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Distribution, ecology, and morphology of the rare mallee *Eucalyptus cunninghamii* (Myrtaceae), Blue Mountains, New South Wales

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***Abstract*:** The small mallee *Eucalyptus cunninghamii* Sweet (family *Myrtaceae*) is restricted to the upper Blue Mountains of New South Wales with an outlier at Wanganderry Walls, 64 km south of Katoomba. It occurs in isolated clusters confined to windswept cliffs facing south and west, with average annual rainfall of at least 1300 mm, slopes of at least 20^0, and a narrow altitudinal range of 790–940 m.

We investigated 38 occurrences, 16 in the Grose Valley north of Katoomba (including the five largest), and 21 in the Jamison Valley, south of Katoomba. We estimated there to be approximately 1560 trees, 75% in the Grose Valley and 25% in the Jamison Valley. Trees in the Grose are significantly shorter (0.8 m high), with more, but thinner trunks than those in the Jamison Valley (2.3 m high). There are about 12 short trees at the Wanganderry outlier.

The Extent of Occurrence (EOO) (excluding the Wanganderry outlier) is about 200 km^2. The Area of Occupation (AOO) for all 38 occurrences is 9420 m^2, or less than one hectare, though despite its limited occurrence *Eucalyptus cunninghamii* could not be considered Vulnerable against IUCN Criteria at present.

Leaf morphology measurements showed that Intramarginal Vein Ratio, Secondary Vein Angle and Oil Gland Density were approximately constant across the upper Blue Mountains. Fire history, bud development and flowering times, and pollination vectors were recorded. Leaf longevity is about 3 years. Flower buds emerge in spring (November) to early summer (December) and develop over a period of 18 months before flowering in late autumn (May). Fruits mature in spring. The time taken to reach flowering from germination and for regrowth after fire is about 5 years, but nearly 7 years to fruit maturity.

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Introduction

The small mallee *Eucalyptus cunninghamii* Sweet (family Myrtaceae) (Cliff Mallee Ash), is restricted to the upper Blue Mountains of New South Wales with a small outlying occurrence 64 km south of Katoomba at Wanganderry Walls, near Mittagong. It is found almost exclusively on rocky, windswept cliffs on the upper margins of the Grose and Jamison Valleys. We have previously examined geologic associations (Coleby & Druitt 2019) and substrate nutrients and trunk diameters (Coleby & Druitt 2020). Here we look at geospatial, conservation, ecological and morphological characters. We sought markers that would indicate trends between attributes, and departures from those trends. The aim was to identify possible differences in attributes that might be aligned with genetic variation as discussed by Rutherford (2017).

Methods

Geospatial and Ecology

We identified 11 occurrences of *Eucalyptus cunninghamii* in the upper Blue Mountains and an outlier on the western edge of the Wanganderry Plateau (west of Mittagong) from Australia's Virtual Herbarium (AVH), and during 2017–2019 we field-checked these and with further exploration found an additional 26 occurrences, resulting in a total of 37 occurrences in the upper Blue Mountains and confirmed the outlier at Wanganderry. Geophysical attributes of all 38 occurrences were shown in Table 1 of Coleby & Druitt (2019) and geospatial distribution of 37 upper Blue Mountains occurrences in Figure 1 of Coleby and Druitt (2019). Overall, the altitudinal range of *Eucalyptus cunninghamii* is 665-945 m (Coleby & Druitt 2019).

At each of the 38 occurrences we recorded GPS latitude and longitude, map reference, altitude (altitude errors are estimated to be ±8 m.), aspect, slope and Area of Occupation (AOO). We recorded vegetation community (using Keith (2004), fire history (from the NSW National Parks & Wildlife Service (NPWS) Blackheath and NSW Rural Fire Service (RFS) and identified native shrub and tree species at each occurrence most commonly occurring alongside *Eucalyptus cunninghamii.* We counted numbers of trees within each AOO, although in some dangerous locations on clifftops we made visual estimates. Isohyets of average rainfall for the period 1961-1990 for the upper Blue Mountains were obtained from the Bureau of Meteorology (BOM), but no update for the present century was available.

Morphological and Biological Attributes

At each of the 38 occurrences we selected at random 4–6 trees and recorded heights, number of trunks and trunk diameters. We took random leaf samples from these trees, and measured leaf lengths, leaf widths, leaf venation, and leaf oil glands. In some instances, where available, we collected and measured fruit capsule sizes. All samples were air-dried for 5–7 days; then catalogued and stored. Leaf length/leaf width ratios at each occurrence were calculated and, for a selected occurrence, leaf widths in annual groups between growth nodes were recorded.

For leaf venation and oil gland densities, six fresh undamaged leaf samples were collected randomly from several trees at each occurrence. Adaxial surfaces of fresh leaf samples were photographed under a binocular 20x microscope with bottom light, with a millimetre scale glued onto the stage. We used large computer images of these photos to measure the ratio of the distances of the intramarginal vein and the leaf margin from the main vein (Brooker & Nicolle 2013). We also measured the angle of the secondary vein from the main vein. We then printed enlarged photos of these leaves in groups of six for each occurrence, enabling reasonably accurate counting of oil glands. Observations of bud development, flowering times and likely pollination vectors were made irregularly at some occurrences. We collected fruit capsules and sent seed for tests of viability and germination to the Australian PlantBank laboratories, Australian Botanic Garden, Mount Annan. We collected data on the time to reach reproductive maturity.

