

# The Phylogeny and Biogeography of *Phyla nodiflora* (Verbenaceae) Reveals Native and Invasive Lineages throughout the World

Caroline L. Gross <sup>1,\*</sup>, Mohammad Fatemi <sup>1,2</sup>, Mic Julien <sup>3,4</sup>, Hannah McPherson <sup>5</sup> and Rieks Van Klinken <sup>3</sup>

<sup>1</sup> Ecosystem Management, University of New England, Armidale 2351, NSW, Australia

<sup>2</sup> Current address: Biology, Golestan University, Beheshti St., Gorgan, Iran; fatemi980@yahoo.com

<sup>3</sup> Ecosystem Sciences, CSIRO, EcoSciences Precinct, Dutton Park 4102, QLD, Australia; rieks.vanklinken@csiro.au

<sup>4</sup> Current address; 64 Tyalgum Creek Rd, Tyalgum 2484, NSW, Australia; mic.julien@hotmail.com

<sup>5</sup> National Herbarium of New South Wales, Royal Botanic Gardens and Domain Trust, Mrs Macquaries Road, Sydney 2000, NSW, Australia; hannah.mcpherson@rbgsyd.nsw.gov.au

\* Correspondence: cgross@une.edu.au; Tel.: +61-2-6773-3759

**Table S1.** Specimens sequenced for nr-DNA and the phylogeography of *Phyla nodiflora*, with voucher information and GenBank accession numbers. Herbarium acronyms stand for: AD = State Herbarium of South Australia; BISH = Herbarium Pacificum; BRI = Queensland Herbarium; CANB = Australian National Herbarium; DNA = Northern Territory Herbarium; FLAS = Florida Museum of Natural History; Gorgan = University of Gorgan; K = Royal Botanic Gardens Kew; MEL = National Herbarium of Victoria; MO = Missouri Botanical Garden Herbarium; MPU = Université Montpellier II; NE = N. C. W. Beadle Herbarium; NSW = Royal Botanic Gardens, Sydney; PERTH = Western Australian Herbarium; PRE = South African National Biodiversity Institute; SI = Museo Botánico; UC = University of California; US = Smithsonian Institution; XAL = Instituto de Ecología, A.C. s.n. = without number.

Ribotype	Voucher	Lat	Long	Provenance	State	GenBank
1	Cope 120, K	22.35	58.80	Oman	Wahiba	HM194095
2	Radcliffe-Smith 3708, K	20.33	57.65	Oman	Rumais	HM194093
3	Miller 2333, K	17.23	54.52	Oman	Dhofar	HM194094
3	Madhu 22, NSW	28.63	77.22	India	Delhi	JQ014150
4	Field 72, K	-7.58	72.42	Chagos	Ile du Coin	HM194092
5	Rowaished <i>et al.</i> , 2697, K	13.03	44.87	Yemen	Lahij	HM194103
6	Spellenberg 7498, K	13.93	44.18	Yemen	Ibb	HM194102
7	Field 141, K	-7.58	72.42	Chagos	Diego Garcia	HM194089
8	Robertson 3075, K	-7.17	56.27	Seychelles	Coetivy	HM194096
9	Kilian & Lobin 1807, K	2.60	45.50	Somalia	Middle Shabeelle	HM194097
10	Kostermans 24891, K	8.95	79.90	Sri Lanka	Mannar	HM194099
11	Kuchar 17496, K	3.22	45.52	Somalia	Jalalaqsi	HM194098
12	Bingham 10386, K	-15.77	27.92	Zambia	Southern	HM194104
13	Hamid 38544, K	30.80	46.90	Iraq	Basrah	HM194090
14	Kalf <i>et al.</i> , 47368, K	33.38	43.57	Iraq	Anbar	HM194091
15	Frontier-Tanzania CFRP 1444, K	-7.83	39.92	Tanzania	Coast	HM194100
15	Wingfield 4177, K	-6.85	39.27	Tanzania	Coast	HM194101
16	Salubeni & Kwatha 4812, K	-15.37	35.32	Malawi	Zomba	HM194087
17	Phillipson 2262, K	-18.83	44.45	Madagascar	Mahajanga	HM194085
17	Salubesi 888, K	-15.37	35.32	Malawi	Dedza	HM194088
18	Leeuwenberg 137707, K	-17.68	49.47	Madagascar	Foulpointe	HM194086
19	PERTH 05392535	-32.28	115.72	Australia	WA	HM194122
19	PERTH 05553202	-31.92	115.83	Australia	WA	HM194123
20	Fatemi <i>et al.</i> , 86, Gorgan	36.75	53.10	Iran	Mazandaran	HM194077
20	Fatemi <i>et al.</i> , 87, Gorgan	36.75	53.10	Iran	Mazandaran	HM194078
20	van Klinken s.n., CANB	-20.74	116.85	Australia	WA	HM194105
20	Thompson s.n., CANB	-16.14	128.71	Australia	WA	HM194106
20	PERTH 06592996	-27.72	114.15	Australia	WA	HM194120
20	PERTH 04104498	-31.53	115.70	Australia	WA	HM194125
20	PERTH 07215290	-31.91	115.76	Australia	WA	HM194126
20	PERTH 02160137	-16.43	123.03	Australia	WA	HM194129
21	BRI533847	-31.75	115.75	Australia	WA	HM194033

