In search of preservation sites for Wollemi pine (*Wollemia nobilis*) in a changing climate

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INTRODUCTION

Wollemi pine (*Wollemia nobilis)* lived in what is now known as the Blue Mountains as long ago as 200 million years and was only known through fossil records before being re-discovered in 1994 by David Noble. *W. nobilis* first appears in the fossil record of the late Cretaceous, reaching its maximum during the Eocene. The climate of this era was warmer and wetter than current with substantially higher CO_2 concentrations, and is also associated with the global spread of angiosperms. The decline of *W. nobilis* coincides with global cooling and the northward movement of Australia during the Tertiary. This was accompanied by a drying trend and increased fire frequency and intensity. Thus, the decline of *W. nobilis* is commonly related to climate change and competition with angiosperms. Today, less than 100 mature trees are found in the wild, in a single catchment in Wollemi National Park in the Blue Mountains east of Sydney, Australia and is considered a shade-tolerant, warm temperature rainforest species. It appears to favor shady-areas, with less rainfall and cooler temperatures.

W. nobilis is one of the seven species in the family *Araucariaceae* found in Australia and is classified as Critically Endangered on the IUCN's Red List. The species is highly vulnerable because of a lack of genetic diversity, slow and inefficient seed recruitment, and although it can reproduce through resprouting, this enhances genetic similarity and is not desirable in such a small population. There is a real danger that *W. nobilis* is under threat of extinction given the rapid warming and drying predicted for SE Australia and habitat fragmentation that may limit the ability of seedlings to become established in other areas. This research investigates possible refuges for the preservation of *W. nobilis* under a changing climate to expand viable groves of trees.

METHODS

Firstly, we needed to develop a climate record of temperature and rainfall representative of the current grove of *W. nobilis.* The nearest BoM site is Nullo (062100) but it does not have a 30-year continuous record (1994-2016). The next closest site is Kelgoola (061215), located in the Blue Mountains but it only has rainfall records (1962-2017) so we also used the temperature data from Mudgee George Street (062021; 1907-1995) to develop a climatogram using the 30-year period (1962-1991). This climatogram was then adjusted using a regression analysis (Table 1) of daily rainfall, T_{max} and T_{min} for each month on overlapping periods between Nullo and Kelgoola (rainfall) and Nullo and Mudgee George Street (temperature) to estimate the current climate for Nullo based on 1962-1991 (Figure 1).

Secondly, we need to determine the climate projections for the Blue Mountains in 2050. To do this, we used the Projections Builder under the Climate Futures Tool from Climate Change in Australia (*https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/projections-builder/*) with the default settings and RCP 8.5 emissions scenario for eastern NSW. We used the average projection for temperature and rainfall (Table 2) to develop from Nullo's climatogram, a climate that will evolve into something similar to Nullo's current climate in 2050 (Figure 3).

Finally, the Climate Analogue Tool (*https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/*) allows identification of sites with similar climate to a chosen site given specified changes in temperature and rainfall. Nullo is not given as an option in this software, so we used sites that are mountainous and along the eastern slopes of NSW, viz., Cooma, Katoomba, Lithgow and Tumut. Sites analogous to these, given the projected climate changes, were then identified as possible refuges for *W. nobilis*.

RESULTS and DISCUSSIONS

1. Climatogram for *W. nobilis*

Rainfall at Kelgoola and T_{max} at Mudgee are closely correlated with conditions at Nullo (regression $r^2 > 0.8$) but T_{min} at Mudgee is not as reliable (Table 1). This is most likely due to the urban nature of the Mudgee site. However, we used all of the regressions to predict a climatogram for Nullo that looks reasonable (Figure 1). Interestingly, temperatures are quite mild with monthly average $T_{min} > 0$ °C and $T_{max} < 25$ °C. Furthermore, the area does not get excessive amounts of rainfall with monthly average rainfall less than 120 mm. This reflects the plant physiology research which suggests that *W. nobilis* does not like its roots in a well wetted substrate.

Table 1. Climate data for (a) rainfall (mm), (b) maximum temperature (°C), and (c) minimum temperature (°C). The first column gives the long-term average climate for (a) Kelgoola and (b,c) Mudgee. The second column shows the percent difference between Nullo and these sites for overlapping years. The third column presents the coefficient of determination r^2 for the associated regression and column four shows the calculated climate for Nullo from the regression analysis.

