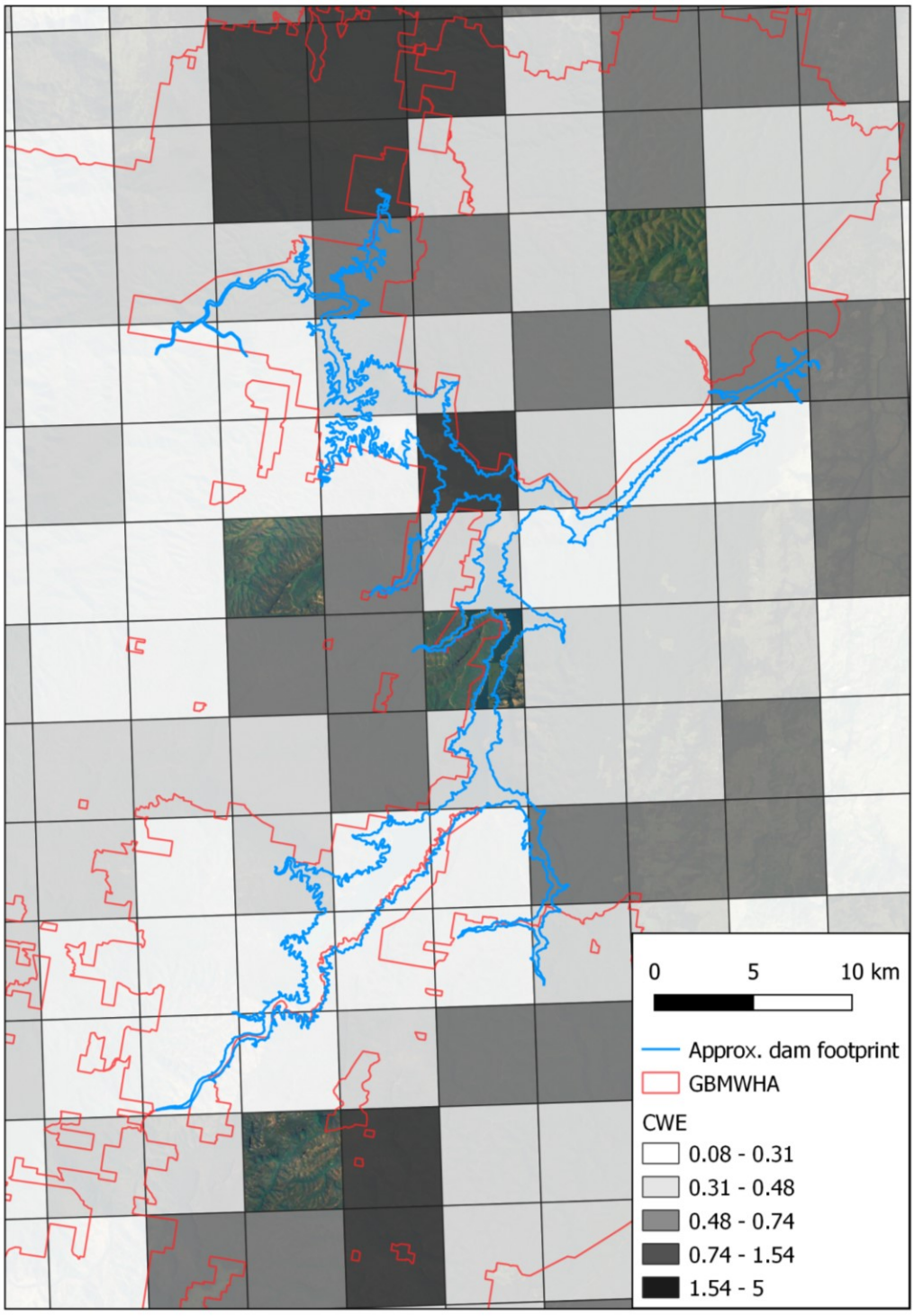

Figure 2. Detail of the intersection of the approximate footprint of the Warragamba dam expansion with the 5 x 5 km grid of *Eucalyptus, Corymbia,* and *Angophora* corrected-weighted endemism.

