Supplementary Material

Phosphorus deficiency alters scaling relationships between leaf gas exchange and associated traits in a wide range of contrasting *Eucalyptus* species

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Table S1. Structural and chemical leaf traits of 28 *Eucalyptus* seedlings growing in tubes, sampled shortly after arrival from the source commercial nurseries

Species were ordered according to mean annual rainfall. Leaf trait values are means ± s.e. ($n=3$). Data on mean annual rainfall over which the species are found in natural ecosystems is provided (with low and high rainfall ranges shown in parentheses). Rainfall data obtained from the *Atlas of Living Australia*. Information on vegetation type is shown Brooker and Kleinig (2006). Abbreviations: LMA, leaf dry mass per unit leaf area; FMA, leaf fresh mass per unit leaf area; DMC, dry matter content of leaves (ratio of dry mass, DM to fresh mass, FM); [N], mass-based nitrogen concentration (% dry mass); [P], mass-based phosphorous concentration (% dry mass). When all species was pooled together, LMA was negatively correlated with [N] and [P] ($p<0.05$; $r^2= 0.41$ and 0.61, respectively)

Species	Mean annual rainfall (mm)	Vegetation type	LMA (g_{DM} m^{-2})	FMA (g_{FM} m^{-2})	DMC (g_{DM} g_{FM}^{-1})	[N] (% DM)	[P] (% DM)
E. socialis	425 (125–850)	Mallee	124.8 ± 5.9	403.8 ± 15.8	0.31 ± 0.00	1.89 ± 0.13	0.19 ± 0.01
E. dumosa	450 (150–650)	Mallee	237.2 ± 8.9	512.1 ± 11.9	0.46 ± 0.01	0.65 ± 0.02	0.09 ± 0.00
E. gracilis	450 (100–800)	Mallee	82.0 ± 10.0	268.4 ± 20.1	0.30 ± 0.02	2.52 ± 0.37	0.29 ± 0.02
E. oleosa	450 (100–800)	Mallee	197.0 ± 9.4	444.2 ± 33.3	0.45 ± 0.01	0.68 ± 0.03	0.05 ± 0.01
E. largiflorens	450 (125–950)	Woodlands	186.9 ± 23.1	463.1 ± 35.6	0.40 ± 0.02	1.34 ± 0.23	0.13 ± 0.03
E. leptophylla	500 (100–900)	Mallee	157.8 ± 13.4	382.2 ± 22.8	0.41 ± 0.02	1.73 ± 0.09	0.09 ± 0.00
E. microcarpa	500 (150–1250)	Woodlands	196.2 ± 19.5	449.4 ± 35.2	0.43 ± 0.01	0.63 ± 0.03	0.15 ± 0.00
E. porosa	500 (150–850)	Mallee	102.6 ± 5.3	338.0 ± 4.0	0.30 ± 0.01	2.35 ± 0.09	0.24 ± 0.02
E. camaldulensis	550 (125–1250)	Tall Tree	106.1 ± 5.4	246.8 ± 13.8	0.43 ± 0.01	1.45 ± 0.17	0.15 ± 0.01
E. viridis	550 (250–850)	Mallee	219.0 ± 13.9	510.3 ± 15.9	0.43 ± 0.03	0.80 ± 0.21	0.12 ± 0.01
E. behriana	550 (250–950)	Mallee	296.7 ± 7.8	617.9 ± 21.4	0.48 ± 0.01	0.63 ± 0.03	0.05 ± 0.00
E. polybractea	550 (350–650)	Mallee	241.6 ± 8.1	524.5 ± 26.1	0.46 ± 0.01	0.66 ± 0.01	0.11 ± 0.01
E. blakelyi	650 (250–1250)	Woodlands	127.0 ± 11.1	291.2 ± 22.9	0.44 ± 0.01	1.02 ± 0.07	0.08 ± 0.00
E. sideroxylon	700 (250–1750)	Medium Tree	130.7 ± 13.3	354.7 ± 21.6	0.37 ± 0.02	1.71 ± 0.21	0.18 ± 0.02
E. macrorhynca	700 (350–1250)	Medium Tree	101.2 ± 8.5	299.7 ± 20.7	0.34 ± 0.01	1.70 ± 0.09	0.23 ± 0.02
E. melliodora	750 (350–1750)	Medium Tree	81.8 ± 6.8	233.4 ± 5.9	0.35 ± 0.02	2.53 ± 0.40	0.19 ± 0.02
E. viminalis	800 (350–4140)	Tall Tree	65.3 ± 2.0	180.9 ± 5.9	0.36 ± 0.02	2.48 ± 0.36	0.16 ± 0.03