Results and Discussion

Extent of Occurrence (EOO)

The geographic range of *Eucalyptus cunninghamii* in the upper Blue Mountains extends from Mount Banks and Walls Clifftop in Grose North, to the gate on Kedumba Valley Road (Kings Tableland, Wentworth Falls) in Jamison South, a total distance of 22 km. The width of its habitat is narrower, less than 9 km. The extent of occurrence (EOO) is therefore about 200 km^2, excluding the outlier at Wanganderry Walls. No occurrences were found on the clifftops of the Megalong Valley to the west of the Jamison and Grose Valleys, nor east of a line between the Mount Tomah Monocline and the Bodington Monocline. None were found in the area north of Bells Line of Road in the Wollangambe Wilderness, nor south of Kedumba Gate on Kings Tableland, nor south of the Golden Stairs on Narrow Neck. The remote outlier at Wanganderry Walls near Mittagong lies in Nattai National Park. No occurrences were found in Megalong Valley as indicated in Euclid (Slee et al, 2015). Our 38 observed occurrences do not necessarily represent all occurrences. There may be some in relatively inaccessible locations in the Jamison Valley or the Grose Valley.

Area of Occupation (AOO) and Vulnerability

Major geographic features (the canyons of the Grose River and Govetts Creek) isolate the 16 occurrences in the Grose Valley into 3 regions, Grose North, Pulpit Rock and Grose South. Similarly, 3 km of rugged terrain between Leura (Sublime Point) and Kings Tableland (Lincolns Rock/Little Switzerland) isolate the 23 occurrences in the Jamison Valley into 2 regions, Jamison West and Jamison South.

Overall *Eucalyptus cunninghamii* has an Area of Occupation (AOO) of 9420 m^2, or less than a hectare (Table 1). Grose

North (2560 m^2), Grose South (1890 m^2) and Pulpit Rock (2000 m^2) together represent 68% of the AOO total: Jamison West (1310 m^2) and Jamison South (1560 m^2) account for only 32%. 37% of the 38 occurrences have an AOO between 5 m^2 and 80 m^2, and 60% between 100 m^2 and 1000 m^2. The largest AOO (2000 m^2) is at Pulpit Rock. we estimated almost 1560 trees in total for all 38 occurrences (Table 1) with 75% in Grose Valley occurrences and 25% in the Jamison Valley. The five largest occurrences are all in the Grose Valley.

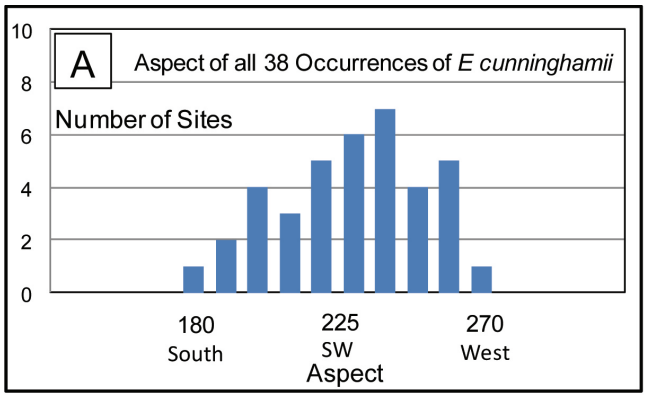
Table 1. Morphological and environmental attributes of 38 occurrences of *Eucalyptus cunninghamii* (including the southern outlier). See Coleby and Druitt (2019) for details of geospatial attributes and sketch map of distribution around the Grose and Jamison Valleys of the upper Blue Mountains. IVR = Intramarginal Vein Ratio, SV = Secondary Vein Angle, OGD = Oil Gland Density, AOO = Area of Occupation.

