

Supplementary Material

Plant morphological traits and leaf nutrient concentration are associated with flammability and phylogenetic relationships in sub-alpine vegetation, New Zealand

Shanta Budha-Magar^{A,B}, Nicola J. Day^C, Hannah L. Buckley^A, Olivia R. Burge^D, Sarah J. Richardson^D, Dylan W. Schwilk^E, Ruby R. Ross^F and Timothy J. Curran^{F,}*

^ASchool of Science, Auckland University of Technology, Auckland, 1010, New Zealand

^BEnvironment Management, NorthTec, Whangārei, 0110, New Zealand

^CSchool of Biological Sciences, Victoria University of Wellington, New Zealand

^DManaaki Whenua – Landcare Research, Lincoln, New Zealand

^EDepartment of Biological Sciences, Texas Tech University, USA

^FDepartment of Pest-management and Conservation, Lincoln University, Lincoln, New Zealand

*Correspondence to: Email: Timothy.Curran@lincoln.ac.nz

2 **Supplementary materials**

3 Table S1: List of the 29 plant taxa from subalpine of South Island, New Zealand, for which
4 flammability components ignition score, maximum temperature, burning time and burnt biomass,
5 leaf nutrient concentration, and shoot and leaf morphological traits were measured. All plant
6 samples were burnt as *ca.* 70 cm shoots, except taxon denoted by *, which were burnt as whole
7 plants (*i.e.*, plants \leq 70 cm height), and those denoted by ** were burnt as clump (plant material
8 starting from the bottom centre of each individual and including dead plant biomass and all other
9 branches and stems). Taxon codes are the first three letters of each of genus and species epithet.
10 Bold taxon codes denote those taxa for which leaf nutrient concentration data were obtained from
11 Richardson et al. (unpublished data). Note that some data are presented at the genus level only,
12 consistent with the permanent plot vegetation data (Burge *et al.* 2020). Taxon names, family,
13 authority, and growth form were taken from Flora of New Zealand (<http://nzflora.info>) and New
14 Zealand Plant Conservation Network (<https://www.nzpcn.org.nz>).

Taxon name	Family	Code
Ferns and lycophytes		
* <i>Blechnum minus</i> (R.Br.) Ettingsh.	Blechnaceae	BLEmin
** <i>Polystichum vestitum</i> (G.Forst.) C.Presl	Dryopteridaceae	POLves
* <i>Lycopodium scariosum</i> G.Forst.	Lycopodiaceae	LYCzca
Grasses		
** <i>Poa colensoi</i> Hook.f.	Poaceae	POAcol
* <i>Agrostis</i> species	Poaceae	AGRost
<i>Rytidosperma</i> species	Poaceae	RYTido
** <i>Chionochloa conspicua</i> (G.Forst.) Zotov	Poaceae	CHIcon
** <i>Chionochloa rubra</i> Zotov	Poaceae	CHIrub
Forbs		
* <i>Anisotome haastii</i> (F.Muell.) Cockayne & Laing	Apiaceae	ANIhaa
** <i>Phormium cookianum</i> Le Jol.	Asphodelaceae	PHOcoo
** <i>Astelia nervosa</i> Hook.f.	Asteliaceae	ASTner
* <i>Celmisia armstrongii</i> Petrie	Asteraceae	CELarm
* <i>Celmisia discolor</i> Hook.f.	Asteraceae	CELdis
* <i>Ourisia macrophylla</i> Hook.	Plantaginaceae	OURmap

Taxon name	Family	Code
Shrubs		
<i>Brachyglottis elaeagnifolia</i> (Hook.f.) B.Nord.	Asteraceae	BRAela
<i>Dracophyllum longifolium</i> (J.R.Forst. & G.Forst.) R.Br. ex Roemer & Schult.	Ericaceae	DRAlon
<i>Dracophyllum traversii</i> Hook.f.	Ericaceae	DRAtra
<i>Dracophyllum uniflorum</i> Hook.f.	Ericaceae	DRAuni
<i>Gaultheria rupestris</i> (L.f.) D.Don	Ericaceae	GAUrup
<i>Veronica subalpina</i> Cockayne	Plantaginaceae	VERsub
<i>Podocarpus nivalis</i> Hook.	Podocarpaceae	PODniv
<i>Myrsine nummularia</i> (Hook.f.) Hook.f.	Primulaceae	MYRnum
<i>Coprosma foetidissima</i> J.R.Forst. & G.Forst.	Rubiaceae	COPfoe
<i>Coprosma serrulata</i> Hook.f. ex-Buchanan	Rubiaceae	COPser
<i>Pimelea oreophila</i> C.J.Burrows	Thymelaeaceae	PIMore
Trees		
<i>Pseudopanax colensoi</i> (Hook.f.) Philipson	Araliaceae	NEOcol
<i>Fuscospora cliffortioides</i> (Hook.f.) Heenan & Smissen	Nothofagaceae	FUScli
<i>Phyllocladus alpinus</i> Hook.f.	Podocarpaceae	PHYalp
<i>Myrsine divaricata</i> A.Cunn.	Primulaceae	MYRdiv

