Frontiers in Plant Science/Functional Plant Ecology

Supplementary material

Early Evidence of Shifts in Alpine Summit Vegetation: A Case Study from Kashmir Himalaya

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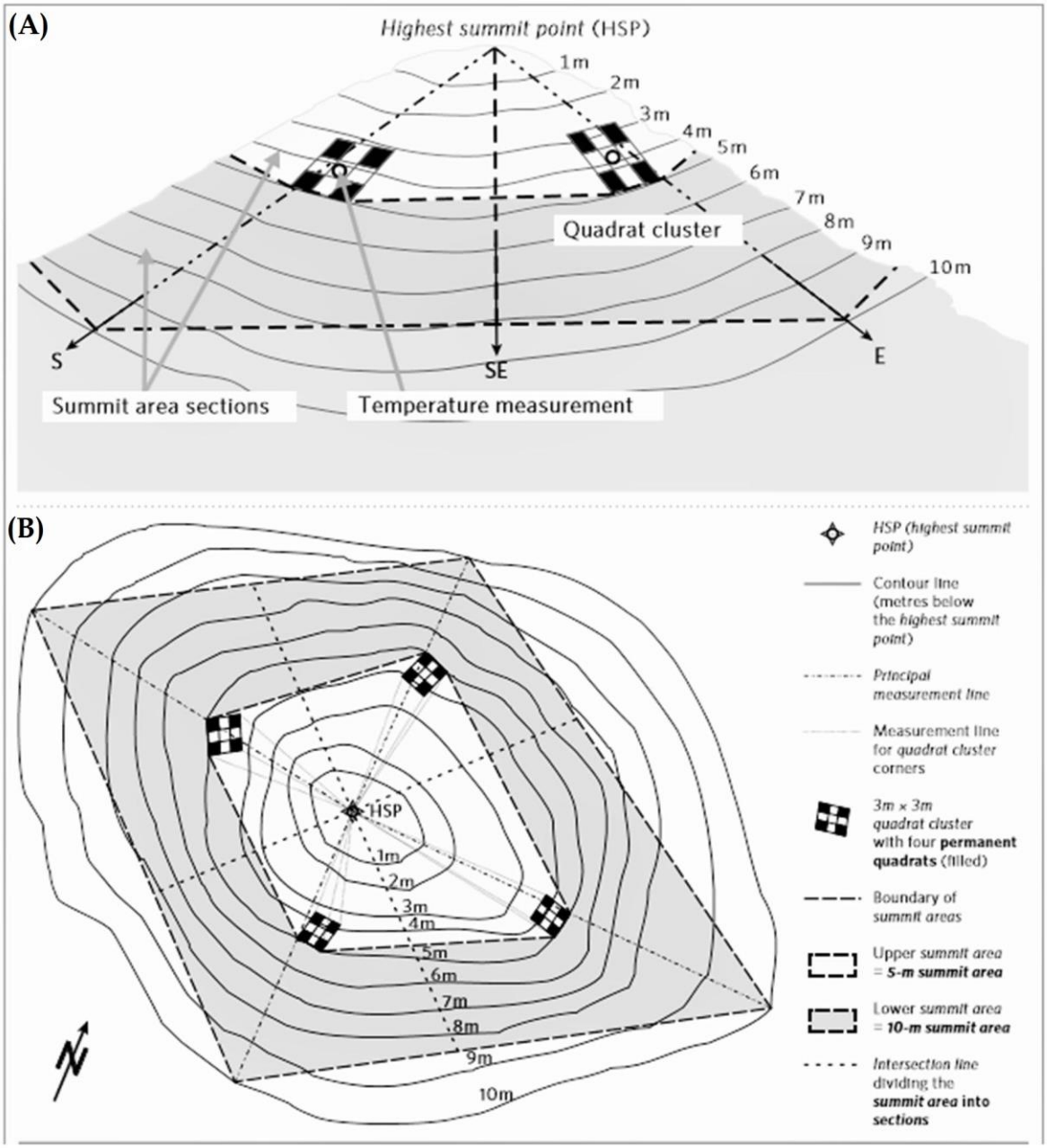
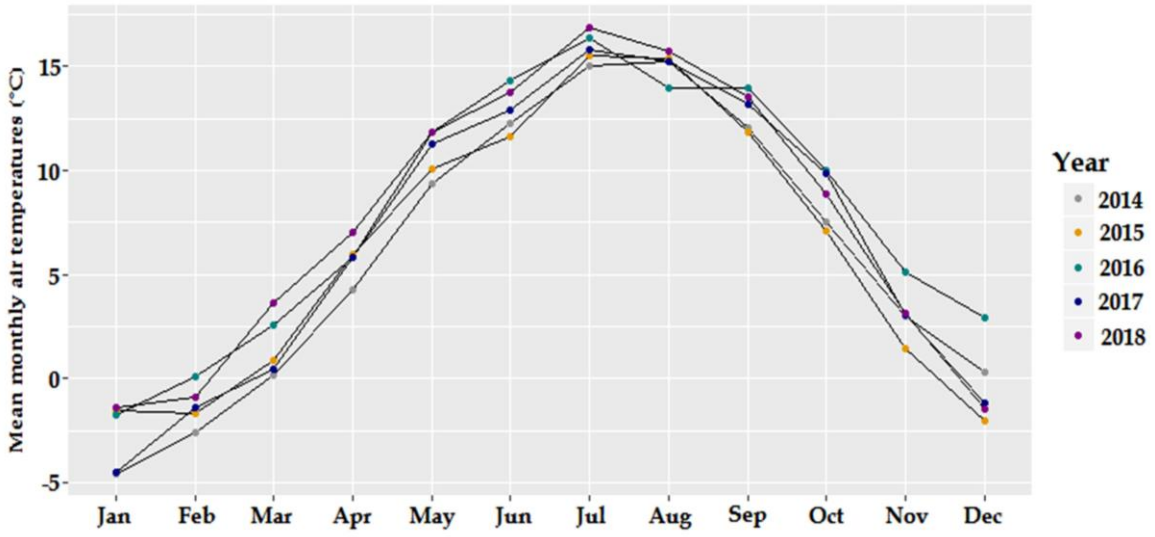
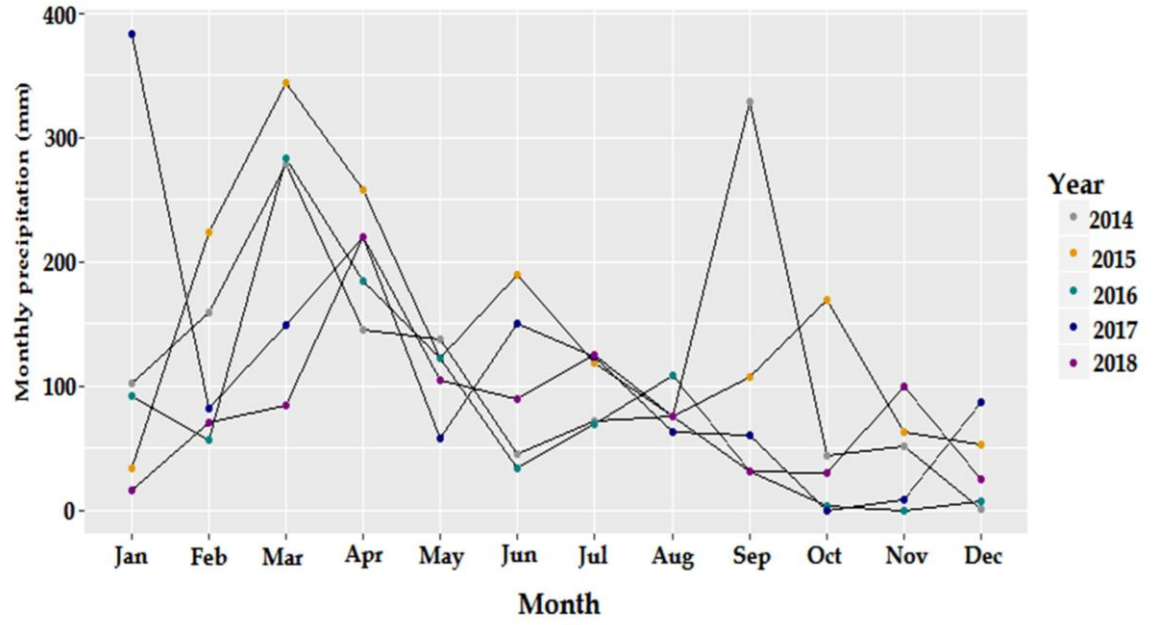


Figure S1 Sampling design of the Multi-Summit approach using GLORIA protocol. **(A)** View of an idealized summit with schematic contour lines 5 and 10m below the highest summit point. **(B)** Top view of the area sampled (light and dark grey area), showing the four 1 m ^{2} permanent plots (black quadrats), one in each compass direction. Additional explanations can be found in GLORIA field manual (Pauli et al., 2015, Source: The GLORIA field manual—standard multi-summit approach).