Occurrence	Code	Trees		Trunks		Leaves						Fruit			
		No. of Trees	Ave. Height (m)	Ave. No.	Ave. Dia. (mm)	Ave. Length (mm)	Ave. width (mm)	Length Width Ratio	IVR	SVA	OGD	Dia (mm)	Aspect	Slope	AOO
Walls Cliff 1	WC 1	2	0.6	7	15	33.2	3.3	10.1	0.74	20	588	5.7	210	20	10
Walls Cliff 2	WC 2	50	0.5	8	15	54.7	5.2	10.5					225	30	200
Wongarra 1	W1	20	0.6	8	12	46.7	4.2	11.1	0.74	20	410		240	40	50
Wongarra 2	W2	16	0.9	7	20	40.8	4.2	9.7	0.74	20.5	465	5.7	220	20	100
Wongarra 3	W3	120	0.6	8	10	33.1	3.2	10.3	0.76	21	432		200	30	1000
Mount Banks 1	MB1	80	0.7	9	12	41	4	10.3	0.75	23.4	616		240	30	300
Mount Banks 2	MB2	100	0.6	8	11	32.3	4	8.1	0.73	23	458		230	35	150
Mount Banks 3	MB3	20	0.6	8	10	41.2	3.4	12.1	0.72	23	453		230	25	50
David Crevasse	DC	100	0.6	9	11	31.3	3.1	10.1	0.69	20	440	6.1	240	30	700
Grose North		508	0.6	8.0	12.9	39.4	3.8	10.3	0.73	21.4	483	5.8	226	29	2560
Pulpit Rock	PR	240	1.8	5.5	26	38.3	4.3	8.9	0.75	21.5	470	6.5	250	25	2000
Fortress Cliff	FC	65	1.8	6	18	35.3	4.5	7.8	0.75	22	455	5.4	260	20	300
Lockley Pylon	LP	20	1.5	6	17	38.7	3.8	10.2	0.74	22	505		180	25	40
Butterbox West	BW	120	0.7	8	12	25.9	2.6	10.0	0.74	20	400		260	20	750
Butterbox South	BS	100	0.8	5	25	32.2	4.2	7.7	0.74	26	447		240	20	500
Butterbox East	BE	30	0.5	6	12	21.9	3.0	7.4	0.74	21	390		270	20	100
Mt Hay SW	MH	80	0.7	7	18	37.8	4.8	7.9	0.71	20	576		255	20	200
Grose South		415	1.2	6.3	17.0	32.0	3.8	8.5	0.74	21.8	462	5.4	244	21	1890
Giant Stairs	GS	6	1.8	2	30	49.3	4.6	10.7	0.72	20	528	5.6	190	20	50
Prince Henry C/W	PH	30	2.2	7	25	46.3	4.5	10.3	0.72	23	440	6.7	210	40	250
Gordon Falls L/O	GF	N/A											200	90	10
Golf Links 1	GL 1	15	2.1	4.5	25	44.3	4.7	9.4	0.78	21.5	473	6.5	200	20	100
Golf Links 2	GL 2	15	5.1	2	25	39.9	4.2	9.5	0.73	22	420		210	40	100
Sublime Point 1	SP1	30	2.4	2.5	35	50.5	4.9	10.3	0.74	23	463	6.3	230	25	400
Sublime Point 2	SP2	5	5.0	2	65	57.0	4.7	12.1	0.75	21.0	510		230	30	100
Sublime Point 3	SP3	4	5.0	2	65	52.6	4.8	10.9	0.77	23.0	530		235	35	100
Sublime Point 4	SP4	10	4.5	4	40	46.0	4.4	10.5	0.75	20.0	542	5.7	230	30	150
Sublime Point 5	SP5	3	1.8	2	25	52.0	4.2	12.4	0.77	23.0	505	6.8	200	30	50
Jamison West		118	3.3	3.1	37.2	48.7	4.6	10.7	0.75	21.8	490	6.3	214	36	1310
Undercliff Track 1	UT1	12	3.8	2	80	54.9	5.2	10.6	0.8	23	485		240	60	60
Undercliff Track 2	UT2	6	3.5	2	65	62.0	4.9	12.7	0.79	20	640		220	60	40
Undercliff Track 3	UT3	1	1	2	14	64.3	4.2	15.3	0.74	20	380		200	60	5
Lincolns Rock	LR	3	0.6	12	12	43.4	3.8	11.4	0.78	25	400		220	30	45
Little Switzerland	LS	40	0.7	2.4	15	41.2	3.9	10.6	0.75	27	506		260	40	100
Kedumba Walls	KW	40	0.6	10	12	46.9	4.7	10.0	0.75	21	406		259	40	10
Podgers Cliff	PC	14	1	9	8	56.7	3.6	15.8	0.78	23	430		261	20	300
Sunset Rock	SR	50	4.2	2.5	70	42.3	4.7	9.0	0.74	25	626	5.9	250	25	400
Colraine Rock	CR	7	2.2	3	20	39.6	3.9	10.2	0.7	22	706	5.5	250	20	20
Kedumba Road	KR	10	2.2	2	50	44.4	4	11.1	0.74	20	403	6.3	240	30	80
Kedumba Gate	KG	80	2.8	2.5	60	41.6	4.2	9.9	0.75	25	547	6.1	230	20	500
Jamison South		263	2.1	4.5	36.9	48.8	4.3	11.5	0.76	22.8	503	6.0	239	37	1560
Wanganderry Walls	WW	12	1.0	7	17	39.3	2.7	14.6	0.70	none	415		250	25	100

Eucalyptus cunninghamii did not comply with IUCN Red List Criteria A–E for a Vulnerable Species and could not at present be considered vulnerable; the emphasis for a vulnerable assessment relies on measured decline. Our data represent the baseline for future assessment.

Aspect, slope and rainfall

Occurrences of *Eucalyptus cunninghamii* are restricted to aspects between south and west i.e. essentially southwest (Figure 1A). *Eucalyptus cunninghamii* inhabits terrain with a minimum slope of 20°. In Grose North the average slope is 29°, and in Grose South the average slope is 21° (Figure 1B). Pulpit Rock has an average slope of 25°.The average slope in Jamison West is 36°, brought about principally by the inclusion of a 90° slope at Gordon Falls. In Jamison South the average slope is 37°, including three steep slopes of 60^0 on the Undercliff Track. The outlier at Wanganderry Walls has a slope of 25°. Slopes of this nature confer good drainage. Both the Jamison and Grose Valley groups of *Eucalyptus cunninghamii* lie within the 1300 mm isohyet of average annual rainfall (Figure 2). Rainfall for Wanganderry Walls is not known; nearby Mittagong experiences a long-term average annual rainfall of 895 mm.



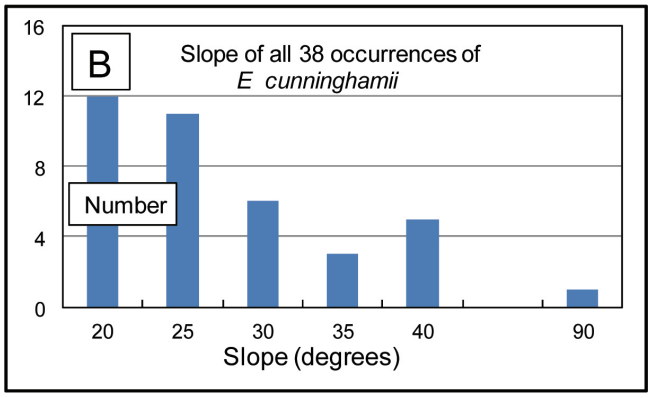


Figure 1. Aspect (A) and Slope (B) for all 38 *Eucalyptus cunninghamii* occurrences