Discussion

The dataset we used was coarse, but large enough to be confident in the general patterns of distribution of the world heritage values related to eucalypts. Our analyses indicate that there are concentrations of world heritage values related to eucalypts in or directly adjacent to the potential expanded footprint of the Warragamba Dam. This result emphasises the importance of thinking about maintenance of values, rather than absolute or proportionate areas that might be affected by any prospective development. While there are some eucalypt species, such as *Eucalyptus ovata*, that can survive weeks of immersion, eucalypts that occur on well-drained land do not survive (Kirkpatrick and Gibson 1998). Much of the inundation will be on this sort of land.

The eucalypts that contribute the most to CWE are those with highly restricted distributions, contributing to the satisfaction of world heritage criteria iv as well as ii. However, even common eucalypts are important under criterion ii. Many occur in the prospective expanded footprint, which includes some environments that are complementary to the rest of the GBMWHA.

Our data assume that the fires of the 2019/2020 summer, that burned 82% of the GBMWHA (Commonwealth of Australia 2020) have not affected the distributions of species. There is a need to determine if any obligate seeding eucalypts have been reduced in distribution by the fires.

References

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Appendix

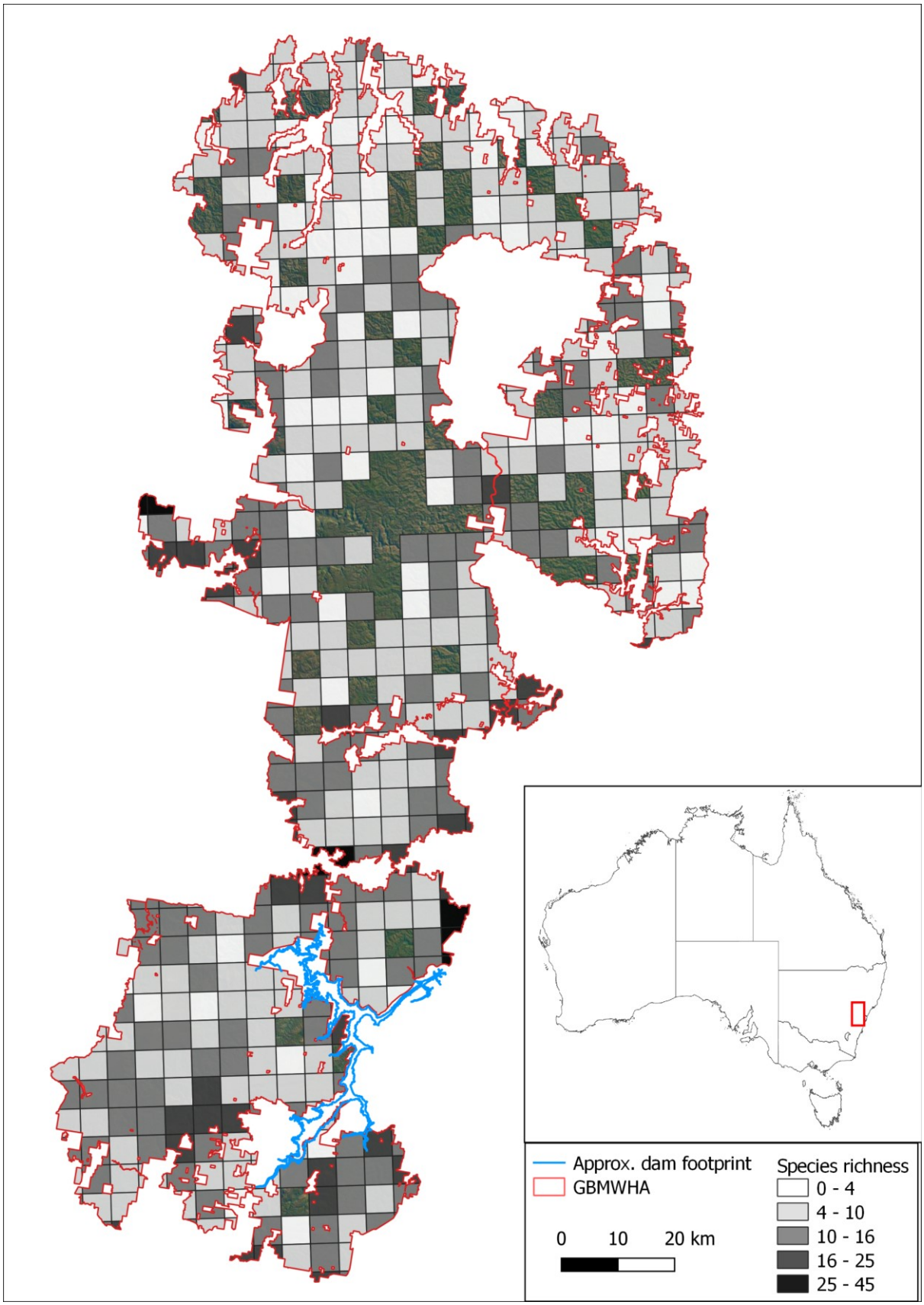

Figure S1. Species richness of *Eucalyptus, Corymbia*, and *Angophora* within the GBMWHA

Table A1. *Eucalyptus*, *Corymbia*, and *Angophora* species found within 5 x 5 km grid squares that intersect the dam expansion footprint.

Species	Inverse rarity