Ribotype	Voucher	Lat	Long	Provenance	State	GenBank
21	Yupeng s.n.	23.10	109.61	China	Gui-Gang City	HM194071
21	Gilbert 479-A, K	10.00	38.33	Ethiopia	Shoa	HM194081
21	Thornhill 269, PRE	-29.37	24.89	South Africa	KwaZulu-Natal	HM194138
21	Hugh s.n., NSW	42.10	108.62	China	North Central	JN705411
21	Baytopp 26, PRE	-22.37	24.89	Botswana		HM194134
21	Ducloux s.n., UC	25.64	103.34	China	Yunnan	JN705410
21	Hiroe 17218, UC	36.48	138.70	Japan	Honshu	JN705433
21	Rechinger 14433, US	35.50	24.01	Crete	Chandia	JN705436
21	Surapat 44, US	13.99	100.32	Thailand	Bangkok	JN705417
21	Kayombo <i>et al.</i> 4402, MO	-5.51	37.54	Tanzania	Kilwa	JN705430
22	Yupeng s.n.	22.63	110.15	China	Guangxi	HM194153
23	Telford 9952, CANB	-12.20	96.83	Indian Ocean	West Island	HM194051
24	Starr 990512-2, BISH	28.22	-177.43	Hawaii	Midway Atoll	HM194073
25	Fraser 336, CANB	-20.60	139.55	Australia	Qld	HM194046
25	Julien s.n., CANB	43.01	9.41	France	Corsica	HM194057
25	Zohary & Amdursky 460, MPU	31.78	34.78	Israel	Tel Aviv	HM194079
25	Waterhouse BMW6582	7.50	134.57	Palau	Peleliu Is	HM194131
25	IPSE 75/394E, MPU	39.87	-3.83	Spain	Valencia	HM194139
26	BRI734146	7.32	134.48	Palau	Peleliu Is	HM194044
26	Furuse 3601, K	36.10	140.53	Japan	Ishiggaki Prov.	HM194084
26	White s.n., CANB	-20.73	139.48	Australia	Qld	HM194113
27	Arboowy 241, MPU	12.27	108.08	Vietnam	Saigon	HM194151
28	Smith 704, K	-18.45	22.05	Botswana	Okavango river	HM194080
28	Wild & Gilbert 416, K	5.17	37.60	Ethiopia	Sidamo	HM194082
28	Ghani 1204, K	29.72	30.30	Egypt	western desert	HM194083
29	BISH 728774	20.80	-156.30	Hawaii	Makawao	HM194074
29	Pence 16, FLAS	28.71	-80.73	USA	Florida	HM194140
29	Pence 26, FLAS	25.45	-80.20	USA	Florida	HM194142
29	Pence 105, FLAS	29.65	-82.24	USA	Florida	HM194145
29	Pence 143, FLAS	29.63	-82.37	USA	Florida	HM194146
29	Tracy 6472, US	32.41	-89.44	USA	Mississippi	JN705391
