

# Determination of baseline metal contamination using peltigeralean lichens in northeastern Canada

## Supplementary Information

Romain Darnajoux<sup>1</sup>, François Lutzoni<sup>2</sup>, Jolanta Miadlikowska<sup>2</sup>, Jean-Philippe Bellenger<sup>1\*</sup>

<sup>1</sup>*Centre Sève, Département de chimie, Université de Sherbrooke, 2500 Boul. de l'Université, Sherbrooke, Québec J1K 2R1, Canada*

<sup>2</sup>*Department of biology, Duke University, 125 Science Drive, Durham, North Carolina, 27708, USA*

## Contents

1. Supplementary methods .....	2
1.1. Principal Component Analysis.....	2
1.2. Compositional biplot .....	2
2. Supplementary discussion .....	2
2.1. Species variability .....	2
2.2. Small anomalies .....	3
2.3. Thallus part composition.....	3
3. Supplementary figures .....	5
Figure S1.....	5
Figure S2.....	6
4. Supplementary tables.....	7
Table S1.....	7
Table S2.....	8
Table S3.....	9
Table S4.....	10
Table S5.....	11
Table S6.....	12
Table S7.....	13
Table S8.....	14
Table S9.....	15
Table S10.....	16
5. Supplementary bibliography.....	17

## 1. Supplementary methods

### 1.1. Principal Component Analysis

Principal component analyses (PCA) used in this study are different from the classical PCA found in most literature on lichen metal content. The mass ratio data (ppm) are not independent one to the other, due to the unity sum of the mass ratio, and belong to the closed data category. With these data, Euclidian geometry is no longer valid, and classical statistics relying on Euclidian distance, such as analysis of variance and factor analysis are no longer valid. This issue has been addressed in numerous publications in the last years (Ranganathan and Borges 2011; Tolosana-Delgado 2012; Buccianti 2013), and we decided to process our data accordingly using a centered-log ratio transformation (Aitchison 2003). In multivariate analysis of compositional data, it is important to state that the analysis of scatter plot is somehow different from classical PCA (Aitchison 2003; Filzmoser et al. 2009). In the space formed by the two axes, the closer the individuals are, the more similar their composition, (i.e. relative content) with regard to each variables. In those plots, a line between two elements represents the ratio of these two elements. The orthogonal projection of a point on these lines informs us on the enrichment of one element with respect to the other (the closer apart from the projection of the center of the plot, the further from the 1:1 ratio). The center of the plot represents the average composition of the lichen thalli, and its projection on these lines represent the 1:1 ratio.

### 1.2. Compositional biplot

Compositional biplot should be analyzed with variables and individual at the same time. In this paper, for convenience we separate in two type of graph; the first type displays clr correlation of the variable in the PC1 and PC2 axes (Fig. 2B and Sup. Info Fig. S1B) and the second type represent the projection of qualitative data (Fig. 2C and Sup. Info Fig. S1C). Closed squares represent centroids of categorical variables highlighted on the graphs. Open squares represent centroids of geographical sampling points. Individuals are hidden to facilitate the interpretation. Ellipses circumscribe the 95% confidence area around centroids. More information on the use of multivariate analysis for compositional data can be found in Aitchison 2003; Ranganathan and Borges 2011; Buccianti 2013; Ziembik et al. 2013

## 2. Supplementary discussion

### 2.1. Species variability

Differences in element contents among species can be due to factors other than species differences. Most specimens of *N. arcticum* were sampled in the northern and far eastern part of the transects (Table S1). While this is consistent with the geographic distribution of this species reported by Brodo et al. 2001, and suggests that *N. arcticum* could be more susceptible to the proximity of anthropogenic activities than the other species, species and geographical differences are partially confounded. Moreover, more than half of *P. neopolydactyla* s.l. specimens were collected in the EW0-W25, SN2 and SN3 areas, i.e.,

closer to urbanized area, while only two specimens were collected in the more pristine sampling sites (SN4-SN9, Table S1). Thus species variability in our sampling reflects more their geographic distribution than a difference in species behavior with regard to metal.