Angophora bakeri	0.052631579
Angophora costata	0.016129032
Angophora floribunda	0.013157895
Angophora hispida	0.090909091
Angophora subvelutina	0.026315789
Corymbia citriodora	0.011764706
Corymbia eximia	0.0625
Corymbia gummifera	0.023809524
Corymbia maculata	0.015151515
Eucalyptus acmenoides	0.015625
Eucalyptus agglomerata	0.032258065
Eucalyptus albens	0.01754386
Eucalyptus amplifolia	0.043478261
Eucalyptus apiculata	0.111111111
Eucalyptus benthamii	0.5
Eucalyptus beyeriana	0.066666667
Eucalyptus bosistoana	0.052631579
Eucalyptus botryoides	0.024390244
Eucalyptus capitellata	0.076923077
Eucalyptus consideniana	0.038461538
Eucalyptus crebra	0.007874016
Eucalyptus cunninghamii	0.5
Eucalyptus cypellocarpa	0.026315789
Eucalyptus deanei	0.047619048
Eucalyptus elata	0.037037037
Eucalyptus eugenioides	0.022222222
Eucalyptus fastigata	0.035714286
Eucalyptus fibrosa	0.019230769
Eucalyptus glaucina	0.091
Eucalyptus globoidea (including *E. oblonga*)	0.023809524
Eucalyptus hypostomatica	0.2
Eucalyptus mannifera subsp. gullickii	0.111111111
Eucalyptus melliodora	0.010204082
Eucalyptus microcorys	0.026315789
Eucalyptus moluccana	0.012987013
Eucalyptus multicaulis	0.111111111
Eucalyptus notabilis	0.066666667
Eucalyptus oreades	0.0625

Eucalyptus ovata	0.016949153
Eucalyptus paniculata	0.043478261
Eucalyptus pilularis	0.025
Eucalyptus piperita	0.055555556
Eucalyptus punctata	0.023809524
Eucalyptus quadrangulata	0.066666667
Eucalyptus radiata	0.020408163
Eucalyptus tenella (incl. *E. ralla*)	0.111
Eucalyptus resinifera	0.027027027
Eucalyptus robusta	0.03125
Eucalyptus racemosa	0.033333333
Eucalyptus saligna	0.021276596
Eucalyptus sieberi	0.023255814
Eucalyptus smithii	0.0625
Eucalyptus sparsifolia	0.0625
Eucalyptus squamosa	0.2
Eucalyptus stricta	0.058823529
Eucalyptus tereticornis	0.009259259