E. cinerea	800 (400–1500)	Woodlands	50.5 ± 2.0	170.9 ± 8.9	0.30 ± 0.00	2.60 ± 0.11	0.18 ± 0.02
E. dives	800 (450–1750)	Medium Tree	117.8 ± 3.9	292.9 ± 4.4	0.40 ± 0.02	1.04 ± 0.14	0.08 ± 0.02
E. polyanthemos	800 (550–1250)	Woodlands	135.3 ± 5.8	306.0 ± 13.3	0.44 ± 0.02	1.02 ± 0.05	0.07 ± 0.01
E. globulus	850 (450–4140)	Tall Tree	115.3 ± 18.4	274.9 ± 20.3	0.41 ± 0.04	0.80 ± 0.05	0.09 ± 0.02
E. grandis	850 (450–4140)	Tall Tree	98.6 ± 9.0	226.2 ± 11.1	0.43 ± 0.02	0.69 ± 0.07	0.09 ± 0.03
E. pauciflora	850 (450–4140)	Medium Tree	191.4 ± 17.4	442.8 ± 38.2	0.43 ± 0.00	0.71 ± 0.06	0.06 ± 0.00
E. mannifera	850 (550–1750)	Medium Tree	78.0 ± 9.5	256.4 ± 23.9	0.30 ± 0.01	1.99 ± 0.37	0.20 ± 0.02
E. nicholii	900 (600–2000)	Medium Tree	103.7 ± 10.3	237.4 ± 22.5	0.44 ± 0.00	0.91 ± 0.01	0.12 ± 0.02
E. saligna	950 (650–4140)	Tall Tree	107.4 ± 13.8	244.0 ± 18.1	0.44 ± 0.03	1.03 ± 0.15	0.11 ± 0.02
E. cordata	950 (750–1750)	Medium Tree	49.5 ± 6.8	207.2 ± 23.5	0.24 ± 0.01	2.81 ± 0.35	0.35 ± 0.02
E. crenulata	950 (800–1500)	Medium Tree	64.2 ± 6.6	186.3 ± 10.8	0.34 ± 0.02	2.15 ± 0.20	0.20 ± 0.02

Table S2. Structural and chemical leaf traits of <u>pre-existing leaves</u> of 14 *Eucalyptus* species according to P-deficient (–P) and P-fertilized (+P) treatments, sampled at week 11 of treatment

Leaf trait values are means ($\pm$ s.e., $n = 3$–4). * indicate significant difference between treatments (t-test, $P < 0.05$). Abbreviations and units used are similar to those in Table 1 (See Results in main text)

