

Supporting Information to

Dwarf shrub expansion and loss of lichens distinctly dominate multi-decadal changes in northern boreal understory plant communities

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Appendix S1. Grazing pressure (number of reindeer/km²) in the Ivalo herding district from 1960 to 2022 (data from Living environment information service Liiteri, 2024 and from Jouko Kumpula from Natural Resources Institute Finland).



References:

Living environment information service Liiteri (2024). Paliskuntien poroluettelot. Paliskuntain Yhdistys. Elinympäristön tietopalvelu Liiteri. 10.4.2024. <https://liiteri.ymparisto.fi>

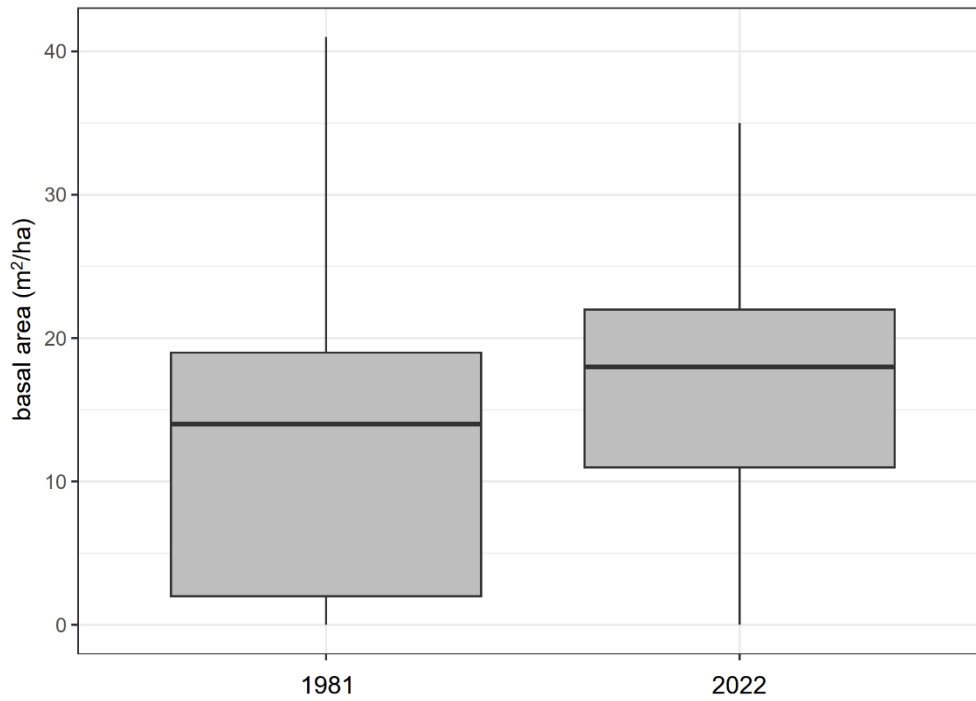
Appendix S2. Species that were combined into genus level.

Bryophytes	Lichens
<i>Barbilophozia sp.</i>	<i>Cladonia arbuscula</i>
<i>B. hatcheri</i>	<i>incl. C. mitis</i>
<i>B. lycopodiodes</i>	<i>Cladonia sp.</i>
<i>Dicranum sp.</i>	<i>C. amaurocraea</i>
<i>D. drummondii</i>	<i>C. bellidiflora</i>
<i>D. fuscescens</i>	<i>C. botrytes</i>
<i>D. flecixaule</i>	<i>C. carneola</i>
<i>D. majus</i>	<i>C. chlorophaea</i>
<i>D. polysetum</i>	<i>C. coccifera</i>
<i>D. scoparium</i>	<i>C. cornuta</i>
<i>D. spurium</i>	<i>C. crispata</i>
<i>D. undulatum</i>	<i>C. deformis</i>
<i>Polytrichum sp.</i>	<i>C. digitata</i>
<i>P. commune</i>	<i>C. gracilis</i>
<i>P. juniperinum</i>	<i>C. macrphylla</i>
<i>P. piliferum</i>	<i>C. phyllophora</i>
	<i>C. pleurota</i>
	<i>C. sp.</i>
	<i>C. subulata</i>
	<i>C. turgida</i>
	<i>C. uncialis</i>
	<i>Peltigera sp.</i>
	<i>P. aphthosa</i>
	<i>P. malacea</i>
	<i>P. scabrosa</i>

Appendix S3. List of all species found, their frequencies (in 1981/in 2022) and mean covers % (in 1981/in 2022) with permuted (9999) p-values before the Holm correction. *Seedlings only. '+' in cover is < 0.1 %. NA = species cover did not vary in either survey year and was not tested.