(A)



(B)

Figure S2 Climate conditions at the study area between 2014 and 2018. **(A)** Monthly mean air temperatures, **(B)** monthly precipitation.

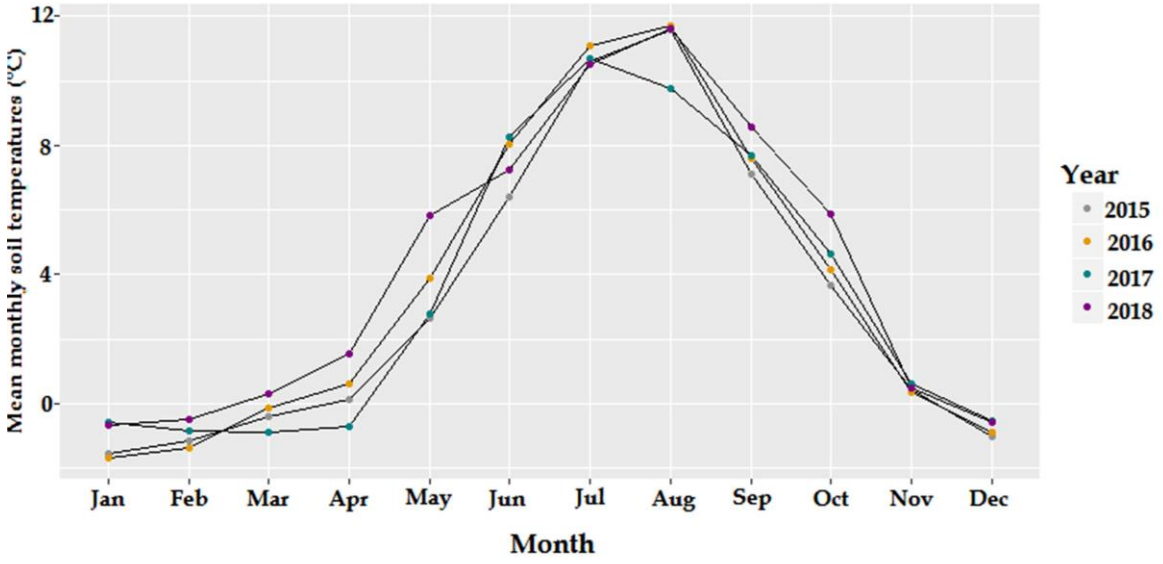


Figure S3 Monthly mean soil temperatures at the study area between 2015 and 2018.

Table S1 Description of the five abundance classes or categories, used to visually estimate the species cover percentage within the summit area sections (after Pauli et al., 2015).

Abundance class	Symbol	Description
Abundant	a	Very abundant, often forming more or less patchy or dense vegetation layers; species covers more than 50% of the summit area section
Common	c	Frequent and widespread occurrence within the section; presence is obvious at the first glance, but it covers less than 50% of the summit area section
Scattered	s	Widespread within the section, species can hardly be overlooked, but the presence is not obvious at the first glance; individuals are not necessarily evenly dispersed over the entire summit area section
Rare	r	Some individuals at several locations that can hardly be overlooked in a careful observation
Very rare	r!	One or a few small individuals

Table S2 Description and distribution margins of the elevational ranks applied in the study (after Gottfried et al., 2012).

Rank	Description	Altitudinal distribution (lower margin / centre / upper margin)
1	Species with a nival distribution centre	nival / nival / nival
2	Alpine to nival species, not descending to treeline	alpine / alpine / nival
3	Alpine centred species, not descending to montane belt	treeline / alpine / alpine
4	Alpine centred species, descending to montane belt or indifferently distributed from the alpine belt to the treeline	montane / alpine / alpine or treeline / indifferent / alpine
5	Species centred in the treeline ecotone or indifferently distributed from montane to alpine belt	montane / treeline / alpine
6	Species with a montane distribution centre or indifferently distributed from the montane belt to the treeline	montane / montane / treeline