15
16 Table S2: Summary of flammability variables (ignition score, time taken to ignite sample minus 10;
17 maximum temperature recorded during burning (°C); burning time (seconds); and burnt biomass (%
18 of biomass consumed) of 26 taxa from subalpine of South Island, New Zealand. Taxon codes are
19 given in supplementary Table S1. The values for each trait are represented by mean (\pm SE) for each
20 taxon. Flammability data were obtained from six individual plants for each taxon. Species that
21 were used from Curran et al. unpublished are not included in this table. Species are ranked in the
22 table by PC1 score, with higher PC1 scores reflecting higher flammability.

Code	Ignition score (s)	Maximum temperature (°C)	Burning time (s)	Burnt biomass (%)	Flammability PC1
PHYalp	8.8 \pm 0.48	625 \pm 61.47	136 \pm 38.39	53.8 \pm 11.97	2.76
CHIrub	6.9 \pm 1.78	553.4 \pm 24.8	162.7 \pm 24.47	49.7 \pm 9.65	2.29
CELdis	9.9 \pm 0.00	451.3 \pm 20.66	37.7 \pm 11.9	75.8 \pm 10.12	2.06
LYCzca	9.8 \pm 0.17	497.3 \pm 35.95	44.3 \pm 15.71	55.2 \pm 14.2	1.78
PHOcoo	6.7 \pm 1.8	443.8 \pm 73.37	218.3 \pm 128.52	20 \pm 9.75	1.53
MYRnum	9.3 \pm 0.21	465.7 \pm 40.25	14.2 \pm 2.2	54.2 \pm 15.41	1.34
CELarm	8.8 \pm 0.6	467.7 \pm 68.87	79.8 \pm 38.59	21.5 \pm 6.37	0.98

Code	Ignition score (s)	Maximum temperature (°C)	Burning time (s)	Burnt biomass (%)	Flammability PC1
POLves	9.5 ± 0.22	429 ± 58.17	32.5 ± 13.08	36.3 ± 10.02	0.94
DRAlon	9.2 ± 0.65	451.2 ± 76.68	48 ± 13.41	26.2 ± 8.89	0.85
DRAuni	9.2 ± 0.54	415.2 ± 94.22	49.8 ± 14.38	30.8 ± 13.86	0.83
CHIcon	9.7 ± 0.33	419.3 ± 40.99	93.5 ± 17.99	11.2 ± 5.23	0.77
GAUrup	9.7 ± 0.21	433.5 ± 44.13	18.2 ± 6.15	30 ± 7.42	0.73
PODniv	9 ± 0.63	428.3 ± 88.88	41.7 ± 22.4	24.7 ± 11.36	0.65
FUScli	9.5 ± 0.22	417.5 ± 54.52	26.8 ± 6.86	21.8 ± 9.82	0.51
BLEmin	7.2 ± 1.6	460.8 ± 74.72	11.2 ± 5.47	29.2 ± 7	0.40
VERsub	8.5 ± 0.43	277.5 ± 29.47	33 ± 17.61	10.8 ± 3.16	-0.40
POAcol	5 ± 2.24	159.2 ± 4.78	3.3 ± 1.74	49.2 ± 22	-0.69
DRAta	3.4 ± 1.33	308.4 ± 42.11	22.8 ± 11.13	3.2 ± 1.77	-1.27
ASTner	3.2 ± 2.01	202.2 ± 34.77	30.3 ± 22.98	2.8 ± 2.46	-1.68
MYRdiv	3.7 ± 2.03	201 ± 31.61	3.5 ± 2.06	0.8 ± 0.4	-1.85
NEOcol	1.5 ± 1.02	253.8 ± 66.42	11.7 ± 7.74	1.2 ± 0.83	-1.89
OURmap	1.7 ± 1.67	170 ± 20	1.7 ± 1.67	2.5 ± 2.5	-2.24
BRAela	1.2 ± 0.75	166.2 ± 14.26	1 ± 0.68	1.5 ± 1.31	-2.35
COPfoe	1.2 ± 0.83	167.5 ± 11.34	1.3 ± 0.88	0.3 ± 0.21	-2.37
COPser	0.5 ± 0.5	152.7 ± 2.67	0.7 ± 0.67	0.3 ± 0.33	-2.53
ANIhaa	0 ± 0.00	150 ± 0.00	0 ± 0.00	0 ± 0.00	-2.63

24 Table S3: Mean (\pm standard error) morphological (leaf and shoot) trait values for 26 plant taxa from subalpine of South Island, New Zealand that
 25 we used for flammability and leaf nutrient trait measurement. Taxon codes are given in supplementary Table S1. Abbreviations of
 26 morphological traits are twig dry matter content (TDMC; g g^{-1}), bulk density (BD; g cm^{-3}), % moisture content (MC), % dead material (Dm),
 27 leaf length (LL; cm), leaf thickness (LT mm), leaf area (LA; cm^2), leaf dry matter content (LDMC; g g^{-1}), specific leaf area (SLA; $\text{cm}^2 \text{g}^{-1}$). Taxa
 28 for which we used data from previous data set of Padullés Cubino *et al.* (2018) are not included in this table.