## 2.2. Small anomalies

Correlations between the groups defined in the main manuscript 3.1.3 (Fig. 2B) revealed small anomalies highlighted in Fig. 1C-D. One anomaly is associated with SN9, located at the northern tree limit and showing higher level of terrigenous than soluble elements (Fig. 1C, 2B and Table S3). Shrub arctic tundra (SN9), and to a lesser extent, the forest tundra domain (SN8), which are less populated with trees, may allow more dry and wet depositions due to a lack of tree canopy. Few excavation sites located in the far north of Québec may also contribute to this slight increase in metal contents detected in lichens at these sites. Finally, transportation of residues from Russia and Western Europe through the polar vortex cannot be ruled out (Fig. 1A-B, Simonetti et al., 2000; Bindler and Renberg, 2001). Samples from EW0 to W12.5 also show a slight enrichment of terrigenous elements (Fig. 1D, Fig. 2B, Table S3). Sampling sites SN5 and SN6 were also anomalous (lower right quadrant), correlating with *P. scabrosa* centroid, and showing higher anthropogenic elements (i.e., Zn, Cu and Ni) to pedogenetic elements ratios than other thalli (Fig. 2, Sup. Info. Table S3). The presence of two active Zn smelters in this area (Gouvernement du Québec, 2013a) may explain these results. Analogous to SN2 and SN3 (see main manuscript 3.1.2), anomalies detected in EW0-EW12.5 might be related to higher anthropogenic activities (Figs. 1). Nonetheless, levels of contamination in those areas remain low with regard to available values in the literature for the Canadian arctic (Nash, 1995).

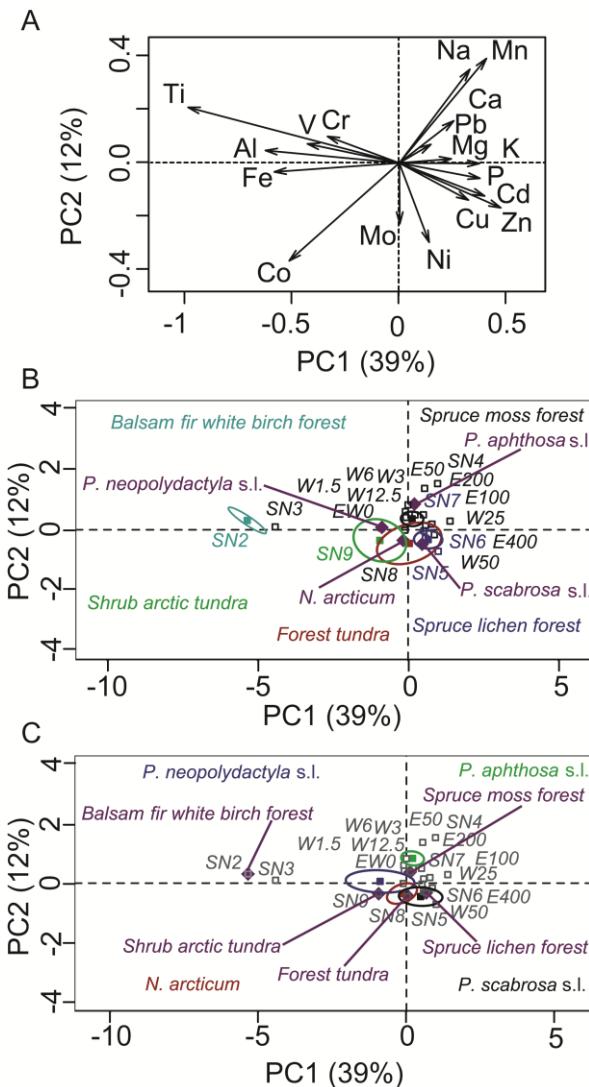
Overall, the PCAs suggest that the source of metals deposited on lichens is homogeneous in most parts of the boreal portion of Québec. This likely reflects the fact that all sampling sites are located on the Canadian Shield, which is mostly geologically uniform. This homogeneity in the elemental composition of lichens also suggests that particles are most likely of pedogenic origin and that particles from anthropogenic origins are limited, with the exception of the southernmost portion of the SN transect (SN1-SN3) representing about one quarter of the full length of this transect.