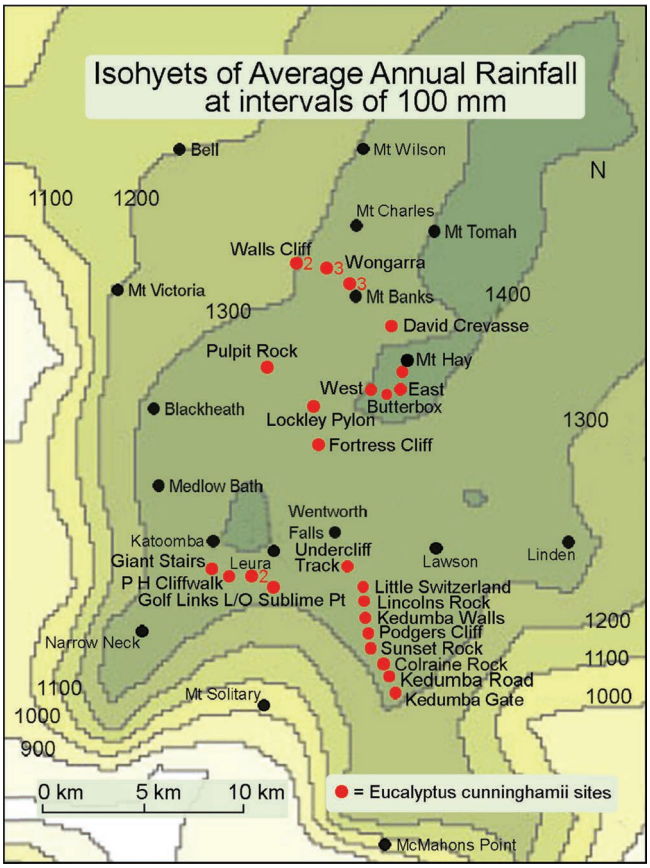


Figure 2. Isohyets of Average Annual Rainfall (1961–1990) and distribution of 37 occurrences of *Eucalyptus cunninghamii* in the upper Blue Mountains.

Habitat and vegetation

Eucalyptus cunninghamii occupies a naturally fragmented habitat on clifftops, but with noticeable differences in habitat between regions. In Grose North almost all habitats are short Sydney Montane Heath (Keith 2004) and contain no other eucalypts (Hammill & Tasker 2010), except where taller mallees *Eucalyptus stricta* and/or *Eucalyptus dendromorpha* occur around the margins. Grose South and Pulpit Rock habitats are mostly tall and shrubby. The largest and most vigorous occurrence of *Eucalyptus cunninghamii* is at Pulpit Rock.

Jamison habitats are largely Open Forest blending into Escarpment Complex, and contains at least one other eucalypt species, usually *Eucalyptus sieberi, Eucalyptus piperita* or *Eucalyptus dendromorpha*, and sometimes, as at the Giant Stairs at Echo Point, *Eucalyptus oreades*. At Little Switzerland, Kedumba Walls and Podgers Cliff the habitat is tall Sydney Montane Heath on steep slopes. At Kedumba Gate (the southernmost occurrence in Jamison South) *Angophora costata* and *Corymbia gummifera* grow alongside *Eucalyptus cunninghamii* and *Eucalyptus piperita.*

Over 70 native plant species (not an exhaustive list) were recorded in the vegetation communities associated with *Eucalyptus cunninghamii*, the most frequent being

Leptospermum trinervium (at 27 sites), *Allocasuarina nana* (20), *Allocasuarina distyla* (18), *Banksia ericifolia* (18), *Hakea dactyloides* (16), *Lambertia formosa* (13) and *Banksia serrata* (15) (Table 2). The small occurrence (12 plants) at the outlier, Wanganderry Walls, is accompanied by *Leptospermum trinervium and Grevillea triternata.*

Table 2. Vegetation Communities at all 38 occurrences of *Eucalyptus cunninghamii*

Principal Species Occurrence	*Leptospermum trinervium*	*Allocasuarina nana*	*Banksia ericifolia*	*Allocasuarina distyla*	*Hakea dactyloides*	*Lambertis formosa*	*Banksia serrata*	*Hakea pachyphylla*	*Eucalyptus stricta*	*Eucalyptus dendromorpha*	*Eucalyptus piperita*	*Eucalyptus sieberi*	*Eucalyptus oreades*
Grose North													
Walls Cliff (2)	1	1	1						1				
Wongarra (3)	3	3	2	2	2	2							
Mount Banks (3)	3	2				3			2				
David Crevasse			1						1				
Pulpit Rock	1	1	1		1				1	1			
Grose South													
Fortress Cliff	1			1				1		1			
Lockley Pylon		1	1			1		1					
Butterbox (3)	3	3	3	3		1	2						
Mt Hay SW	1		1		1	1							
Jamison West													
Giant Stairs		1			1		1				1	1	1
Prince Henry C/W	1	1			1				1	1			
Gordon Falls L/O	1				1		1						
Golf Links (2)	2	1	2	2	2	1	1						
Sublime Point (5)	3			2	2		3				1	2	
Jamison South													
Undercliff Track (3)							1						
Kedumba Walls	1	1	1	1	1		1	1					
Lincoln's Rock	1	1	1	1			1						
Little Switzerland	1	1	1	1		1	1	1					
Podgers Cliff	1	1	1	1	1	1	1	1					
Sunset Rock			1	1	1		1		1		1		
Colraine Rock	1			1	1					1		1	
Kedumba Road				1		1			1		1		
Kedumba Gate	1	1		1	1	1				1	1	1	
Wanganderry Walls	1	1	1				1						
Totals	27	20	18	18	16	13	15	5	8	5	5	5	1

Fire history and flowering

Eucalyptus cunninghamii has both a lignotuber and epicormic buds. After fire has removed all aerial growth, the lignotuber resprouts, reaching an average 600 mm height within two years. Epicormic buds on the stems may erupt at any time without the stimulus of fire. This may arise when a mature trunk, for whatever reason, exposes dormant leaf buds to strong sunlight. These epicormic growths may survive and prosper, drawing nutrients to the detriment of higher branches, which may wither and die, and eventually fall off.