Code	Shoot morphological traits				Leaf morphological traits				
	BD	TDMC	MC	Dm	LA	LL	LT	LDMC	SLA
ANIhaa	0.058 \pm 0.035	0.2 \pm 0.02	148.5 \pm 17.63	0 \pm 0.00	1.4 \pm 0.37	1.5 \pm 0.15	0 \pm 0.00	0.3 \pm 0.02	289.4 \pm 37.21
ASTner	0.01 \pm 0.002	0.3 \pm 0.02	144.6 \pm 15.94	11.7 \pm 7.49	176.8 \pm 42.6	65.3 \pm 8.41	0.1 \pm 0.03	0.3 \pm 0.01	68.9 \pm 10.76
BLEmin	0.003 \pm 0.000	0.3 \pm 0.01	32 \pm 15.14	2 \pm 1.63	16.6 \pm 1.34	11.0 \pm 0.35	0 \pm 0.00	0.3 \pm 0.01	125.4 \pm 18.88
BRAela	0.005 \pm 0.001	0.3 \pm 0.01	161.2 \pm 28.49	0.8 \pm 0.65	24.2 \pm 1.6	7.8 \pm 0.39	0.1 \pm 0.00	0.3 \pm 0.01	93.4 \pm 15.17
CELarm	0.014 \pm 0.001	0.3 \pm 0.05	62.7 \pm 8.53	8.5 \pm 3.95	29.6 \pm 4.31	21.8 \pm 1.83	0.1 \pm 0.00	0.4 \pm 0.01	54.9 \pm 6.37
CELdis	0.014 \pm 0.002	0.3 \pm 0.02	39.8 \pm 8.65	25.7 \pm 6.18	1.6 \pm 0.14	2.1 \pm 0.12	0 \pm 0.00	0.4 \pm 0.01	71.6 \pm 4.23
CHIcon	0.038 \pm 0.003	0.4 \pm 0.01	89.4 \pm 6.59	45 \pm 5.00	30.4 \pm 5.36	94.4 \pm 4.46	0 \pm 0.00	0.4 \pm 0.01	24.6 \pm 2.26
CHIrub	0.047 \pm 0.007	0.7 \pm 0.01	42.7 \pm 6.02	27 \pm 8.15	3.9 \pm 0.43	81.9 \pm 5.53	0.1 \pm 0.00	0.5 \pm 0.02	8.6 \pm 0.74
COPfoe	0.001 \pm 0.000	0.3 \pm 0.00	113.1 \pm 8.57	0 \pm 0.00	3.8 \pm 0.27	3.6 \pm 0.12	0 \pm 0.00	0.3 \pm 0.00	159.8 \pm 9.43
COPser	0.006 \pm 0.001	0.3 \pm 0.01	100.1 \pm 2.18	0 \pm 0.00	8.1 \pm 1.09	4.2 \pm 0.34	0.1 \pm 0.00	0.4 \pm 0.01	51.5 \pm 2.24
DRAlon	0.007 \pm 0.001	0.6 \pm 0.06	48 \pm 2.65	1 \pm 0.37	1.3 \pm 0.19	9 \pm 0.79	0 \pm 0.00	0.5 \pm 0.01	58.8 \pm 13.81
DRAtra	0.005 \pm 0.001	0.4 \pm 0.04	84.7 \pm 11.85	0.8 \pm 0.8	104.2 \pm 7.95	52.6 \pm 1.7	0.1 \pm 0.01	0.5 \pm 0.01	53.6 \pm 2.83
DRAuni	0.007 \pm 0.001	0.5 \pm 0.03	50.7 \pm 4.08	3.3 \pm 1.52	0.5 \pm 0.15	3.8 \pm 0.15	0 \pm 0.00	0.5 \pm 0.01	88.1 \pm 25.25
FUScli	0.002 \pm 0.000	0.4 \pm 0.07	56.6 \pm 8.16	0.5 \pm 0.34	0.6 \pm 0.06	1.0 \pm 0.06	0 \pm 0.01	0.4 \pm 0.02	106.7 \pm 4.85