## 2.3. Thallus part composition.

We compared the elemental contents of the outer margin (3 to 5 mm wide) with the elemental contents of the whole thallus. This approach was used in many studies to establish a proper baseline (e.g., Bergamaschi et al., 2004; Monaci et al., 2012); as the margin of the thallus represents the most recent years of growth, while the whole thallus represents elemental accumulation (deposition and other sources) over the entire lifetime of the thallus. In our study, the margin was defined as the outer layer showing a clearer (lighter) color (as seen from the upper surface of the thallus) compared to the rest of the thallus. Thalli margins were manually dissected and samples digested as described above. For this procedure, we selected lichen thalli that have low Fe, Al and V contents (within the first tertile for each element). Two-way MANOVA was performed to compare cellular metal content at the margin of lichen thalli with cellular metal content of whole thalli.

Our results show that most studied elements are equally concentrated at the margin of the thallus ( $\leq 5$  mm) as throughout the entire thallus (Tables S9 and S10). Results of a two-way multivariate ANOVA with species as second factor shows that only four elements were significantly different: Al, Fe, Ni and Zn ( $p < 0.05$ , Sup. Info. Table S10B). Al and Fe are more concentrated in the entire thallus than at the margin. Ni and Zn concentrations are only significantly higher at the margin, compare to the entire thallus for *P. scabrosa* s.l. (Sup. Info. Table S10B; interaction p-value  $< 0.05$ ). These results show that Ni and Zn contaminations are likely recent and most certainly localized, however the number of replicate for *P. scabrosa* s.l. is too low to be conclusive ( $n = 4$  for margin and  $n = 3$  for the entire thallus). The concentration of essential nutrients P, K and Mg was expected to be higher at the margin of thalli, where thallus growth is more active (Loppi et al., 1997). While not statistically significant, our data seem to support this assumption, since P, K and Mg are slightly more concentrated at the thalli margins when compared to whole thalli. Overall, these results show that, for our dataset, there is no significant difference between using whole thalli vs thalli margins for the determination of a baseline for elemental deposition in northeastern Canada, except for Al, Fe, Ni and Zn.