29	Fosberg 46296, NY	13.44	144.75	Guam		JN705388
29	Asplund 16587, NY	-0.77	-79.96	Ecuador	Manabi	JN705390
29	Adams 14657, NY	10.39	-61.26	Trinidad	Scotland Bay	JN705393
29	Karl 39636, NY	32.39	-86.67	USA	Alabama	JN705392
29	Summers & Borsch 8432A, MO	27.63	-81.15	USA	Florida	JN705413
29	Bradley & Stone 937, MO	27.63	-81.15	USA	Florida	JN705412
29	Lewis 7129, MO	24.66	-78.06	Bahamas	Grand Bahama Island	JN705420
30	Segura & Martinez 4486, XAL	19.75	-70.40	Dominican Republic	Cabarete	HM193965
30	Pence 2, FLAS	28.15	-81.23	USA	Florida	HM194141
30	Pence 7, FLAS	28.15	-81.23	USA	Florida	HM194143
30	Pence 10, FLAS	30.76	-83.32	USA	Florida	HM194144
30	Pence 15, FLAS	30.18	-85.66	USA	Florida	HM194147
30	Pence 27, FLAS	30.18	-85.66	USA	Florida	HM194149
31	Pence 21, FLAS	30.57	-86.92	USA	Florida	HM194148
32	Julien 2007, CANB	28.60	-80.60	USA	Florida	HM194070
33	J. Fattefone s.n., MPU	33.22	-7.07	Morocco		HM194115
34	Niger 909, MPU	15.18	6.52	Niger	Maradi	HM194117
35	BRI 564613	-21.54	148.26	Australia	Qld	HM194036
35	Sharpe 2114, CANB	-26.58	153.08	Australia	Qld	HM194052
35	Coveny 12454, CANB	-30.00	153.22	Australia	NSW	HM194053
35	Macdonald s.n. NE	-30.03	153.20	Australia	NSW	HM194056
35	Carter s.n., CANB	-16.00	125.00	Australia	WA	HM194152
35	Evans 243, NY	13.44	144.75	Guam		JN705419
36	Craven 4394, CANB	-13.50	130.48	Australia	NT	HM194054
37	van Klinken s.n., CANB	-12.53	131.30	Australia	NT	HM194025
37	BRI 490033	-25.12	151.13	Australia	Qld	HM194029
37	BRI 492328	-20.47	148.70	Australia	Qld	HM194030
37	BRI 548957	-4.09	144.78	PNG	Madang	HM194034
37	BRI 560205	-12.50	132.50	Australia	NT	HM194035
37	BRI 585377	-24.79	151.23	Australia	Qld	HM194038
37	BRI 599126	-12.81	143.54	Australia	Qld	HM194039
37	BRI 603545	-25.13	152.59	Australia	Qld	HM194040
37	BRI 676053	-24.97	151.12	Australia	Qld	HM194041
37	BRI 680060	-8.33	140.73	Indonesia	Irian Jaya	HM194042