Code	Shoot morphological traits			Leaf morphological traits					
	BD	TDMC	MC	Dm	LA	LL	LT	LDMC	SLA
GAUrup	0.005 ± 0.001	0.4 ± 0.01	63.2 ± 4.76	2.5 ± 1.12	1 ± 0.09	1.7 ± 0.07	0.1 ± 0.00	0.4 ± 0.01	44.7 ± 2.93
LYCzca	0.005 ± 0.002	0.4 ± 0.01	32.5 ± 6.48	0 ± 0.00	0 ± 0.00	0.4 ± 0.02	0.1 ± 0.01	0.4 ± 0.02	127.4 ± 16.54
MYRdiv	0.002 ± 0.000	0.3 ± 0.06	61 ± 7.53	0.2 ± 0.17	0.7 ± 0.07	1.0 ± 0.04	0.0 ± 0.00	0.3 ± 0.01	158.5 ± 5.73
MYRnum	0.004 ± 0.001	0.4 ± 0.01	46.4 ± 7.43	0.5 ± 0.34	1.6 ± 0.73	0.9 ± 0.03	0.0 ± 0.00	0.4 ± 0.02	317.9 ± 149.9
NEOcol	0.009 ± 0.002	0.4 ± 0.02	124.5 ± 6.8	0 ± 0.00	24.1 ± 3.35	8.5 ± 0.56	0.1 ± 0.00	0.4 ± 0.01	51.5 ± 4.00
OURmap	0.037 ± 0.006	0.2 ± 0.01	134.5 ± 25.54	0 ± 0.00	47.5 ± 8.2	9.7 ± 0.8	0.1 ± 0.00	0.2 ± 0.01	100.6 ± 13.94
PHOcoo	0.03 ± 0.005	0.4 ± 0.01	76.5 ± 7.73	35 ± 8.47	294.9 ± 69	74.1 ± 5.02	0.1 ± 0.00	0.4 ± 0.02	30.3 ± 4.8
PHYalp	0.007 ± 0.002	0.4 ± 0.01	53 ± 3.98	0.8 ± 0.31	1.7 ± 0.22	2.6 ± 0.12	0.1 ± 0.00	0.5 ± 0.01	46.4 ± 3.82
POAcol	0.021 ± 0.01	0.4 ± 0.02	43.7 ± 17.56	0.5 ± 0.34	0.3 ± 0.02	5.7 ± 0.35	0.0 ± 0.00	0.4 ± 0.01	89.3 ± 9.55
PODniv	0.003 ± 0.001	0.4 ± 0.01	45.1 ± 3.22	0 ± 0.00	0.2 ± 0.03	1.1 ± 0.09	0.0 ± 0.01	0.4 ± 0.02	71.4 ± 12.15
POLves	0.004 ± 0.00	0.3 ± 0.01	64.1 ± 11.69	8 ± 4.58	0.4 ± 0.11	1.0 ± 0.11	0.0 ± 0.00	0.3 ± 0.01	178.9 ± 45.49
VERsub	0.016 ± 0.011	0.5 ± 0.01	104.5 ± 7.88	1.5 ± 0.56	1 ± 0.08	2.3 ± 0.13	0.1 ± 0.00	0.4 ± 0.01	55.7 ± 5.2