Species	Treatment	LMA (g_{DM} m^{-2})	FMA (g_{FM} m^{-2})	DMC (g_{DM} g_{FM}^{-1})	[N] (% DM)	[P] (% DM)
E. behriana	–P	267.2 ± 10.6	475.0 ± 16.6	0.56 ± 0.01	1.28 ± 0.07	0.05 ± 0.01*
	+P	278.6 ± 8.7	524.7 ± 30.3	0.53 ± 0.01	1.30 ± 0.07	0.14 ± 0.02*
E. blakelyi	–P	154.5 ± 12.6	302.6 ± 17.3	0.51 ± 0.04	1.91 ± 0.01	0.05 ± 0.01*
	+P	136.5 ± 5.4	281.9 ± 21.2	0.49 ± 0.02	1.76 ± 0.14	0.14 ± 0.02*
E. dives	–P	155.2 ± 8.9	339.8 ± 31.9	0.46 ± 0.02	1.55 ± 0.07	0.04 ± 0.01*
	+P	139.5 ± 6.2	318.7 ± 16.5	0.44 ± 0.01	1.39 ± 0.09	0.20 ± 0.02*
E. dumosa	–P	252.5 ± 9.1	505.6 ± 25.6	0.50 ± 0.01	1.15 ± 0.15	0.06 ± 0.04
	+P	249.1 ± 13.9	469.5 ± 28.7	0.53 ± 0.02	1.12 ± 0.06	0.16 ± 0.01
E. grandis	–P	97.2 ± 7.2	204.3 ± 25.1	0.48 ± 0.03	1.61 ± 0.15	0.08 ± 0.01*
	+P	86.4 ± 4.8	190.8 ± 16.1	0.46 ± 0.02	1.77 ± 0.09	0.27 ± 0.03*
E. largiflorens	–P	188.2 ± 13.9	372.9 ± 29.9*	0.51 ± 0.02	1.81 ± 0.12	0.07 ± 0.02
	+P	229.6 ± 17.5	474.8 ± 25.1*	0.48 ± 0.02	1.67 ± 0.13	0.22 ± 0.08
E. macrorhynca	–P	120.3 ± 5.6*	279.2 ± 16.3	0.43 ± 0.02*	1.87 ± 0.15	0.04 ± 0.01*
	+P	96.0 ± 5.3*	264.0 ± 9.4	0.36 ± 0.01*	1.49 ± 0.10	0.34 ± 0.04*
E. melliodora	–P	92.8 ± 7.5	199.9 ± 17.9	0.47 ± 0.02	2.84 ± 0.12	0.07 ± 0.00*
	+P	84.1 ± 4.3	167.7 ± 16.3	0.52 ± 0.07	2.66 ± 0.16	0.32 ± 0.05*
E. pauciflora	–P	190.7 ± 16.3	419.6 ± 53.6	0.46 ± 0.03	1.64 ± 0.24	0.05 ± 0.00*
	+P	169.5 ± 5.5	407.7 ± 18.9	0.42 ± 0.02	1.71 ± 0.07	0.12 ± 0.02*
E. polyanthemos	–P	149.5 ± 6.1	287.0 ± 31.2	0.53 ± 0.04	1.77 ± 0.10	0.06 ± 0.00*
	+P	141.7 ± 4.7	294.8 ± 19.8	0.49 ± 0.03	1.58 ± 0.07	0.23 ± 0.03*
E. polybractea	–P	247.9 ± 5.5	469.5 ± 18.4	0.53 ± 0.01	1.54 ± 0.10	0.13 ± 0.03*
	+P	258.3 ± 8.3	501.3 ± 36.1	0.52 ± 0.03	1.39 ± 0.08	0.26 ± 0.03*
E. porosa	–P	111.4 ± 10.7	289.5 ± 22.8	0.38 ± 0.01*	2.41 ± 0.17	0.13 ± 0.03*
	+P	92.6 ± 3.6	279.7 ± 15.4	0.33 ± 0.01*	2.52 ± 0.11	0.39 ± 0.02*

E. socialis	–P	142.6 ± 8.7	318.6 ± 26.5	0.45 ± 0.02	1.91 ± 0.08	0.12 ± 0.02*
	+P	159.9 ± 10.2	380.9 ± 19.9	0.42 ± 0.01	1.80 ± 0.12	0.31 ± 0.06*
E. viridis	–P	253.7 ± 16.3	479.3 ± 32.0	0.53 ± 0.00	1.77 ± 0.08	0.10 ± 0.02*
	+P	243.8 ± 18.6	489.3 ± 12.9	0.50 ± 0.02	1.62 ± 0.09	0.44 ± 0.02*

Table S3. Physiological characteristics of <u>pre-existing</u> leaves of 14 *Eucalyptus* species according to low P (-P) and high P (+P) treatments, sampled at week 11 of treatment

Leaf trait values are means ± error s.e. ($n = 3$–4). * indicate sig. difference between treatments ($P < 0.05$). Abbreviations and units as in Table 2