Table S3 Elevational ranks for the vascular plants {based on the species' position on summit, supplemented with local floras (Dhar and Kachroo, 1983; Polunin and Stainton, 1984)}

Scientific Name	**Rank**
Achillea millefolium L.	6
Aconitum heterophyllum Wall. ex Royle	4
Aconitum violaceum Jacquem. ex Stapf	3
Alchemilla trollii Rothm.	3
Anaphalis royleana DC.	5
Androsace rotundifolia Hardw.	5
Anemone obtusiloba D.Don	5
Aquilegia fragrans Benth	6
Arabis tibetica Hook.f. & Thomson	4
Artemisia roxburghiana Besser	5
Aster falconeri (C.B.Clarke) Hutch.	5
Aster thomsonii C.B.Clarke	6
Astragalus grahamianus Benth.	6
Berberis jaeschkeana C.K.Schneid.	5
Bergenia stracheyi (Hook.f. & Thomson) Engl.	5
Betula utilis D.Don	6
Bupleurum candollei Wall. ex DC.	5
Campanula aristata Wall.	5
Carex nubigena D.Don	5
Cassiope fastigiata (Wall.) D. Don	2
Cerastium glomeratum Thuill.	5
Chaerophyllum villosum Wall. ex DC.	4
Chrysopogon gryllus (L.) Trin.	5
Cimicifuga kashmiriana J.Compton & Hedd.	6
Circaea alpina L.	5
Cirsium wallichii DC.	6

Clinopodium umbrosum (M.Bieb.) K.Koch	5
Codonopsis ovata Benth.	5
Cortia depressa (D.Don) C.Norman	5
Cortusa brotheri (R.Knuth) Losinsk.	2
Corydalis cashmeriana Royle	2
Corydalis diphylla Wall.	4
Corydalis rutifolia (Sm.) DC.	4
Corydalis thyrsiflora Prain	5
Cotoneaster microphyllus Wall. ex Lindl.	3
Cremanthodium decaisnei C.B.Clarke	1
Crepis sancta (L.) Babc.	6
Crucihimalaya himalaica (Edgew.) Al-Shehbaz, O'Kane & R.A.Price	4
Cynoglossum wallichii G. Don	6
Delphinium vestitum Wall. ex Royle	4
Dipsacus inermis Wall.	5
Doronicum roylei DC.	5
Elsholtzia eriostachya (Benth.) Benth.	2
Epilobium parviflorum Schreb.	6
Erigeron multicaulis Wall.	5
Euphorbia wallichii Hook.f.	6
Euphrasia parviflora Schag.	5
Fagopyrum tataricum (L.) Gaertn.	3
Galium aparine L.	6
Gaultheria trichophylla Royle	2
Gentiana carinata (D. Don) Griseb.	4
Geranium nepalense Sweet	6
Geranium pratense L.	6

Geranium wallichianum D. Don ex	6
Geum elatum Wall. ex G.Don	5
Gypsophila sedifolia Kurz	6
Heracleum candicans Wall. ex DC	5
Hieracium umbellatum L.	6
Impatiens brachycentra Kar. & Kir.	3
Impatiens sulcata Wall.	6
Impatiens thomsonii Hook.f.	6
Inula royleana DC.	5
Jaeschkea canaliculata Knobl.	5
Juniperus squamata Buch.-Ham. ex D.Don	4
Jurinea dolomiaea Boiss.	4
Koeleria pyramidata (Lam.) P.Beauv.	5
Lactuca macrorhiza (Royle) Hook.f.	5
Lamium album L.	2
Leontopodium jacotianum Beauverd	5
Ligularia amplexicaulis DC.	1
Ligularia fischeri Turcz.	2
Lomatogonium caeruleum (Royle) Harry Sm. ex B.L.Burtt	5
Lonicera obovata Royle ex Hook.f. & Thomson	3
Mazus pumilus (Burm.f.) Steenis	5
Meconopsis latifolia (Prain) Prain	2
Melica persica Kunth	5
Morina coulteriana Royle	5
Morina longifolia Wall. ex DC.	5
Myosotis alpestris F.W.Schmidt	6
Myosotis stricta Link ex Roem. & Schult.	5