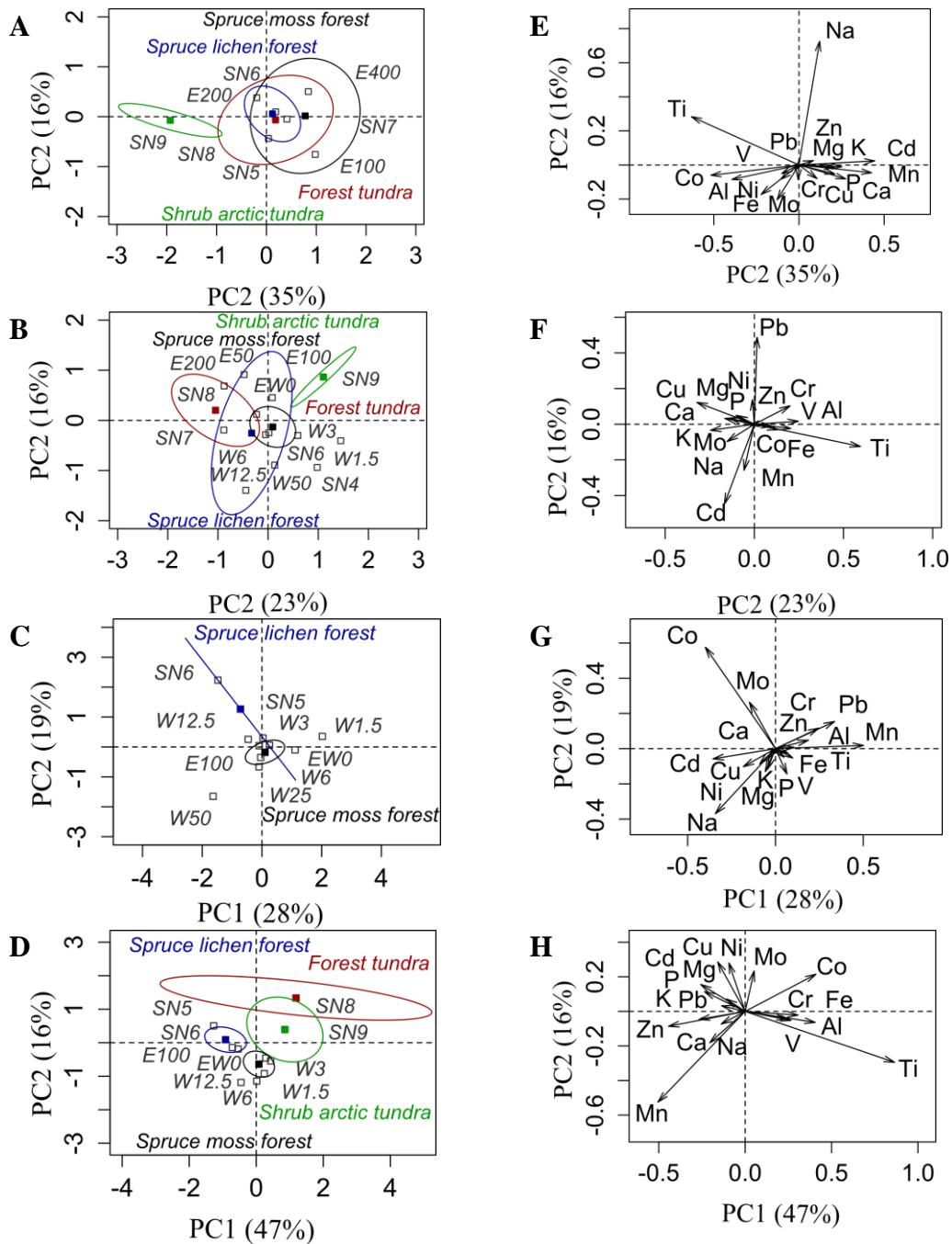
### 3. Supplementary figures



**Figure S1. Correlations among elements and the effect of bioclimatic zones and species on data structure including all samples.** (A) Correlation among elements projected on the first two principal components. Variable plots highlighting bioclimatic domains (B) and lichen-forming species (C).

*Comments on Fig. S1:*

About 50% of the variance can be explained with the two first PCs. The first component (PC1), which explains 39% of the total variance, opposes elements such as Al, Fe, Ti, V and Cr to more soluble elements such as P, Mg, Mn, K and Cd (Fig. S2A). The second component (PC2), which explains 12% of the variance, opposes Co and Ni, and to a lesser extent Mo, Zn and Cu to elements such as Mn, Na, Ca and Pb. Balsam fir white birch forest centroid (Fig. S2B) as well as SN2 and SN3 (Fig. S2C) are clearly separate from the other vegetation domains and sampling points. Those samples are characterized by higher terrigenous elements (Ti, Al, Fe, V, Cr, Co) to soluble elements (Mn, Ca, Zn, Na) ratio.



**Figure S2. Geographical localities and vegetation types associated with metal deposition levels for each lichen-forming species.** PCA results are shown for (A, E) *Nephroma arcticum* (n=31), (B, F) *Peltigera aphthosa* s.l. (n=30), (C, G) *P. neopolydactyla* s.l. (n=16) and (D, H) *P. scabrosa* s.l. (n=33). Anomalies (SN2 and SN3) were not considered. Ellipse:  $p = 0.95$ . The lengths of arrows are generally short, i.e., closer to the center of the plot, compare to when all species are combined. This is highlighting the intraspecific homogeneity of the elemental composition.

#### 4. Supplementary tables

**Table S1. Number of specimens per species per site, with geographic coordinates for each sampling site used in this study.** See Fig. 1A for the location of all sites relative to dominant vegetation types.