Ribotype	Voucher	Lat	Long	Provenance	State	GenBank
37	BRI 680062	−1.47	136.12	Indonesia	Irian Jaya	HM194043
37	BRI 772166	−17.09	139.62	Australia	Qld	HM194045
37	DNA 0132982	−12.88	130.58	Australia	NT	HM194060
37	DNA 0177123	−8.00	125.00	East Timor	Los Palos	HM194063
37	MEL287620	−25.00	151.00	Australia	Qld	HM194107
37	MEL1611832	−12.00	133.00	Australia	NT	HM194110
37	MEL1586921	−13.00	135.00	Australia	NT	HM194111
37	Julien s.n., CANB	−15.00	133.00	Australia	NT	HM194116
37	van Klinken s.n., CANB	−16.73	128.57	Australia	NT	HM194118
37	Bean 7041, NSW	−25.17	152.5	Australia	Qld	JN705422
38	BRI 480192	−16.53	122.86	Australia	WA	HM194028
38	DNA 0145306	−15.63	130.47	Australia	NT	HM194061
38	DNA 0049090	−14.92	133.07	Australia	NT	HM194065
38	PERTH 04181913	−15.81	128.65	Australia	WA	HM194127
38	PERTH 03151522	−17.83	122.74	Australia	WA	HM194128
39	DNA 0061991	−11.93	130.97	Australia	NT	HM194066
40	DNA 0125002	−12.38	132.13	Australia	NT	HM194059
40	PERTH 05770068	−19.77	121.37	Australia	WA	HM194124
41	DNA 0178568	−15.00	130.00	Australia	NT	HM194064
41	DNA 0076240	−14.92	133.07	Australia	NT	HM194067
42	BRI 507274	−19.29	147.04	Australia	Qld	HM194031
42	BRI 518273	−11.68	136.84	Australia	NT	HM194032
42	DNA 0172436	−11.36	132.31	Australia	NT	HM194062
42	DNA 0076375	−11.30	131.83	Australia	NT	HM194068
42	DNA 0076710	−12.18	136.77	Australia	NT	HM194069
42	MEL 1617640	−11.00	132.00	Australia	NT	HM194108
42	MEL 713745	−11.00	133.00	Australia	NT	HM194109
42	MEL 1582951	−15.00	133.00	Australia	NT	HM194112
43	PERTH 01411373	−21.59	117.07	Australia	WA	HM194130
44	DNA 0123102	−11.17	132.52	Australia	NT	HM194058
45	BRI 344747	−12.31	143.08	Australia	Qld	HM194026
46	BRI 565769	−18.60	144.66	Australia	Qld	HM194037
47	BRI 436599	−23.79	151.34	Australia	Qld	HM194027
48	PERTH 06840582	−16.48	128.54	Australia	WA	HM194119
49	PERTH 07158777	−19.12	121.52	Australia	WA	HM194121
50	CANB 398284	−13.17	130.03	Australia	NT	HM194048
51	CANB 13152	−20.30	118.58	Australia	WA	HM194049
52	CANB 582359	−14.88	141.60	Australia	Qld	HM194047
52	Whaite 3958, NSW	−16.5	136.33	Australia	NT	JN705437
53	CANB 440608	−14.95	132.15	Australia	NT	HM194050
54	Rinehart LR24500	15.50	144.83	Guam	Yigo	HM194132
55	Reinhart LR27793	13.50	144.83	Guam	Northwest Field	HM194133
56	Stanford 747, NY	24.29	−98.72	Mexico	Tamaulipas	JN705418
57	Nelson s.n., NE	−32.13	150.85	Australia	NSW	HM193957
57	Thomas <i>et al.</i> 71632, NSW	32.32	−93.71	USA	Louisiana	JQ014151
57	Bush 471, US	36.49	−90.07	USA	Missouri	JQ014152
57	Demaree 1327, US	35.38	−97.34	USA	Oklahoma	JQ014153
57	Palmer 151, US	16.73	−93.18	Mexico	Chiapas	JQ014154
57	Crutchfield 3614, NY	35.01	−97.05	USA	Oklahoma	JQ014155
57	Lehto L22827, NY	28.65	−106.00	Mexico	Chihuahua	JQ014156
57	Higgins 7664, NY	34.43	−100.22	USA	Texas	JQ014157
58	How 70924, UC	20.04	110.38	China	Hainan	JN705428
59	Welsh 23215, NY	39.37	−110.86	USA	Utah	JN705435
60	Wooton s.n., US	34.81	−105.12	USA	New Mexico	JN705425
61	Hiroe 13285, UC	36.03	138.38	Japan	Honshu	JN705433
62	Robinson 1334, NY	11.95	108.44	Vietnam	Annam	JN705426
62	Rothschild 436, MO	19.52	−104.95	Mexico	Chamela Bay	JN705416
63	Richardson 107, US	7.42	134.53	Palau	Caroline Island	JN705423
64	Robbins s.n., UC	11.2	−84.44	Nicaragua	Boaco	JN705400
64	Ream 557, UC	25.16	121.67	Taiwan	Northern Tip	JN705399
64	Ward 7819, NY	19.17	−96.13	Mexico	Vercruz	JN705403
64	King 1699, NY	17.06	−96.72	Mexico	Oaxaca	JN705402
64	Breedlove 27300, NY	16.15	−92.9	Mexico	Chiapas	JN705401
64	Sidwell <i>et al.</i> 560, MO	13.68	−89.05	El Salvador	Lake Illopango	JN705424
<i>P.canescens</i> A	Julien & Sosa 332, CANB	−35.46	−72.48	Chile	Maule	HM193960