Species	Treatment	C_i	g_s	A_{area}	A_{mass}	R_{area}	R_{mass}	$R{:}A$	V_{cmax} (area)	V_{cmax} (mass)	PNUE
E. behriana	–P	249.2 ± 8.0	0.20 ± 0.03	12.64 ± 0.85	47.84 ± 4.95	−1.25 ± 0.06	4.74 ± 0.39	0.100 ± 0.002	64.0 ± 2.5	241.5 ± 18.8	37.09 ± 2.34
	+P	258.3 ± 12.3	0.25 ± 0.04	14.03 ± 1.11	50.62 ± 4.70	−1.41 ± 0.10	5.07 ± 0.44	0.104 ± 0.015	69.6 ± 6.1	251.4 ± 26.5	39.26 ± 3.70
E. blakelyi	–P	290.8 ± 4.3	0.52 ± 0.05	18.31 ± 0.77	121.75 ± 13.88	−1.41 ± 0.06	9.34 ± 0.97	0.077 ± 0.004	79.4 ± 3.5	527.3 ± 59.6	63.81 ± 7.18
	+P	292.0 ± 5.3	0.43 ± 0.08	15.12 ± 2.16	109.78 ± 13.27	−1.48 ± 0.20	10.93 ± 1.62	0.103 ± 0.019	66.4 ± 8.9	483.8 ± 56.1	62.80 ± 6.68
E. dives	–P	276.7 ± 2.5	0.43 ± 0.05	18.79 ± 1.41	122.68 ± 12.88	−1.06 ± 0.03	6.91 ± 0.47	0.058 ± 0.006	83.4 ± 5.9	544.7 ± 57.6	79.24 ± 8.08
	+P	278.8 ± 4.7	0.48 ± 0.10	18.38 ± 2.64	130.21 ± 13.97	−1.11 ± 0.18	7.85 ± 0.94	0.060 ± 0.001	81.0 ± 11.2	574.7 ± 58.9	93.44 ± 6.51
E . dumosa	–P	276.4 ± 7.2	0.43 ± 0.08	18.37 ± 1.71	73.30 ± 8.53	−1.26 ± 0.15	4.84 ± 0.50	0.069 ± 0.015	82.4 ± 5.3	327.6 ± 27.7	64.12 ± 3.24
	+P	287.1 ± 1.4	0.57 ± 0.03	20.16 ± 0.35	81.72 ± 4.90	−1.18 ± 0.11	4.94 ± 0.48	0.060 ± 0.003	86.8 ± 1.5	350.9 ± 23.2	73.56 ± 5.30
E. grandis	–P	300.7 ± 6.6	0.53 ± 0.11	16.01 ± 1.99	169.47 ± 27.21	−1.01 ± 0.05	10.56 ± 1.04	0.065 ± 0.008	66.4 ± 7.4	701.1 ± 105.2	104.00 ± 10.44
	+P	311.5 ± 6.4	0.63 ± 0.07	17.44 ± 1.23	203.70 ± 18.72	−1.08 ± 0.05	12.56 ± 0.45	0.062 ± 0.003	70.4 ± 5.3	821.4 ± 74.5	115.30 ± 9.65
E. largiflorens	–P	283.2 ± 1.5	0.53 ± 0.04	22.35 ± 1.73	121.88 ± 16.54	−1.30 ± 0.09	7.11 ± 1.02	0.059 ± 0.004	97.3 ± 7.6	530.7 ± 72.2	66.75 ± 5.94
	+P	281.0 ± 5.5	0.48 ± 0.04	21.27 ± 1.39	93.78 ± 6.97	−1.30 ± 0.26	5.53 ± 0.69	0.061 ± 0.012	93.7 ± 6.5	410.8 ± 23.3	56.39 ± 2.01
E. macrorhynca	–P	282.2 ± 11.4	0.54 ± 0.12	18.61 ± 1.57	157.34 ± 19.48	−1.17 ± 0.17	9.76 ± 1.39	0.066 ± 0.015	81.6 ± 5.1	689.0 ± 73.6	85.55 ± 12.37
	+P	287.1 ± 6.1	0.44 ± 0.04	16.71 ± 0.70	174.50 ± 4.62	−1.04 ± 0.07	10.99 ± 1.06	0.063 ± 0.005	72.3 ± 3.6	755.4 ± 28.9	118.47 ± 6.66
E. melliodora	–P	268.9 ± 1.9	0.35 ± 0.02	17.60 ± 1.25	191.96 ± 15.97	−1.41 ± 0.11	15.26 ± 0.77	0.081 ± 0.008	81.9 ± 5.7	891.9 ± 66.5	67.57 ± 4.84
	+P	270.8 ± 5.1	0.35 ± 0.06	16.87 ± 1.79	198.96 ± 11.98	−1.31 ± 0.10	15.78 ± 1.94	0.081 ± 0.013	77.6 ± 6.5	917.8 ± 35.3	75.79 ± 7.19
E. pauciflora	–P	292.6 ± 4.9*	0.63 ± 0.05	19.41 ± 1.36	104.07 ± 10.95	−1.50 ± 0.07	8.19 ± 1.23	0.078 ± 0.006	83.9 ± 6.5	449.7 ± 49.2	65.37 ± 5.35
	+P	266.4 ± 7.7*	0.44 ± 0.07	19.93 ± 1.15	117.58 ± 5.70	−1.58 ± 0.09	9.31 ± 0.43	0.080 ± 0.006	93.3 ± 3.4	551.8 ± 23.8	69.14 ± 5.58
E. polyanthemos	–P	274.9 ± 4.7	0.39 ± 0.04	17.51 ± 1.13	117.01 ± 5.20	−1.34 ± 0.05	8.96 ± 0.41	0.077 ± 0.006	79.6 ± 4.9	533.0 ± 26.6	66.59 ± 4.25
	+P	290.4 ± 5.2	0.47 ± 0.03	17.24 ± 1.69	121.57 ± 10.59	−1.25 ± 0.03	8.84 ± 0.30	0.074 ± 0.006	74.8 ± 8.0	527.1 ± 49.8	76.83 ± 4.33
E. polybractea	–P	273.9 ± 9.3	0.32 ± 0.02	16.55 ± 1.21	66.63 ± 3.89	−1.14 ± 0.02	4.61 ± 0.16	0.070 ± 0.006	75.4 ± 6.1	303.7 ± 22.3	44.14 ± 5.02
	+P	291.2 ± 4.6	0.42 ± 0.04	15.79 ± 0.79	61.23 ± 3.14	−1.19 ± 0.20	4.56 ± 0.67	0.075 ± 0.011	68.3 ± 4.1	264.7 ± 15.5	44.44 ± 3.24
E. porosa	–P	281.8 ± 12.0	0.58 ± 0.15	19.49 ± 2.53	175.66 ± 15.37	−1.46 ± 0.23	13.63 ± 2.73	0.076 ± 0.010	87.6 ± 12.9	791.3 ± 89.9*	72.81 ± 4.70*
	+P	278.9 ± 7.8	0.55 ± 0.04	21.17 ± 1.43	228.04 ± 9.19	−1.32 ± 0.07	14.33 ± 1.05	0.063 ± 0.006	94.3 ± 7.9	1014.3 ± 53.5*	90.43 ± 0.91*