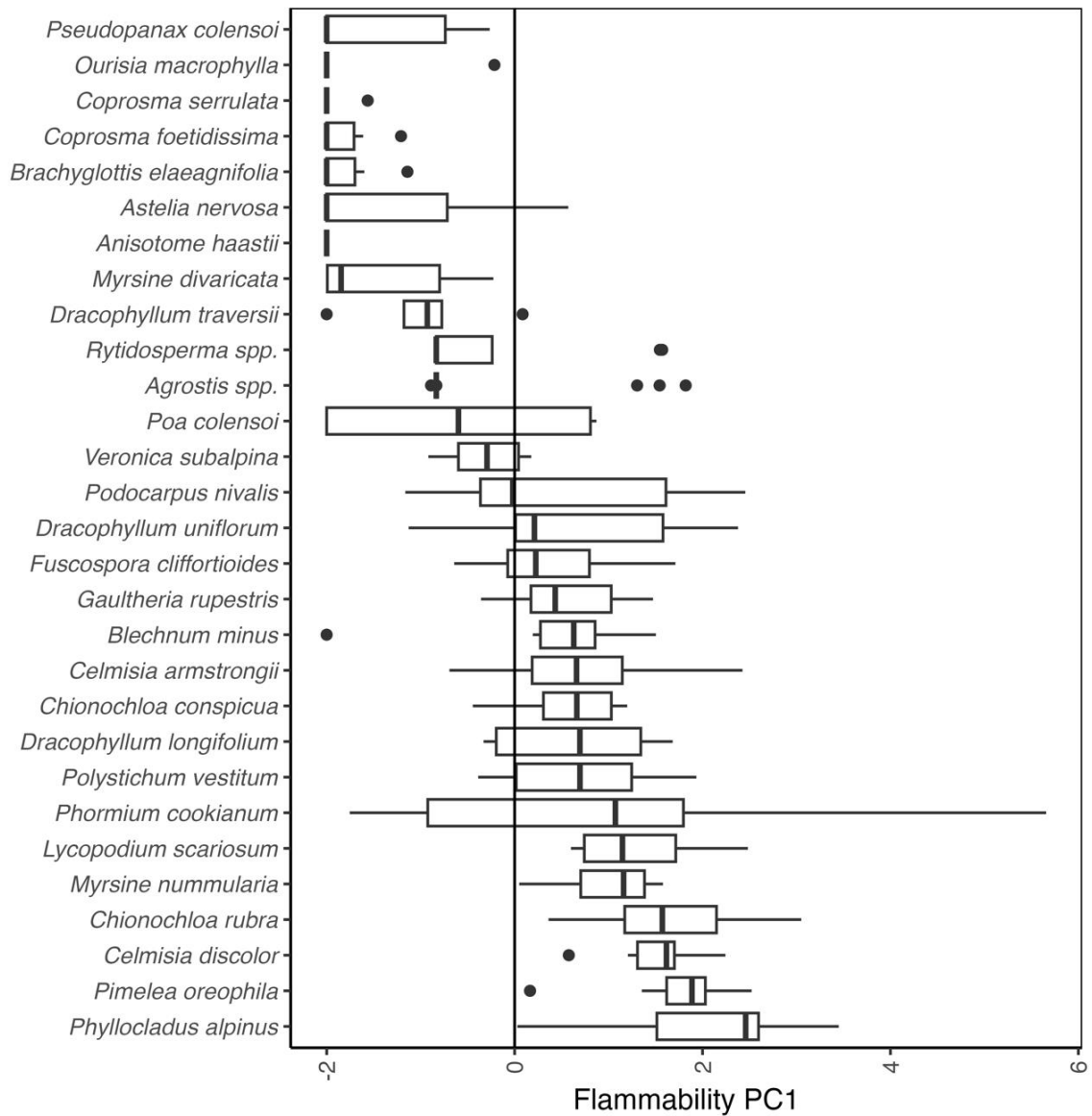
30 Table S4: List of all 29 plant taxa from subalpine of South Island, New Zealand, for which
 31 DNA sequences were downloaded from National library of medicine (NCBI)
 32 (<https://www.ncbi.nlm.nih.gov>). DNA sequence accession number represents the DNA
 33 sequence identifier number in NCBI and sequence length represents base pairs in the
 34 sequence. Taxa denoted by asterik (*) represent those taxa for which DNA sequences of
 35 another species within same genus found in New Zealand were downloaded. For example for
 36 *Agrostis* spp., *rbcl* DNA sequence of *Agrostis magellanica* found in New Zealand was
 37 downloaded. For the species *Pimelea oreophila* denoted by **, *rbcl* DNA sequence of
 38 *Daphne bholua* within same family was downloaded.

Taxa	DNA sequence accession number	Sequence length
<i>Agrostis</i> species*	MG226663.1	552
<i>Anisotome haastii</i>	JQ933219.1	1,383
<i>Astelia nervosa</i>	MZ047944.1	1,323
<i>Blechnum minus</i>	AB040569.1	1,301
<i>Brachyglottis elaeagnifolia</i> *	JQ933243.1	1,321
<i>Celmisia armstrongii</i> *	JQ933257.1	1,383
<i>Celmisia discolor</i> *	JQ933257.1	1,383
<i>Chionochloa conspicua</i> *	EU400657.1	703
<i>Chionochloa rubra</i>	EU400657.1	1,308
<i>Coprosma foetidissima</i>	MK141475.1	1,398
<i>Coprosma serrulata</i> *	MK141482.1	1,107
<i>Dracophyllum longifolium</i>	L12614.2	1,398
<i>Dracophyllum traversii</i>	GQ392928.1	1,402
<i>Dracophyllum uniflorum</i> *	GQ392918.1	1,402
<i>Fuscospora cliffortioides</i> *	L13363.2	1,345
<i>Gaultheria rupestris</i> *	AF124574	1,310
<i>Lycopodium scariosum</i> *	MG560491.1	1,247
<i>Myrsine divaricata</i> *	KT626747.1	1,284
<i>Myrsine nummularia</i> *	KT626747.1	1,284
<i>Pseudopanax colensoi</i>	FJ470147.1	1,281
<i>Ourisia macrophylla</i>	KT626825.1	1,324
<i>Phormium cookianum</i> *	HQ182444.1	1,449
<i>Phyllocladus alpinus</i>	AY442151	1,324

Taxa	DNA sequence accession number	Sequence length
<i>Pimelea oreophila</i> **	MG833726.1	748
<i>Poa colensoi</i> *	KC483588.1	552
<i>Podocarpus nivalis</i>	AF249619.1	1,330
<i>Polystichum vestitum</i>	AY300099.1	1,203
<i>Rytidosperma</i> species*	GQ471701.1	1,291
<i>Veronica subalpina</i>	AJ389604.1	1,317