Nepeta connata Royle ex Benth.	5
Nepeta laevigata (D.Don) Hand.-Mazz.	4
Nepeta linearis Royle ex Benth.	5
Onosma hispida Wall. ex G.Don	6
Origanum vulgare L.	6
Oxyria digyna (L.) Hill	5
Pedicularis siphonantha D. Don	5
Phleum alpinum L.	5
Phlomoides bracteosa (Royle ex Benth.) Kamelin & Makhm.	5
Picris hieracioides Sibth. & Sm.	6
Pinus wallichiana A.B. Jacks.	6
Plantago himalaica Pilg.	5
Poa angustifolia L.	5
Podophyllum hexandrum Royle	6
Polemonium caeruleum L.	5
Polygonatum multiflorum (L.) All.	6
Polygonum affine D. Don	4
Polygonum amplexicaule D. Don	6
Polypogon fugax Nees ex Steud.	5
Potentilla atrosanguinea G. Lodd. ex D. Don	5
Primula elliptica Royle	5
Primula macrophylla D. Don	5
Primula rosea Royle	6
Pseudomertensia moltkioides (Royle ex Benth.) Kazmi	6
Ranunculus brotherusii Freyn	5
Ranunculus hirtellus Royle	6
Ranunculus palmatifidus Riedl	6

Rheum webbianum Royle	4
Rhodiola himalensis (D. Don) S.H. Fu	6
Rhododendron anthopogon D. Don	3
Ribes orientale Desf.	6
Rosa webbiana Wall. ex Royle	5
Rumex nepalensis Spreng.	6
Salix denticulata Andersson	6
Salix flabellaris Andersson	2
Salvia hians Royle ex Benth.	5
Saussurea candolleana Wall. ex C.B.Clarke	3
Saussurea costus (Falc.) Lipsch.	5
Saxifraga hirculus L.	1
Saxifraga sibirica L.	3
Scutellaria prostrata Jacquem. ex Benth.	5
Sedum ewersii Ledeb.	6
Senecio chrysanthemoides DC.	5
Sibbaldia cuneata Edgew.	5
Sigesbeckia orientalis L.	6
Silene graminifolia Otth	5
Silene himalayensis (Rohrb.) Majumdar	2
Silene nigrescens (Edgew.) Majumdar	3
Solidago virgaurea L.	5
Stellaria decumbens Edgew.	6
Stipa sibirica (L.) Lam.	5
Swertia petiolata D. Don	4
Tanacetum tibeticum Hook.f. & Thomson	4
Taraxacum officinale aggr. auct.	5
Thalictrum alpinum L.	4

Themeda anathera (Nees ex Steud.) Hack.	5
Thlaspi cochleariforme DC.	4
Thymus linearis Benth	5
Trifolium pratense L.	6
Trifolium repens L.	6
Valeriana pyrolifolia Decne	6
Verbascum thapsus L.	6
Veronica laxa Benth.	5
Viola biflora L.	5

Table S4 One-way ANOVA results for the effect of year on growing degree days (GDD).

	df	**SSR**	**MSR**	**F**	**P**
Effect of year	1	26	26.3	0.051	0.823
Residuals	30	15509	517.0		

Table S5 A comparison of number of growing degree days (GDD) at summits between August 2014-July 2015 and August 2017-July 2018.

Summit	**Year**	**Aspect**			
		N	S	E	W
GUL1	August 2014-July 2015	77	116	109	82
	August 2017-July 2018	80	118	112	83
GUL2	August 2014-July 2015	61	93	98	68
	August 2017-July 2018	63	95	98	69
GUL3	August 2014-July 2015	53	50	78	55
	August 2017-July 2018	55	52	80	57
GUL4	August 2014-July 2015	46	70	67	37
	August 2017-July 2018	49	72	68	39

Table S6 GUL1 **(A)** One-way ANOVA results for the effect of aspect (nested within summit) on species richness, and **(B)** Tukey multiple comparison test between aspects. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '**.**' for P < 0.1.

(A)

	df	**SSR**	**MSR**	**F**	**P**
Effect of aspect (nested within summit)	3	126.5	42.17	5.988	0.0098 **
Residuals	12	84.5	7.04		

(B)

Pair wise comparison	**Estimate Std.**	**SE**	**t**	**P**
N - E	-0.250	1.876	-0.133	0.99911
S - E	5.000	1.876	2.665	0.08401 ·
W- E	-2.750	1.876	-1.466	0.48608
S- N	5.250	1.876	2.798	0.06705 ·
W - N	-2.500	1.876	-1.332	0.56128
W- S	-7.750	1.876	-4.130	0.00656 **

Table S7 GUL2 **(A)** One-way ANOVA results for the effect of aspect (nested within summit) on species richness, and **(B)** Tukey multiple comparison test between aspects. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '**.**' for P < 0.1.