E. socialis	−P	266.2 ± 4.1	0.38 ± 0.02	21.94 ± 1.56	157.54 ± 21.72	−1.34 ± 0.10	9.57 ± 0.97	0.063 ± 0.008	101.2 ± 6.7	725.9 ± 94.8	81.77 ± 7.87
	+P	274.7 ± 9.0	0.54 ± 0.07	24.28 ± 1.58	154.62 ± 17.70	−1.22 ± 0.13	7.67 ± 0.84	0.050 ± 0.005	107.9 ± 7.0	685.9 ± 75.4	86.28 ± 8.65
E. viridis	−P	271.4 ± 7.0	0.47 ± 0.06	19.70 ± 1.48	79.46 ± 10.78	−1.35 ± 0.12	5.31 ± 0.22*	0.071 ± 0.011	90.1 ± 6.4	361.8 ± 42.8	44.61 ± 4.62
	+P	270.8 ± 1.9	0.42 ± 0.08	19.54 ± 2.77	80.77 ± 11.82	−1.77 ± 0.18	7.20 ± 0.25*	0.097 ± 0.018	91.2 ± 12.2	376.1 ± 48.7	49.73 ± 6.47

Pre-treatment
Survey of leaf traits; LMA, leaf [N] and [P] on pre-existing leaves ($n=28$)

Week 6, 8 and 10 of fertilisation treatment
Monitoring P-deficiency phenotypes by non-destructive leaf gas exchange measurements on pre-existing leaves ($n=9$)

Week 11 of fertilisation treatment
Leaf gas exchange measurements followed by harvest of pre-existing leaves to measure A, R, LMA, leaf [N] and [P] ($n=14$)

Week 15 of fertilisation treatment
Leaf gas exchange measurements followed by harvest of newly-developed leaves to measure A, R, LMA, leaf [N] and [P] ($n=17$)