There are large differences in the fire history of the regions (Table 3). Grose Valley occurrences were burnt in the 2019–2020 fires. Prior to this event fire intervals in the Grose ranged down from 15 years at Fortress Cliff, 12 years at Pulpit Rock, Lockley Pylon, David Crevasse and Mt Hay, 12 at each of three Butterbox occurrences, to 5 years at the remainder. Occurrences that have experienced a fire within the last five years do not exhibit buds, flowers or fruit. At Mount Banks buds had re-appeared in February 2018, five years after the previous fire, but had not had time to flower before experiencing the 2019–2020 fires.

In the Jamison Valley, most occurrences have not been burnt for 50 or more years, except for the August 2015 burns at Lincolns Rock, Kedumba Walls and Podgers Cliff. Based on our observations, we predict that *Eucalyptus cunninghamii* at these three sites will have new flower buds emerging in December 2020, followed by an 18 month interval before flowering in April/May 2022 and fruit set in September 2022. All the Jamison Valley occurrences escaped the 2019–2020 fires.

Table 3. Fire History at all 38 occurrences of *Eucalyptus cunninghamii*

Occurrence	Years since last burn	Comments
Grose North		
Walls Cliff (2)	0	2019-2020; HRB 2013; Spring 2006; 1992-3.
Wongarra (3)	0	2019-2020; HRB 2013; 2006-7; 1992-3.
Mount Banks (3)	0	2019-2020; November 2013; October 2006.
David Crevasse	0	2019-2020: November 2013; Spring 2006.
Pulpit Rock	0	2019-2020; October 2006; edge in 1993-4; also 1982--3
Grose South		
Fortress Cliff	0	2019-2020; 2002-3, 1993-94, 1982-83.
Lockley Pylon	0	2019-2020; Spring 2006; 2002-3, 1993-94, 1982-83.
Butterbox (3)	0	2019-2020; 2006-7; 2002-3; 1993-4 (details unknown)
Mt Hay SW	0	2019-2020; Spring 2006; 2002-3; 1993-4 (details unknown)
Jamison West		
Giant Stairs	50+	Nearest adjacent burn to the west in 1985-86.
Prince Henry C/W	50+	Not burnt for over 50 years
Gordon Falls L/O	50+	Not burnt for over 50 years
Golf Links (2)	50+	Not burnt for over 50 years
Sublime Point (5)	25 (?)	1992-93 in the area, but may not have affected the site
Jamison South		
Undercliff Track (3)	16	2002-3 in patches; 1980-81:
Little Switzerland	50+	Adjacent last burn 1992-93
Lincoln's Rock	4	Burnt in August 2015
Kedumba Walls	4	Burnt in August 2015
Podgers Cliff	4	Burnt in August 2015
Sunset Rock	50+	Not burnt for over 50 years
Colraine Rock	50+	Not burnt for over 50 years
Kedumba Road	50+	Not burnt for over 50 years
Kedumba Gate	50	Last burn 1977-78, E of Kedumba Valley Road
Wanganderry Walls		Not known

Growth form

Average tree height differed between Grose (0.8 m) and Jamison (2.3 m) with a large height range within each population (0.5–5.0 m). The average number of trunks per tree (overall 6.2), is much higher in Grose North (8.0), Pulpit Rock (5.5) and Grose South (6.3) than Jamison West (3.1) or Jamison South (4.5) (Figures 3A–3C).

There is a high negative correlation (-0.98) between the average number of trunks and tree height (Figure 3A, and average trunk diameter and number of trunks (-0.95),

(Figure 3C) and a positive correlation between trunk diameter and tree height (0.92) (Figure 3B), all consistent with a gradient of small multistemmed mallees to bigger more tree-like individuals. Shorter mallees predominated in the Grose catchment with more treelike forms in the Jamison. Several occurrences where trunk diameters are large (50–80 mm in diameter) were recorded in Jamison South.