(a) Rainfall	Kelgoola (1962-91)	% Difference	Regression r^2	Nullo (1962-1991)	(b) T_{max} (°C)	Mudgee (1962-91)	% Difference	Regression r^2	Nullo (1962-1991)	(c) T_{min} (°C)	Mudgee (1962-91)	% Difference	Regression r^2	Nullo (1962-1991)
January	98.2	25.3	0.549	119.6	January	30.4	-23.1	0.879	23.3	January	15.7	-20.0	0.510	12.6
February	79.5	13.4	0.854	83.6	February	29.8	-25.0	0.823	22.6	February	15.7	-22.0	0.724	12.2
March	79.0	18.3	0.837	91.7	March	27.3	-29.1	0.977	19.5	March	13.3	-17.7	0.332	10.7
April	63.2	4.1	0.801	63.5	April	23.2	-29.4	0.825	16.2	April	9.0	-9.2	0.196	7.8
May	70.2	20.4	0.782	77.1	May	18.6	-34.3	0.989	11.8	May	5.7	1.4	0.528	5.6
June	63.9	17.8	0.909	81.0	June	15.4	-41.2	0.940	9.1	June	2.9	3.9	0.096	2.7
July	45.2	26.5	0.727	57.8	July	14.2	-39.4	0.929	8.6	July	1.4	46.3	0.727	2.3
August	65.0	17.9	0.858	73.4	August	15.8	-34.9	0.959	9.8	August	2.6	51.3	0.226	3.2
September	55.6	30.9	0.786	70.8	September	19.0	-30.7	0.901	13.2	September	4.7	-11.1	0.338	4.0
October	75.0	25.9	0.870	89.4	October	22.8	-27.5	0.951	16.5	October	8.0	-17.9	0.030	6.7
November	64.6	24.8	0.776	80.6	November	26.1	-24.7	0.893	19.8	November	10.9	-18.3	0.963	8.7
December	73.1	6.7	0.769	81.1	December	29.2	-27.1	0.899	21.5	December	13.8	-24.2	0.525	10.2

2. Climate Projections for 2050

On average, T_{max} is expected to increase by 1.8–2.2 °C and T_{min} by 1.7–1.9 °C depending on seasons with greatest increases in autumn and spring. Rainfall is predicted to decline by between 10 % in summer to 26 % in spring (Table 2). This means that the climatogram for refuge sites need to be cooler by up to 2.2 °C and wetter by up to 26 % of current conditions (Figure 2).

Table 2. Average temperature and rainfall projections from the Climate Futures Tool using default settings and RCP 8.5. The default settings are used as we have no *a priori* knowledge to assume that one aspect is more important than another at this point.

2050 Projections	T_{max} (°C)	T_{min} (°C)	Rainfall (%)
Summer	1.82	1.71	-9.53
Autumn	2.01	1.80	-20.03
Winter	1.97	1.71	-23.70
Spring	2.22	1.95	-26.07

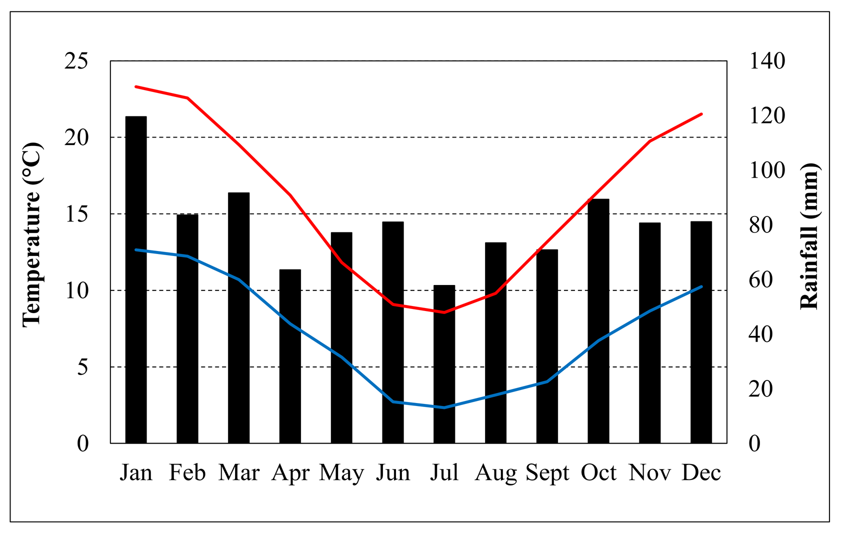

Figure 1. Climatogram (1962-1991) for Nullo in the Blue Mountains near the grove of *W. nobilis*. The data were compiled from short-term comparisons between Nullo and Kelgoola for rainfall and Mudgee for temperature, and climatograms for these two sites (see text for details).