Week 20 of fertilisation treatment
CO_2 response curves followed by harvest of newly-developed leaves to measure V_{max} and LMA ($n=3$)

Week 30 of fertilisation treatment
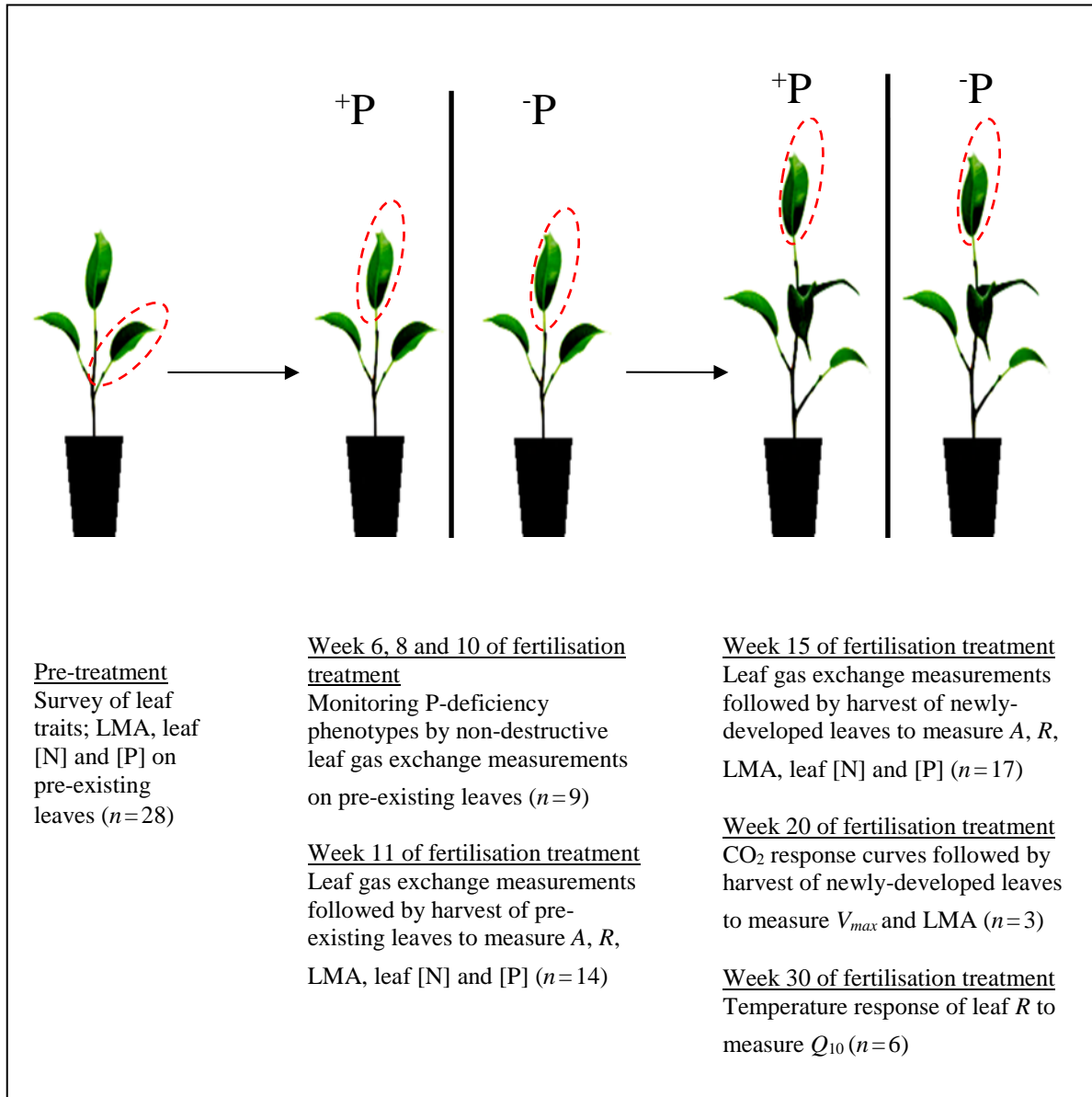Temperature response of leaf R to measure Q_{10} ($n=6$)