Vascular plants	freq.	mean %	p.perm	Bryophytes	freq.	mean %	p.perm
<i>Andromeda polifolia</i>	4 / 6	+ / +	0.091	<i>Aulacomnium palustre</i>	0 / 1	0 / +	0.502
<i>Antennaria dioica</i>	1 / 1	+ / +	0.506	<i>Barbilophozia sp.</i>	72 / 80	4.4 / 6.0	0.095
<i>Arctous alpina</i>	14 / 6	0.2 / +	0.001	<i>Brachythecium sp.</i>	0 / 3	0 / +	0.125
<i>Arctostaphylos uva-ursi</i>	19 / 15	0.3 / 0.2	0.167	<i>Dicranella sp.</i>	0 / 1	0 / +	0.502
<i>Avenella flexuosa</i>	43 / 43	0.5 / 0.5	0.402	<i>Dicranum sp.</i>	80 / 80	24.9 / 21.7	0.133
<i>Betula pubescens</i>				<i>Hylocomium splendens</i>	26 / 28	2.4 / 3.1	0.234
<i>ssp. czerepanowii*</i>	8 / 4	+ / +	0.098	<i>Pleurozium schreberi</i>	75 / 80	38.6 / 35.6	0.134
<i>Betula nana</i>	12 / 12	0.8 / 0.9	0.380	<i>Pohlia nutans</i>	13 / 33	+ / 0.2	0.000
<i>Bistorta vivipara</i>	0 / 1	0 / +	0.490	<i>Polytrichum sp.</i>	35 / 22	0.8 / 0.2	0.000
<i>Calluna vulgaris</i>	69 / 65	12.8 / 7.7	0.000	<i>Ptilidium ciliare</i>	31 / 38	0.9 / 0.3	0.015
<i>Campanula rotundifolia</i>	0 / 1	0 / +	0.500	<i>Ptilium crista-castrensis</i>	0 / 1	0 / +	0.497
<i>Cornus suecica</i>	0 / 2	0 / +	0.252	<i>Rhodobryum roseum</i>	0 / 1	0 / +	0.498
<i>Diphasiastrum alpinum</i>	2 / 3	+ / +	NA	<i>Sphagnum capillifolium</i>	1 / 0	+ / 0	0.501
<i>Diphasiastrum complanatum</i>	10 / 5	+ / +	0.101	<i>Tetraplodon sp.</i>	0 / 2	0 / +	0.258
<i>Empetrum nigrum</i>	80 / 80	9.9 / 15.1	0.000				
<i>Euphrasia sp.</i>	0 / 1	0 / +	0.497	Lichens	freq.	mean %	p.perm
<i>Festuca ovina</i>	6 / 1	+ / +	0.016	<i>Alectoria ochroleuca</i>	1 / 0	+ / 0	0.507
<i>Geranium sylvaticum</i>	1 / 1	+ / +	0.500	<i>Cetraria ericetorum</i>	14 / 2	0.2 / +	0.000
<i>Hieracium spp.</i>	4 / 1	+ / +	0.191	<i>Cetraria islandica</i>	16 / 17	0.1 / 0.1	0.071
<i>Huperzia selago</i>	0 / 1	0 / 1	0.499	<i>Cladonia arbuscula</i>	79 / 73	6.9 / 0.4	0.000
<i>Juniperus communis</i>	13 / 12	0.4 / 0.3	0.421	<i>Cladonia rangiferina</i>	78 / 77	4.0 / 0.5	0.000
<i>Linnaea borealis</i>	19 / 21	0.1 / 0.1	0.392	<i>Cladonia stellaris</i>	68 / 43	2.4 / 0.1	0.000
<i>Listera cordata</i>	0 / 1	0 / +	0.502	<i>Cladonia sp.</i>	80 / 80	3.0 / 1.4	0.000
<i>Luzula pilosa</i>	7 / 7	+ / +	NA	<i>Flavocetraria nivalis</i>	2 / 2	0.3 / +	0.249
<i>Spinulum annotinum</i>	2 / 5	+ / +	0.504	<i>Nephroma arcticum</i>	9 / 3	+ / +	0.056
<i>Lycopodium clavatum</i>	0 / 2	+ / +	0.251	<i>Peltigera sp</i>	9 / 8	+ / +	0.443
<i>Melica nutans</i>	2 / 1	+ / +	0.496	<i>Sphaerophorus globosus</i>	1 / 0	+ / 0	0.511
<i>Melampyrum pratense</i>	6 / 8	+ / +	0.379	<i>Stereocaulon sp.</i>	20 / 3	0.1 / +	0.000
<i>Oreojuncus trifidus</i>	3 / 1	+ / +	0.254				
<i>Orthilia secunda</i>	2 / 0	+ / +	0.253				
<i>Pedicularis lapponica</i>	1 / 0	+ / 0	0.501				
<i>Phyllodoce caerulea</i>	2 / 7	0.1 / 0.2	0.136				
<i>Picea abies*</i>	1 / 2	+ / +	0.379				
<i>Pinus sylvestris*</i>	30 / 41	0.1 / 0.3	0.003				
<i>Pyrola rotundifolia</i>	0 / 1	0 / +	0.494				
<i>Rhododendron tomentosum</i>	1 / 2	+ / +	0.499				
<i>Selaginella selaginoides</i>	0 / 1	+ / +	0.501				
<i>Solidago virgaurea</i>	4 / 2	+ / +	0.250				
<i>Sorbus aucuparia*</i>	1 / 1	+ / +	NA				
<i>Trientalis europaea</i>	7 / 10	+ / +	NA				
<i>Vaccinium myrtillus</i>	78 / 78	6.0 / 9.2	0.001				
<i>Vaccinium uliginosum</i>	22 / 22	0.3 / 0.9	0.012				
<i>Vaccinium vitis-idaea</i>	80 / 80	5.0 / 8.1	0.000				