(A)

	df	**SSR**	**MSR**	**F**	**P**
Effect of aspect (nested within summit)	3	74.75	24.917	10.31	0.00122 **
Residuals	12	29.00	2.417		

(B)

Pair wise comparison	**Estimate Std.**	**SE**	**t**	**P**
N - E	3.000	1.099	2.729	0.07520 ·
S - E	-2.500	1.099	-2.274	0.15888
W- E	-2.000	1.099	-1.819	0.31152
S- N	-5.500	1.099	-5.003	0.00148 **
W - N	-5.000	1.099	-4.549	0.00324 **
W- S	0.500	1.099	0.455	0.96741

Table S8 GUL3 **(A)** One-way ANOVA results for the effect of aspect (nested within summit) on species richness, and **(B)** Tukey multiple comparison test between aspects. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '**.**' for P < 0.1.

(A)

	df	**SSR**	**MSR**	**F**	**P**
Effect of aspect (nested within summit)	3	185.19	61.73	14.6	0.000262 ***
Residuals	12	50.75	4.23		

(B)

Pair wise comparison	**Estimate Std.**	**SE**	**t**	**P**
N - E	2.500	1.454	1.719	0.35614
S - E	-2.750	1.454	-1.891	0.28198
W- E	6.500	1.454	4.470	0.00377 **
S- N	-5.250	1.454	-3.610	0.01630 *
W - N	4.000	1.454	2.751	0.07250 ·
W- S	9.250	1.454	6.361	< 0.001 ***

Table S9 GUL4 **(A)** One-way ANOVA results for the effect of aspect (nested within summit) on species richness, and **(B)** Tukey multiple comparison test between aspects. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '**.**' for P < 0.1.

(A)

	df	**SSR**	**MSR**	**F**	**P**
Effect of aspect (nested within summit)	3	153.2	51.08	29.9	< 0.001***
Residuals	12	20.5	1.71		

(B)

Pair wise comparison	**Estimate Std.**	**SE**	**t**	**P**
N - E	-0.7500	0.9242	-0.812	0.8479
S - E	1.7500	0.9242	1.894	0.2810
W- E	-6.5000	0.9242	-7.033	<0.001 ***
S- N	2.5000	0.9242	2.705	0.0785 ·
W - N	-5.7500	0.9242	-6.222	<0.001 ***
W- S	-8.2500	0.9242	-8.927	<0.001 ***

Table S10 (A) One-way ANOVA results for the effect of summit on species richness, and **(B)** Tukey multiple comparison test between summits. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '**.**' for P < 0.1.

(A)

Summit	**df**	**SSR**	**MSR**	**F**	**P**
Effect of summit	3	947.6	315.88	28.62	< 0.001***
Residuals	124	1368.7	11.04		

(B)

Pair wise comparison	**Estimate Std.**	**SE**	**t**	**P**
GUL2-GUL1	-3.1563	0.8306	-3.800	0.00131 **
GUL3-GUL1	-7.5938	0.8306	-9.143	< 0.001 ***
GUL4-GUL1	-4.4062	0.8306	-5.305	< 0.001 ***
GUL3-GUL2	-4.4375	0.8306	-5.343	< 0.001 ***
GUL4-GUL2	-1.2500	0.8306	-1.505	0.03761 *
GUL4-GUL3	3.1875	0.8306	3.838	0.00114 **

Table S11 Two-way ANOVA results for the effect of summit and year of sampling on species richness. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '.' for P < 0.1.

	df	**SSR**	**MSR**	**F**	**P**
Effect of summit	3	947.6	315.88	28.62	< 0.001***
Effect of year	1	59.1	59.13	5.424	0.0215 *
Interaction effect between summit and year	3	50.2	12.40	3.37	0.0404 *
Residuals	120	1308.3	10.90		

Table S12 Two-way ANOVA results for the effect of summit and aspect on soil temperature. Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '.' for P < 0.1

	df	**SSR**	**MSR**	**F**	**P**
Effect of summit	3	53.98	17.995	7662.5	< 0.001***
Effect of aspect	3	24.51	8.171	3479..3	< 0.001***
Interaction effect between summit and aspect	9	14.01	1.557	662.8	< 0.001***
Residuals	48	0.11	0.002		