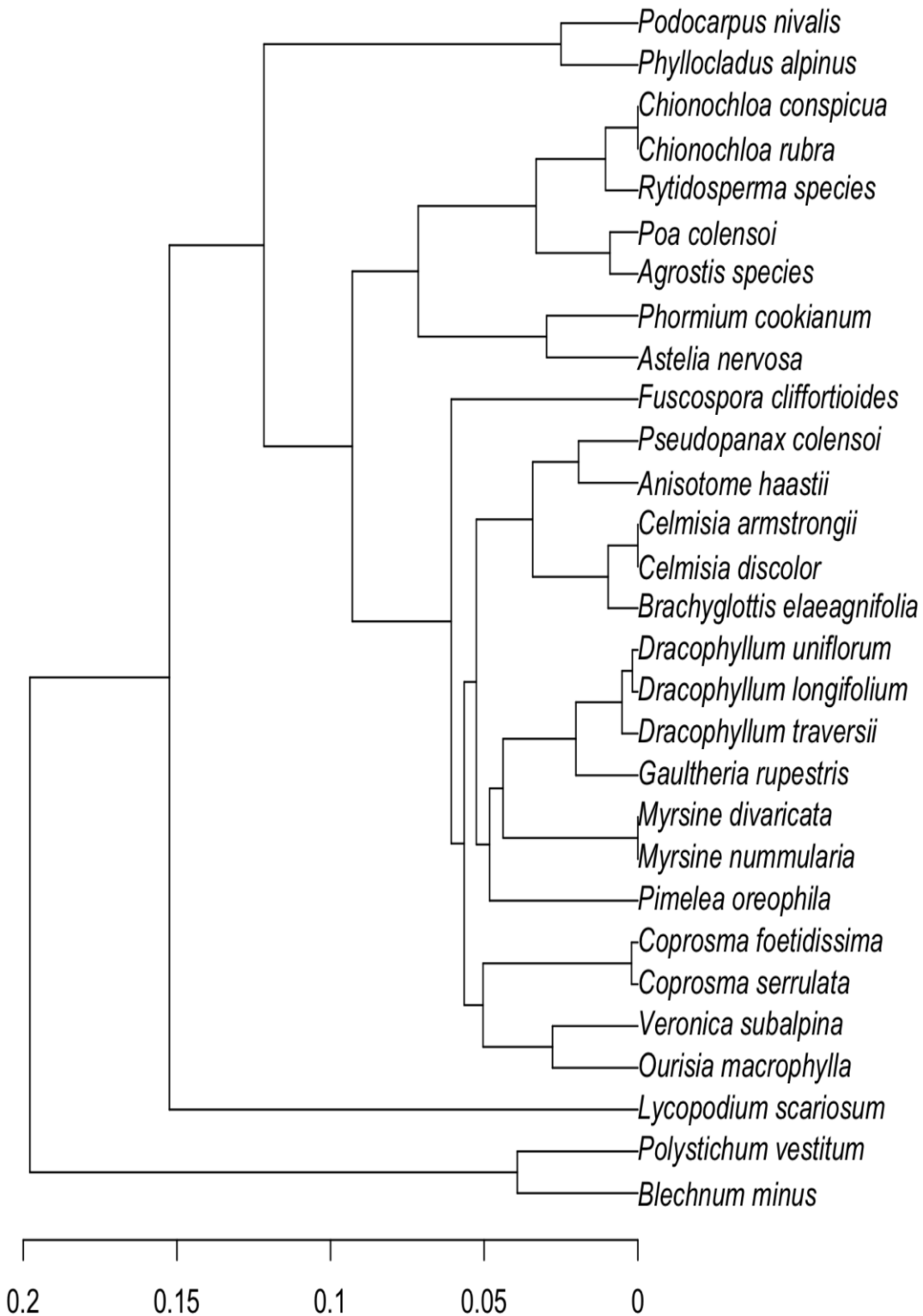
39 Table S5: Loadings of the four measurements of leaf and shoot/whole flammability for the 29
40 taxa from subalpine of South Island, New Zealand on the first two principal components of
41 PCA on flammability (Fig. 1).