3. Possible Refuges for *W. nobilis*

We sought sites that are between 1.5 and 2 °C cooler and between 10 and 25 % wetter than the chosen sites in order to identify locations that in 2050 will have climates similar to that at Nullo (1962-1991). Of the four sites considered as surrogates, Katoomba and Lithgow were identified as being the most like Nullo. Interestingly, no sites were identified as having a climate that would result in Katoomba's climate in 2050. This is a disturbing result as it suggests that any ecosystem in the Katoomba region that is sensitive to the climate variables considered here will not survive the change in temperature or rainfall. Lithgow's results were more promising with Katoomba and sites in NW Tasmania being identified as possible refuge sites. The results for Tumut (sites along coastal Victoria and SW Western Australia) and Cooma (sites along the central axis of Tasmania north of Hobart) are also promising. Further analysis into the weather and climate of these sites is needed before attempting a relocation experiment.

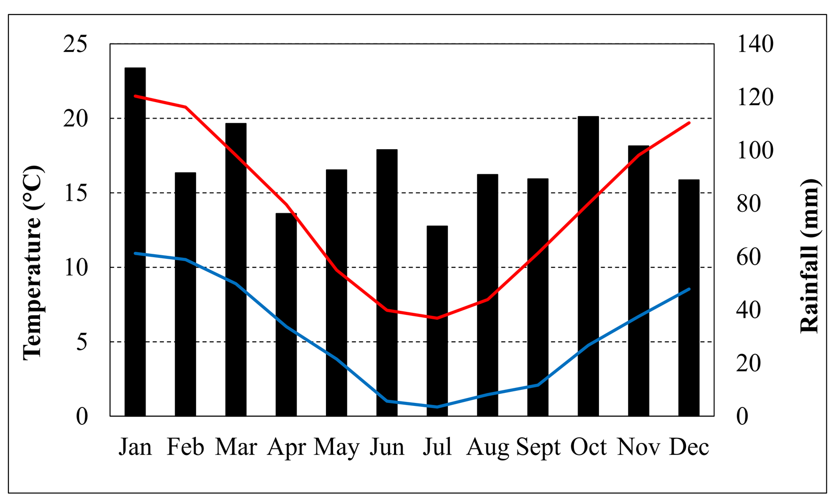

Figure 2. Climatogram required for a site to have the same climate in 2050 as that of the *W. nobilis* grove in 1962-1991. The data have been corrected for climate projections from the Climate Futures Tool using RCP 8.5.

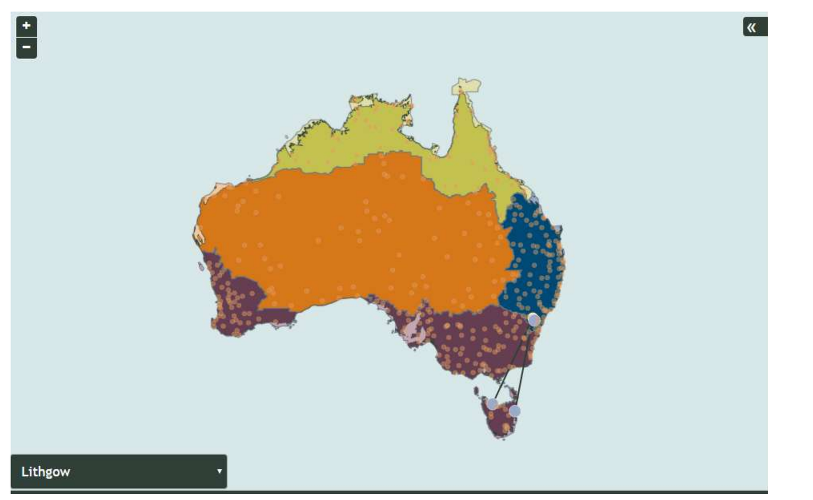

Figure 3. Screen output from the Climate Analogue Tool showing sites with a climate 2 °C cooler and 20 % wetter than that at Lithgow.

CONCLUSIONS

Several climate refuge sites for *W. nobilis* have been identified, viz., the Katoomba region and NW Tasmania. It is possible that some sites may be found along the coast of S Victoria and in SW Western Australia. Many mountainous BoM sites are not represented in the Climate Analogues Explorer and mountainous areas around Canberra and into N Victoria also be considered.

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