**Table S2.** The 101 variable sites of the aligned sequences of the ITS1, 5.8S and ITS2 regions yielding 64 ribotypes in *Phyla nodiflora*. A dot (.) indicates that the character states are the same as for ribotype 1 and a dash (-) indicates an insertion in the aligned sequences.

**Data S1.** The mostly univariate sites of the aligned sequences of Petb and trnL-F in *Phyla nodiflora*. A dot (.) indicates that the character states are the same as for ribotype 1, N stands for any base and a dash (-) indicates an insertion in the aligned sequences.

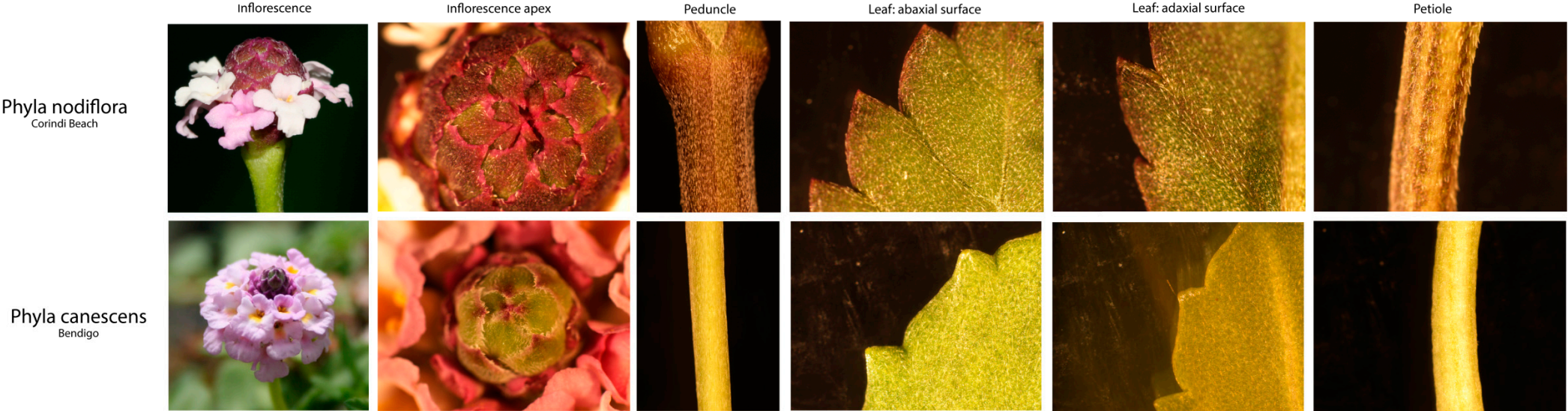
**To be linked to an excel file called *Appendix I Data S1 chloroplastdata.xlsx***

**Data S2.** Estimates of evolutionary divergence between ribotypes (ribotype number is the first column and row). The number of base substitutions per site between sequences is shown. Standard error estimates are shown above the diagonal. Analyses were conducted using the Maximum Composite Likelihood model (Tamura *et al.*, 2004 [33]) implemented in MEGA5 (Tamura *et al.*, 2011 [27]). The analysis involved 64 DNA sequences and a total of 630 positions in the final dataset. 0= ribotypes are identical and 1=ribotypes differ in all positions.

**To be linked to an excel file called *Appendix I Data S2 Divergence matrix.xlsx***



**Figure S1a.** Floral and leaf characters for *Phyla nodiflora* (ribotype 35, GenBank HM194056) from Corindi Beach NSW, Australia (30.0155° S, 153.1855° E) and *Phyla canescens* from Bendigo, Victoria, Australia (36.7570° S, 144.2794° E). Images taken by M. Fatemi 2006.



**Figure S1b.** Habit and spent flower heads of *Phyla nodiflora* (ribotype 26, GenBank HM194113) from Mt Isa, Qld (20.7256° S, 139.4927° E) and *Phyla canescens* from Kialami, New South Wales, Australia (30.4503°S, 151.5325°E). Images taken by A. White (CSIRO) 2007 (lower left) and C.L. Gross 2008 (lower right).



*Phyla nodiflora*



*Phyla canescens*