Flammability traits	PC1	PC2
Percent variance explained	66.15 %	20.98 %
Ignition score	0.83	-0.31
Maximum temperature (°C)	0.94	0.09
Burnt time (s)	0.60	0.78
Burnt biomass (%)	0.84	-0.35



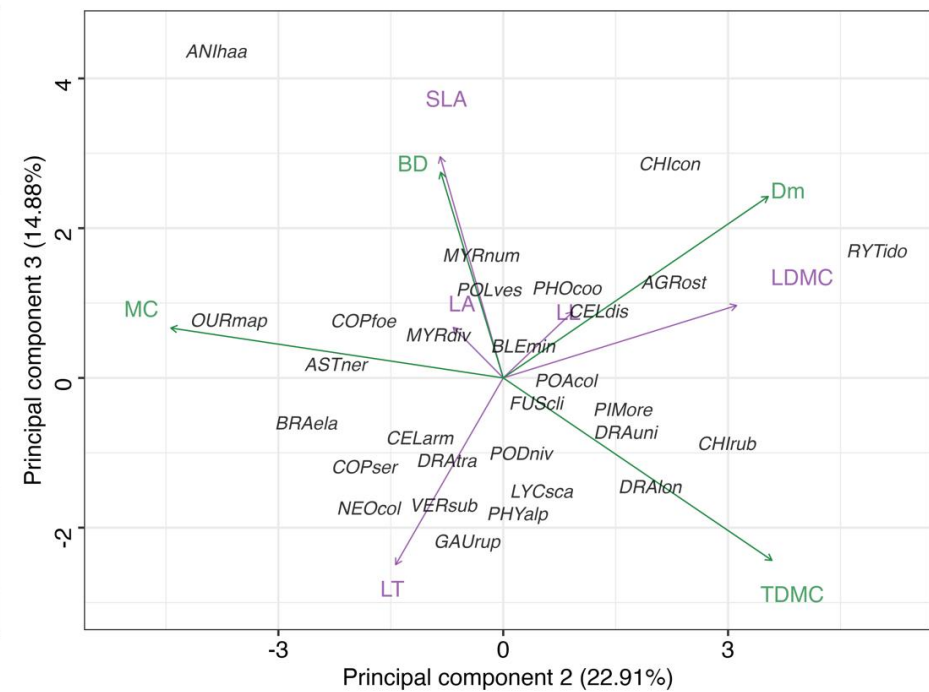
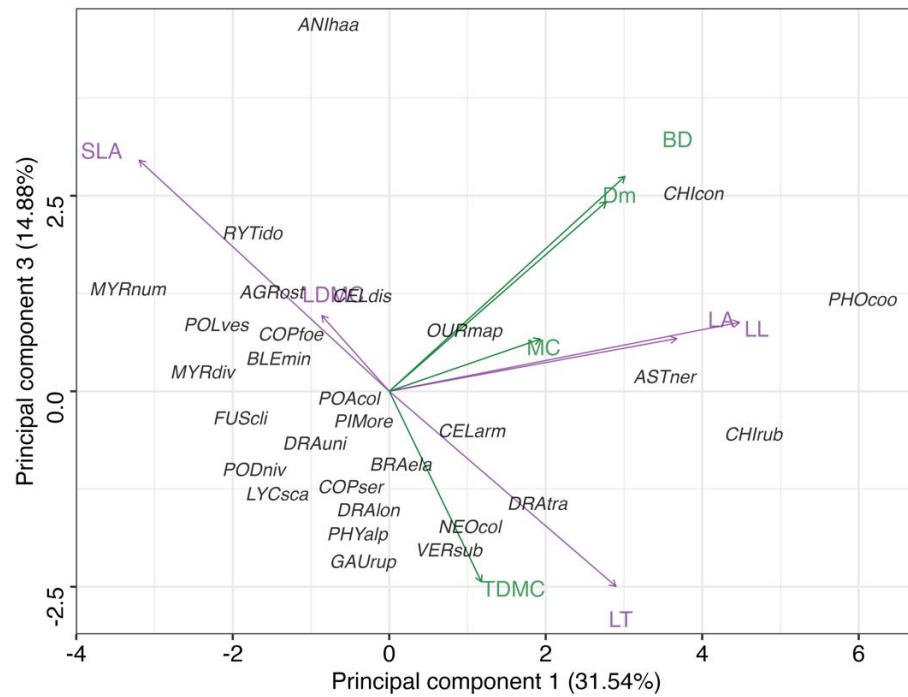
42

43 Fig. S1: Box plot of relative flammability (PC1) for all individuals of the 29 plant taxa from
 44 subalpine of South Island, New Zealand. The first and second principal components
 45 explained 57.39% and 21.28% of the individual specimen level variation in relative
 46 flammability. The size of box represents flammability PC1 variation within taxon. Points
 47 represent outliers within taxa.