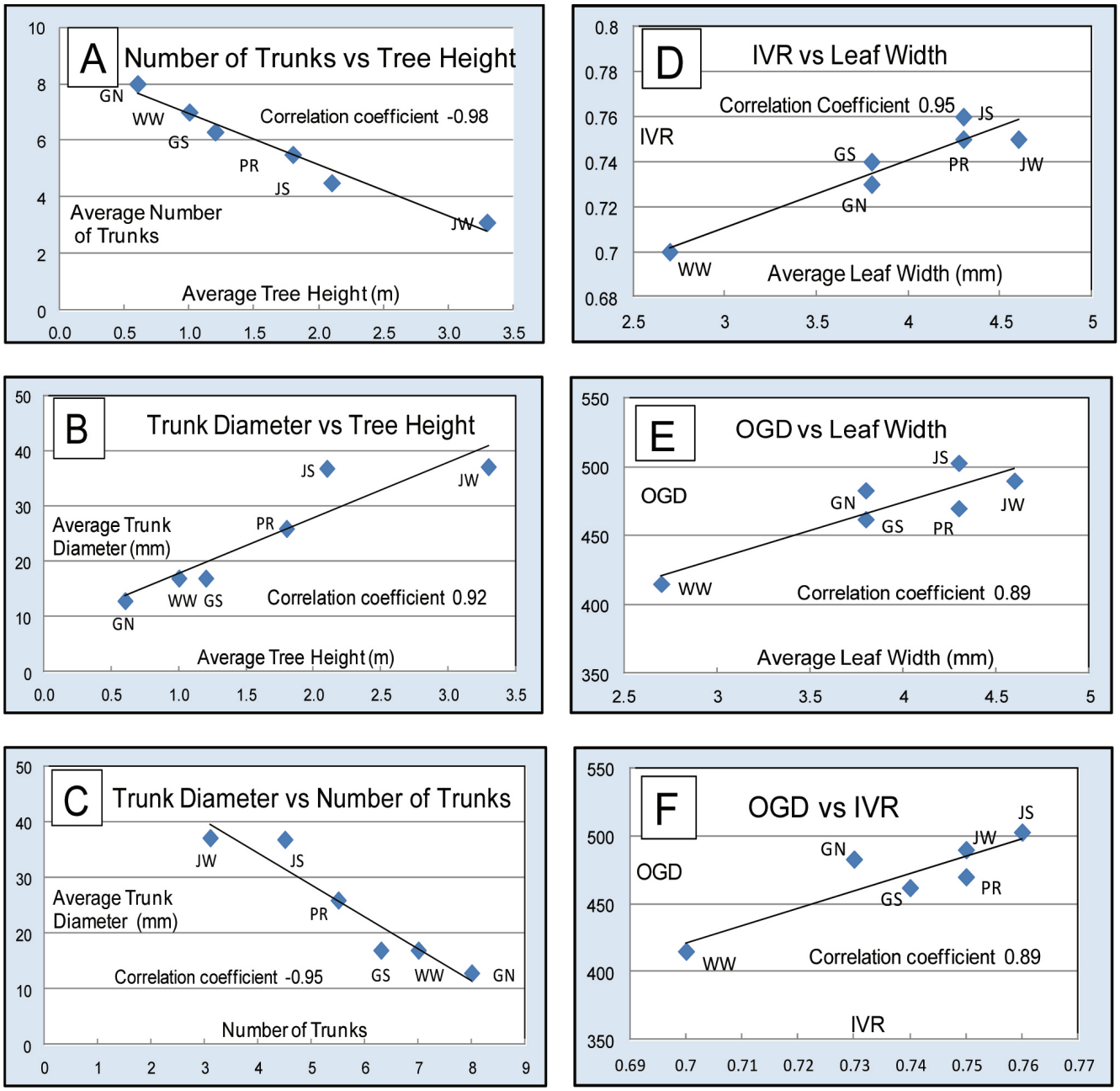


Figure 3. Two sets of three correlation graphs for all six regions (see Table 1 for codes). Left set of gross morphology, [A] Number of Trunks vs Tree Heights, [B] Trunk Diameters vs Tree Heights, [C] Trunk Diameters vs Number of Trunks. Right set of leaf venation and oil glands, [D] IVR vs Leaf Width, [E] OGD vs Leaf Width, [F] OGD vs IVR. OGD = Oil Gland Density, IVR = Intramarginal Vein Ratio.

Leaf Lengths and Widths

Average leaf lengths (including petioles), leaf widths, and length to width ratios are consistently larger in the Jamison than in the Grose (Table 1), possibly another indication of different nutrient soils (Coleby & Druitt, 2020).At Wanganderry Walls average leaf length is 39.3 mm, but leaves have a narrow average width of 2.7 mm, the ratio of leaf length to leaf width is a high 14.6, there are no secondary leaf veins, and intramarginal veins are most often indistinct or even absent.

Of the 8000 leaves measured in our study only 21 were 80 mm or more in length, and none were 90 mm or greater. (Euclid (Slee et al 2015) describes leaf lengths from 3–10 cm, and it is not clear whether Euclid measurements include the petiole). Similarly, we measured widths of over 2000 leaves (Table 1) but found 99% were less than 7.5 mm wide (Figure 4A). (Euclid describes leaf widths 0.3–0.8 cm).

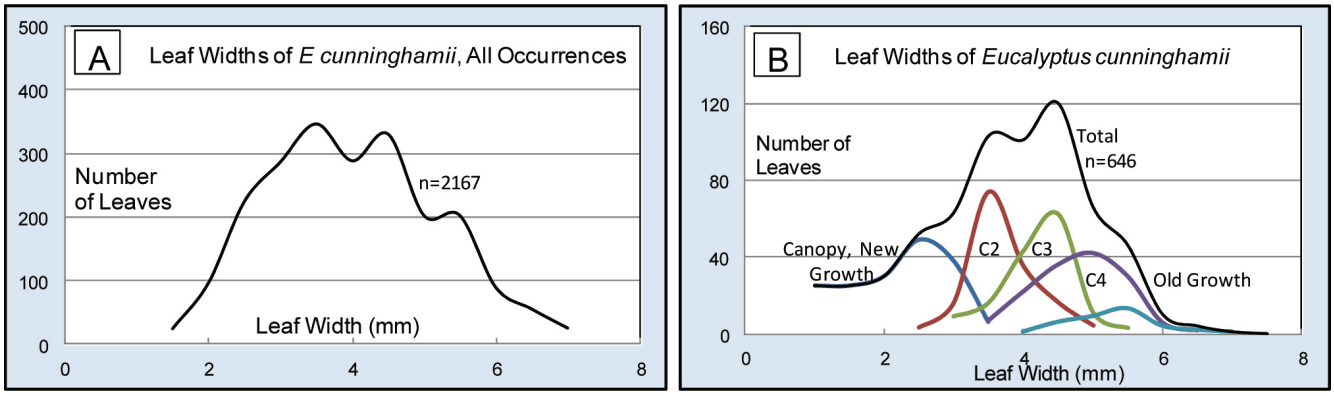


Figure 4. (A) Average Leaf Widths of all occurrences in the Grose and Jamison Valleys, and (B) Cohort analysis of a sample branch of 646 leaves (see text).