Fig. S1. The progression of leaf trait measurements in this study, with respect to different leaf developmental stages. Dashed circles represent selected leaves at a particular sampling period. The number of species sampled as each measurement is provided in brackets.
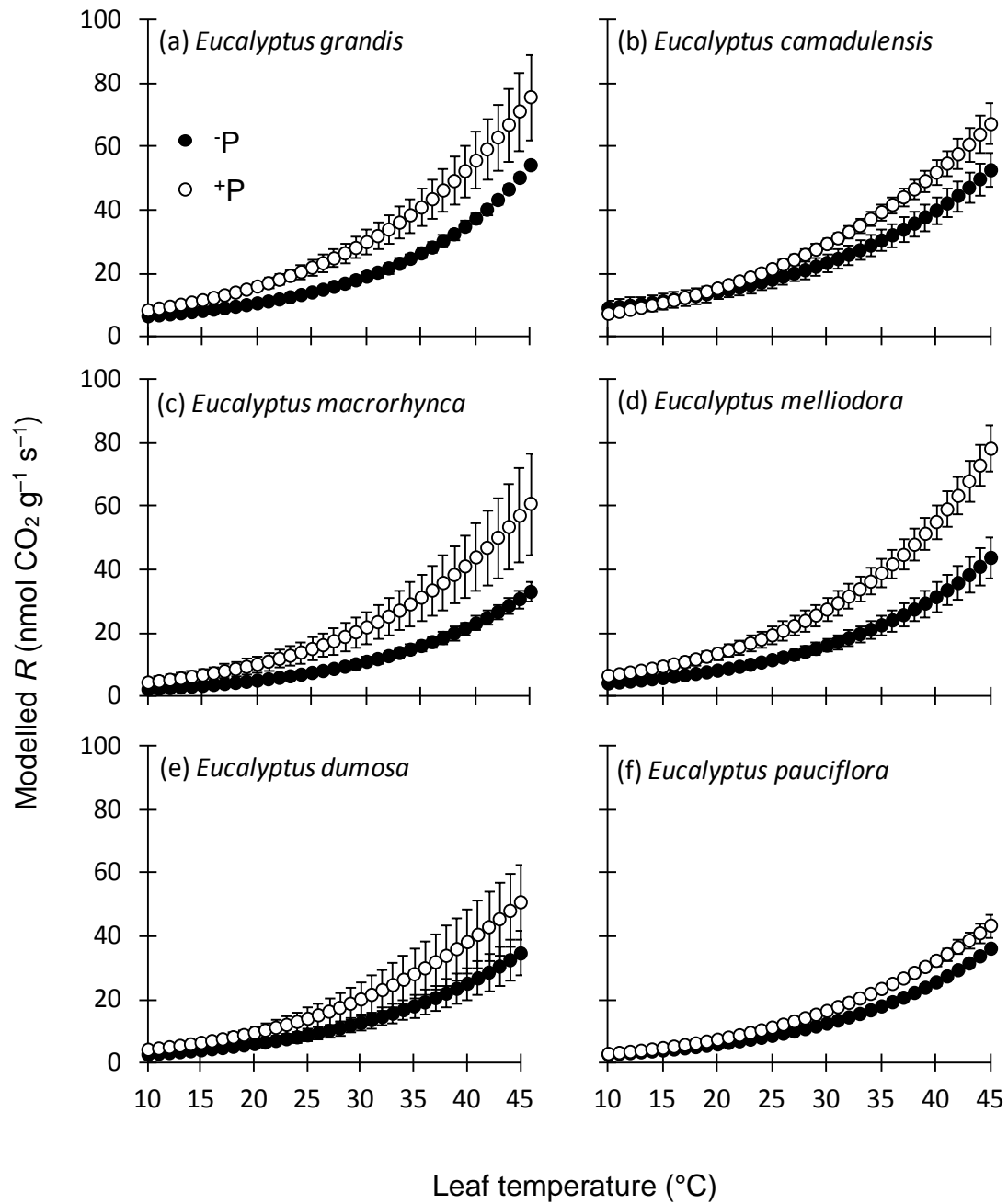
Fig. S2. Modelled temperature response of leaf R per unit dry mass of the six *Eucalyptus* species measured (error bars show $\pm$ s.e., $n = 3$). (a) and (b) correspond to low LMA, (c) and (d) correspond to species with moderate LMA and (e) and (f) correspond to species with high LMA.
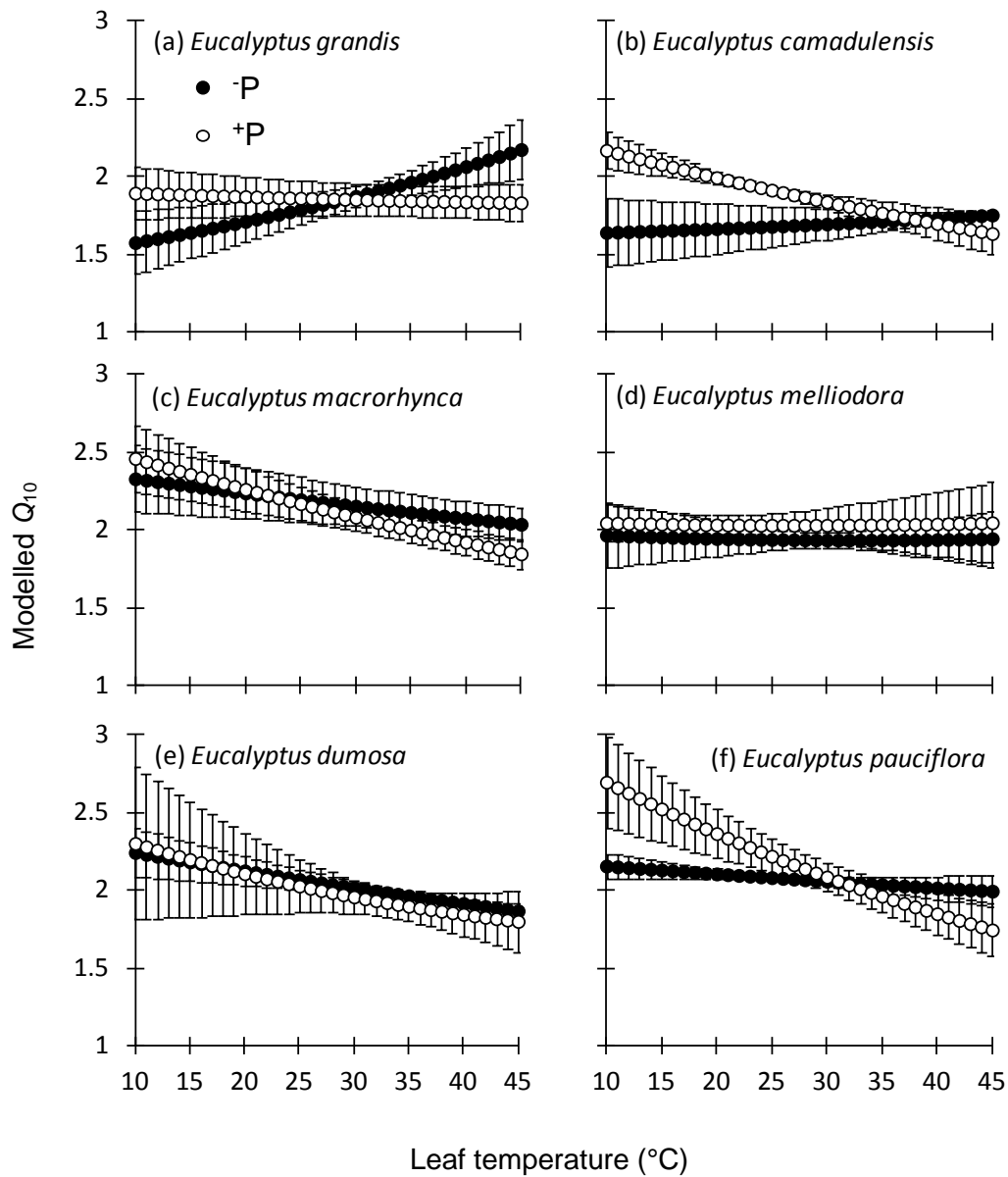
Fig. S3. Modelled temperature response of Q_{10} of the six *Eucalyptus* species measured (error bars show ± s.e., *n* = 3). (a) and (b) correspond to low LMA, (c) and (d) correspond to species with moderate LMA and (e) and (f) correspond to species with high LMA.