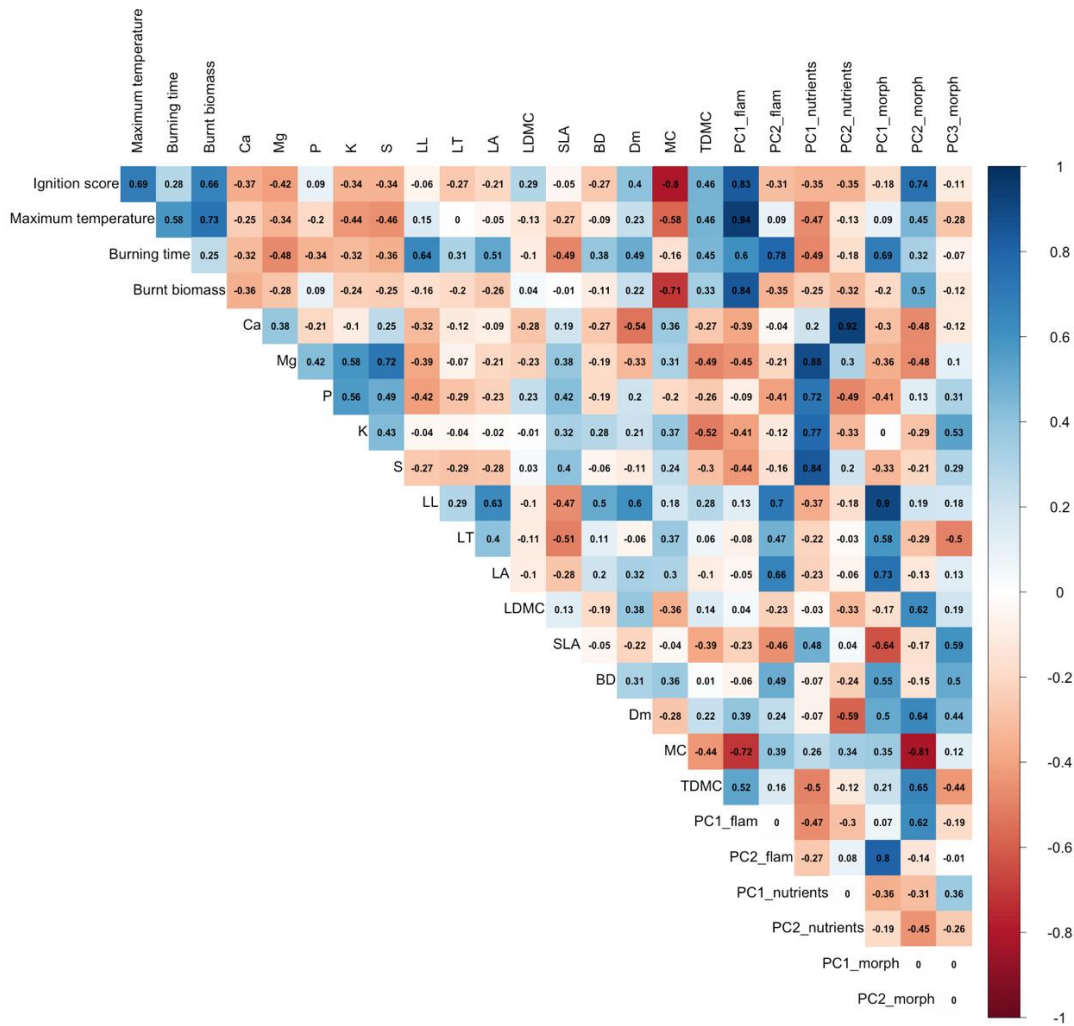
48

49 Fig. S2: Phylogenetic tree for the 29 taxa of vascular plants from subalpine, South Island,
 50 New Zealand. The phylogenetic relatedness of 29 taxa were obtained from an R package
 51 ‘phangorn’. Branch lengths represent evolutionary distance. Nodes represent group of the
 52 taxon that have a common ancestor. Tip labels represent plant taxon.



53

54 Fig. S3: Principal component analysis (PC1 and PC3; PC2 and PC3) of the mean scores for each taxon based on measurement leaf (green) and
 55 shoot (purple) morphological traits for the 29 taxa from subalpine of South Island, New Zealand. Taxon codes are the first three letters of each of
 56 genus and species epithet as code (see full species list, supplementary Table S1). PC1 represents leaf dimensions (LL, LA and LT), PC2
 57 represents moisture content. Trait abbreviations are given in Fig. 5.



58

59 Fig. S4: Pearson correlation coefficients for pairwise comparisons of plant
60 flammability, leaf nutrient concentrations and leaf morphology and shoot traits for the
61 29 plant taxa from subalpine of South Island, New Zealand, in addition to their
62 correlations with principal components from PCA of each variable set. Trait
63 abbreviations are given in Fig. 5. PC1_flam explained 66.15% of the total variation and
64 PC2_flam explained 20.98%. PC1_nutrients explained 52.56% of the variation among
65 taxa in leaf nutrient concentrations, and PC2_nutrients explained 26.64%. PC1_morph
66 explained 31.54% of the variation among taxa in leaf and shoot morphological traits,
67 PC2_morph explained 22.91%, and PC3_morph explained 14.88%. Square box colour
68 represents positive (blue) to negative (red) correlation among flammability, leaf, shoot
69 and leaf nutrient traits. Critical value of correlation (r) for 29 taxa is 0.34.