Annual Leaf Growth

The trimodal peaks of leaf width (Figure 4A) are sufficiently prominent to perhaps represent a succession of annual leaf growth cohorts. We took a sample branch (a November sample with new growth) with 646 leaves from Sunset Rock (Jamison South). We measured Leaf widths from internode branchlets i.e. cohorts where differences between two adjacent nodes represent annual growth (Figure 4B) allowed us to identify the new growth cohort (age zero), three other annual cohorts of former years, and a small fifth cohort. There is overlap across cohorts, suggesting Node Position is much more flexible than figures would suggest. As branchlet length increases from Cohort 1 through to Cohort 5, leaf density decreases, and the sparse distribution in Cohort 5 is followed by total leaf loss. We estimate that the lifetime of a leaf to be approximately 3 years.

Leaf Venation and Oil Glands

Over the six regions the average Intramarginal Vein Ratio (IVR) was 0.74 (range 0.7–0.8), and the Secondary Vein Angle (SVA) was 21.6° (range 20–27°). Island oil glands are consistently round in all leaves, with an average density of 479 cm^{-2} (range 390–626 cm^{-2}). No tertiary veins were found on any leaves. A typical leaf sample from Kedumba Walls in Jamison Valley is shown in Figure 5. Our data are consistent with published attributes (Brooker & Nicolle, 2013).

Correlations of IVR, OGD and Leaf Width, in which positive linear relationships are evident, probably related to nutrient status of soils in different regions (Figures 3D–3F). Specimens from Wanganderry have narrower leaves, leaf length to width ratios of 14.6 as against 9.9 for the upper Blue Mountains, total absence of secondary veins, and relatively low Intramarginal Vein Ratio (0.70 as against 0.74 for the upper Blue Mountains) and low Oil Gland Density (415 cm^{-2}, as against a Blue Mountains average of 480 cm^{-2}).

Reproductive maturity, flowering and pollination

We found that *Eucalyptus cunninghamii* juveniles can initiate flower buds when five years old, with fruit maturing after nearly seven years. This time frame is similar for regrowth and reproduction from resprouts after fire.

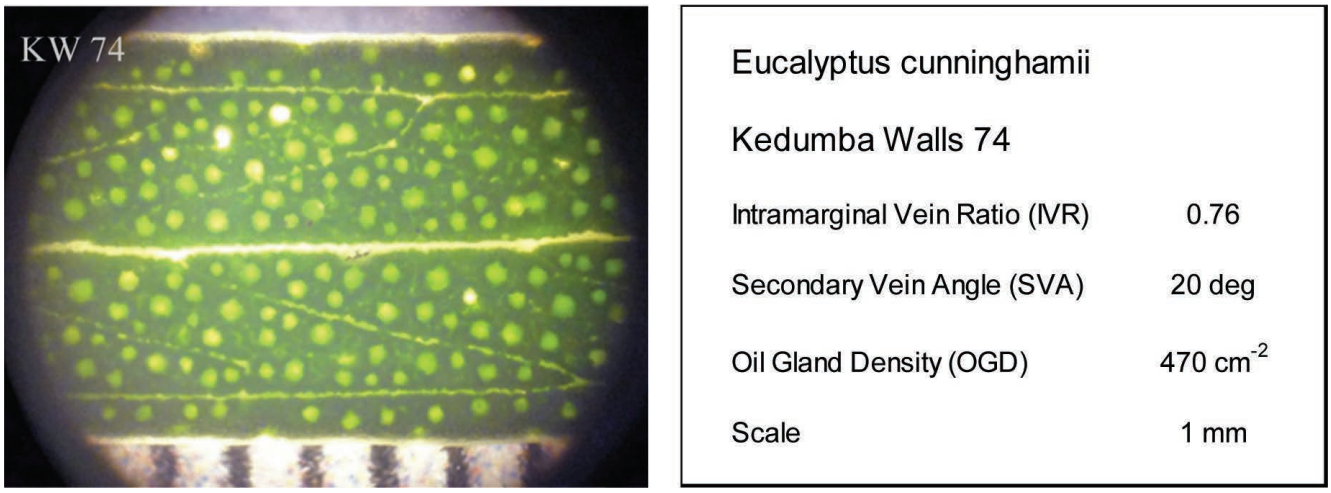


Figure 5. Photo of leaf venation from Kedumba Walls with leaf measurements.

Buds emerge from leaf axils in late spring (November) and early summer (December onwards), and develop for approximately 18 months before they flower. Buds appear to experience a winter vernalisation to stimulate flowering 9 months later next autumn. Young buds that have not passed through vernalisation remain unopened on the tree for another year. At maturity the conical opercula of 16-month-old buds are noticeably reddish and warty, whereas the younger 4-month-old buds on the upper part of the same branchlet are greener, slimmer and less warty (Figure 6).

Flowers emerge at the end of March and into April. Peak flowering occurs in April–May, and diminishes into June-July, with very occasional spot flowering up to the end of August (Figure 6). This idealised skew-normal flowering progression is confounded by variable start of flowering times between different occurrences, often between different trees within one occurrence, and sometimes even between different trunks on one tree. (These data contrast with those of Euclid (Slee et al, 2015) which records flowering in April, September and December).

Insects are the most likely *Eucalyptus cunninghamii* pollinators; we observed visits by both native Australian and introduced European hive bees (*Apis mellifera*). Blue-banded Bees (*Amegilla sp.*) and Reed Bees (*Exoneura sp*) are two species that are capable of surviving winter, whereas many other native bees are not (Dollin 2007).