Sampling site	N coordinate	W coordinate	<i>N. arcticum</i>	<i>P. aphthosa</i> s.l.	<i>P. neopolydactyla</i> s.l.	<i>P. scabrosa</i> s.l.	Total
W400	50.317	77.519	0	0	0	0	<b>0</b>
W200	50.640	72.970	0	0	0	0	<b>0</b>
W100	50.823	70.730	0	0	0	0	<b>0</b>
W50	50.904	69.565	0	1	1	0	<b>2</b>
W25	50.945	69.016	0	0	1	0	<b>1</b>
W12,5	50.955	68.719	0	2	2	1	<b>5</b>
W6	50.966	68.587	0	3	2	1	<b>6</b>
W3	50.970	68.511	0	3	1	1	<b>5</b>
W1,5	50.976	68.435	0	2	1	3	<b>6</b>
EW0	50.979	68.354	0	1	3	5	<b>9</b>
E50	51.069	67.171	0	1	0	0	<b>1</b>
E100	51.152	66.028	2	3	3	2	<b>10</b>
E200	51.303	63.765	1	3	0	0	<b>4</b>
E400	51.618	59.150	3	0	0	0	<b>3</b>
SN1	46.777	72.976	0	0	0	0	<b>0</b>
SN2	48.162	73.010	0	0	2	1	<b>3</b>
SN3	49.557	73.037	0	0	2	0	<b>2</b>
SN4	50.964	73.065	0	1	0	0	<b>1</b>
SN5	52.362	73.092	2	0	1	4	<b>7</b>
SN6	53.755	73.120	5	2	1	7	<b>15</b>
SN7	55.138	73.147	6	1	0	0	<b>7</b>
SN8	56.535	73.180	8	4	0	4	<b>16</b>
SN9	57.833	73.205	4	3	0	5	<b>12</b>
<b>Total</b>			<b>31</b>	<b>30</b>	<b>20</b>	<b>34</b>	<b>115</b>

**Table S2. Characteristics of the analytical methods.** Method detection limits are the instrument detection limits corrected for dilution and weighing. Instrument detection limits represent three times a blank standard deviation. Replicability and repeatability are standard error of the same sample repeated intra-day and inter-day. Apparent recovery was obtained with addition of standard at a concentration between 50% and 150% of the sample concentration, except for Ca, K (10%) and Mg (25%).

	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>Method Detection Limits (ppm)</b>	-	12.5	12.5	5	50	12.5	25	1.25	0.025	0.075	0.5	0.5	0.025	0.125	0.125	1.25	0.025	0.025	0.025
<b>Replicability (%)</b>	5	-	2.1	0.7	2.2	-	-	11.8	1.9	1.1	0.6	6.2	3.3	1.6	1.4	3.6	2.9	2.8	0.9
<b>Repeatability (%)</b>	3	-	18.6	1.8	4.1	-	-	26.5	4.5	4.4	6.1	17.6	12.2	4.6	6.5	1.5	0.8	2.6	1.4
<b>Apparent recovery (%)</b>	-	0.99	1.01	1.03	1.26	-	1.00	0.98	1.04	1.09	1.12	0.97	1.07	1.06	1.06	1.10	1.03	1.01	0.80
<b>SLRS 5</b>																			
<b>Certified value</b>	-	5380	2540	49.5	-	839	10500	-	0.315	0.208	4.33	91.2	0.05	0.476	17.4	0.845	0.5	0.006	0.081
<b>Tolerance</b>	-	0.4	160	5	-	36	400	-	0.033	0.023	0.18	5.8	-	0.064	1.3	0.095	-	0.001	0.006
<b>Average</b>	11	5316	2612	47.39	-	833.2	10546	-	0.341	0.208	3.954	97.94	0.053	0.525	16.76	0.967	0.426	0.008	0.073
<b>Repeatability (%)</b>		20.0	6.2	-	14.8	22.8	-	11.5	13.7	4.0	5.9	4.6	5.2	3.6	35.2	43.8	6.6	5.3	
<b>Accuracy (%)</b>	-	0.99	0.97	0.96	-	0.99	1.00	-	0.92	1.00	0.91	0.93	0.95	0.90	0.96	0.86	0.85	0.59	0.90

**Table S3. Elemental concentration at each site (see Fig. 1).** Data from all lichen-forming species were pooled for each site. Data are reported in µg of element per g of oven dry weight lichen (µg.g<sup>-1</sup>, dry weight) as median ± median absolute deviation for each site.