Appendix S4. Basal area (m^2/ha) during the original survey and the resurvey. Based on a paired t-test, there was no significant difference in the basal area between the surveys ($t = 1.496$, $df = 30$, $p = 0.145$). Basal area was measured from 31 sites using a standard size chain relascope with 65 cm chain and 13 mm aperture.



Appendix S5. Anova tables for LMMs made for seven cover (%) variables in response to time (survey), site type and their interaction.

Model		numDF	denDF	F-value	p-value
sqrt(E.nigrum)	(Intercept)	1	75	1027.32	<.0001
	survey	1	75	35.42	<.0001
	site type	4	36	6.30	0.001
	survey:site type	4	75	3.73	0.008
sqrt(C.vulgaris)	(Intercept)	1	75	208.67	<.0001
	survey	1	75	18.56	<.0001
	site type	4	36	5.71	0.001
	survey:site type	4	75	3.52	0.011
sqrt(V.myrtillus)	(Intercept)	1	75	404.20	<.0001
	survey	1	75	16.35	0.000
	site type	4	36	2.89	0.036
	survey:site type	4	75	5.90	0.000
sqrt(V.vitis-idaea)	(Intercept)	1	75	808.20	<.0001
	survey	1	75	43.61	<.0001
	site type	4	36	9.39	<.0001
	survey:site type	4	75	2.46	0.053
sqrt(vascular plants)	(Intercept)	1	75	1377.75	<.0001
	survey	1	75	16.93	0.000
	site type	4	36	6.33	0.001
	survey:site type	4	75	8.77	<.0001
bryophytes	(Intercept)	1	75	704.24	<.0001
	survey	1	75	4.49	0.037
	site type	4	36	8.79	<.0001
	survey:site type	4	75	7.95	<.0001
sqrt(lichens)	(Intercept)	1	75	2311.97	<.0001
	survey	1	75	490.37	<.0001
	site type	4	36	56.40	<.0001
	survey:site type	4	75	24.17	<.0001

Appendix S6. Tukey's post hoc test statistics.

Model	Pairs of years		Estimate	Std. Error	z	p-value
sqrt(C.vulgaris)	2014	1980	-1.038	0.363	-2.856	0.012
	2022	1980	-1.117	0.363	-3.074	0.006
	2022	2014	-0.079	0.363	-0.218	0.974
sqrt(E.nigrum)	2014	1980	0.394	0.291	1.355	0.365
	2022	1980	0.959	0.291	3.298	0.003
	2022	2014	0.565	0.291	1.942	0.127
sqrt(V.vitis-idaea)	2014	1980	0.778	0.175	4.443	< 0.001
	2022	1980	0.531	0.175	3.035	0.007
	2022	2014	-0.246	0.175	-1.408	0.337
sqrt(V.myrtillus)	2014	1980	0.407	0.267	1.522	0.281
	2022	1980	0.660	0.267	2.468	0.036
	2022	2014	0.253	0.267	0.947	0.611
sqrt(Vascular plants)	2014	1980	0.278	0.294	0.948	0.610
	2022	1980	0.274	0.294	0.935	0.618
	2022	2014	-0.004	0.294	-0.013	1.000
sqrt(Bryophytes)	2014	1980	-1.710	0.361	-4.734	<1e-05
	2022	1980	0.111	0.361	0.307	0.949
	2022	2014	1.821	0.361	5.041	<1e-05
sqrt(Lichens)	2014	1980	-1.794	0.270	-6.639	<1e-05
	2022	1980	-1.707	0.270	-6.318	<1e-05
	2022	2014	0.087	0.270	0.321	0.945