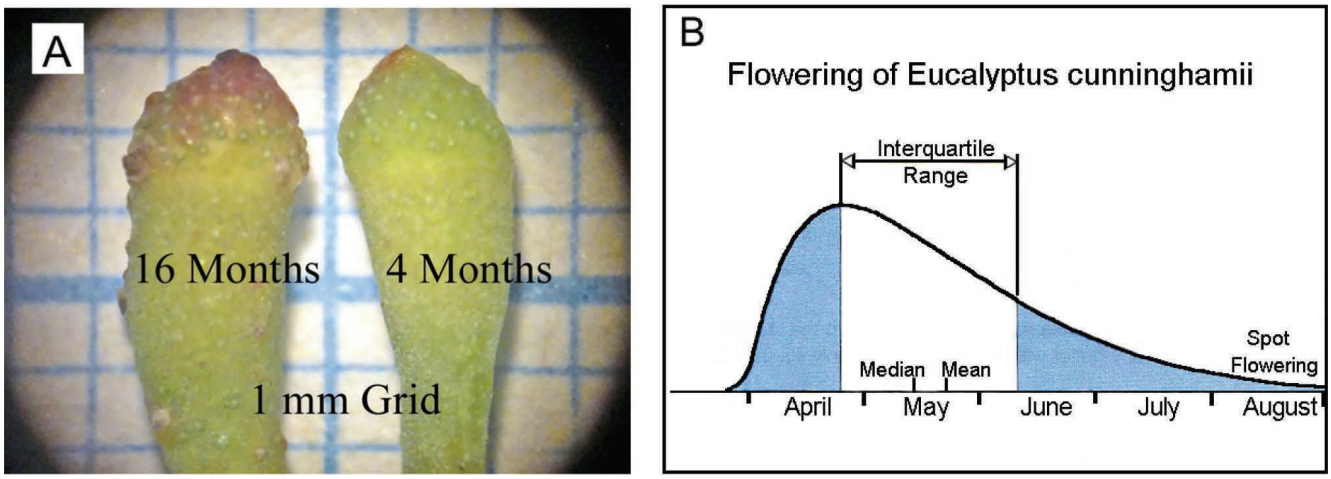


Figure 6. *Eucalyptus cunninghamii* (A) Bud comparisons and (B) Flowering Progression

Fruit capsules and seeds

Only 15 of our 38 occurrences exhibited fruit during the three-year study (Table 1). Persistent fruit capsules develop in winter and mature in spring. They are regularly globose, minutely warty, and about 6 x 6 mm in size; the disc is descending, valves 3 or 4, enclosed (Figure 7A , Table 1). Average fruit diameter varied: Grose North - 5.8 mm, Grose South - 5.4 mm, Jamison West - 6.3 mm, and Jamison South - 6.0 mm. The largest fruit (at Pulpit Rock) averaged 6.5 mm diameter. Seeds are smooth, brown and pyramidal, with at least one well-rounded facet (Figure 7B). They are consistently about 1.2 mm long and, when fresh, there are about 1000 seeds per gram.

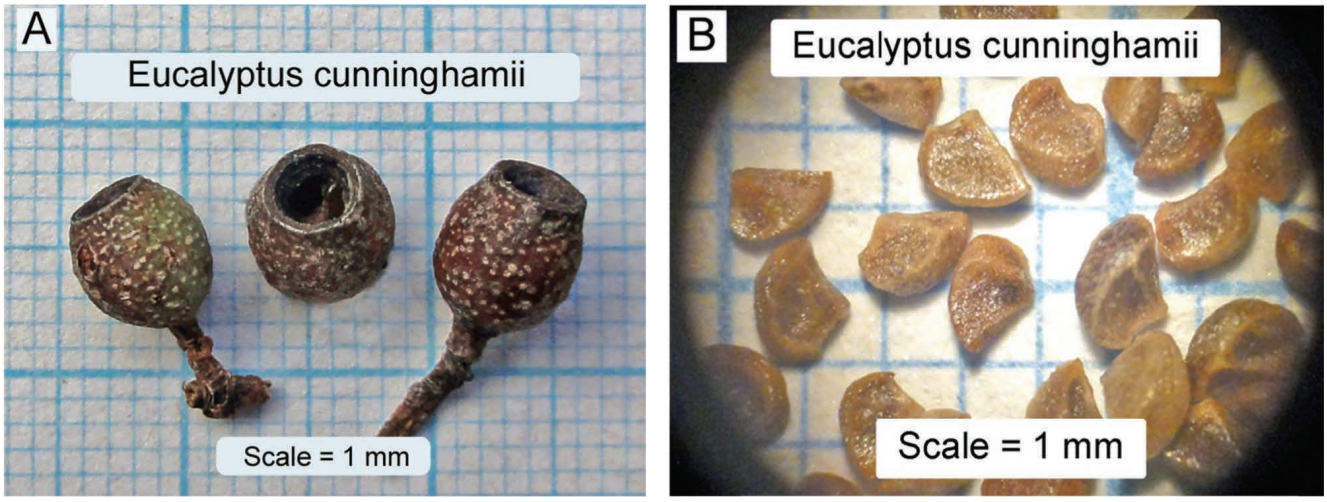


Figure 7. *Eucalyptus cunninghamii* (A) Fruit Capsules and (B) Seeds.

Seed Germination and recruitment

A batch of seeds of indeterminate age (but probably more than 2 years old) exhibited poor germination rates of only 10% (80% of seeds were empty, and of the remainder 50% rotted during germination). A second batch of seed from nearly 1000 fresh (green) capsules exhibited higher viability (30%). Environmental conditions affect seed maturation and it is not unusual for some eucalypts to have low levels of seed viability (Booth, 2017).

In spite of diligent searches we found no evidence of seedling recruitment of *Eucalyptus cunninghamii* at any occurrence. However, it is easily propagated in plant nursery conditions, and seedlings will thrive in cultivation, even in an apparently unfavourable habitat such as an urban nature strip.

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