Sites	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>W400- W100</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W50</b>	2	163±120	457±29	28±6	818±59	6008±781	910±44	1±0	0.16±0.05	0.11±0.02	62±12	38±1	0.03±0.01	1.4±0.8	3.6±1.0	17±3	0.03±0.00	0.12±0.08	0.12±0.05
<b>W25</b>	1	198	570	24	2615	9586	919	1	0.24	0.11	345	50	0.09	1.4	5.5	37	0.04	0.08	0.21
<b>W12.5</b>	5	316±70	522±68	54±19	1773±313	8297±762	1203±234	2±0	0.34±0.06	0.18±0.03	218±56	69±4	0.19±0.11	1.0±0.5	4.9±1.4	40±8	0.04±0.01	0.09±0.03	0.26±0.01
<b>W6</b>	6	123±67	456±74	43±12	1731±488	6146±1081	757±40	2±1	0.24±0.05	0.16±0.03	320±57	60±12	0.08±0.03	0.7±0.2	4.4±1.2	39±7	0.03±0.01	0.04±0.00	0.28±0.05
<b>W3</b>	5	135±77	482±39	43±18	1417±305	8088±374	818±90	2±0	0.24±0.02	0.17±0.02	224±52	69±9	0.07±0.01	0.8±0.4	4.5±0.3	32±12	0.05±0.01	0.04±0.01	0.21±0.06
<b>W1.5</b>	6	61±8	473±62	36±9	1587±330	7677±279	717±73	2±1	0.15±0.01	0.18±0.03	210±50	59±2	0.04±0.01	0.7±0.2	2.4±0.3	34±12	0.04±0.01	0.04±0.01	0.25±0.05
<b>EW0</b>	9	176±85	521±94	48±12	1386±178	7055±685	825±76	3±1	0.26±0.08	0.15±0.02	183±31	88±14	0.09±0.04	1.5±0.3	4.3±0.7	75±43	0.04±0.01	0.05±0.01	0.24±0.05
<b>E50</b>	1	188	518	36	824	7263	818	1	0.21	0.16	294	66	0.03	0.6	4.6	31	0.03	0.04	0.48
<b>E100</b>	10	75±35	413±54	24±4	1151±185	5574±1106	662±155	1±0	0.16±0.02	0.09±0.04	152±39	44±5	0.06±0.03	0.5±0.2	2.5±0.5	36±12	0.05±0.01	0.03±0.00	0.32±0.09
<b>E200</b>	4	91±37	480±34	30±5	1590±210	8044±364	1045±124	1±0	0.17±0.01	0.12±0.01	93±17	33±6	0.06±0.01	0.5±0.1	3.2±0.2	27±7	0.03±0.00	0.03±0.01	0.64±0.08
<b>E400</b>	3	131±28	458±136	35±14	1713±62	6586±633	623±37	1±0	0.16±0.02	0.10±0.00	86±2	30±6	0.10±0.07	0.3±0.1	3.2±1.2	42±1	0.04±0.02	0.08±0.02	0.29±0.07
<b>SN1</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN2</b>	3	190±8	1283±75	1448±107	1983±43	8496±1349	2121±13	64±1	6.48±0.03	2.46±0.08	184±15	4224±338	1.25±0.25	2.4±0.3	6.7±0.4	32±5	0.18±0.02	0.05±0.00	0.83±0.05
<b>SN3</b>	2	90	687±164	586±182	1462±213	7708	1551	63±12	2.02±0.29	1.35±0.32	301±126	978±222	0.61±0.11	2.5±0.0	6. 9±0.0	51±19	0.15±0.06	0.12±0.10	0.40±0.13
<b>SN4</b>	1	-	533	22	1472	-	-	4	0.14	0.17	504	18	0.03	0.3	4.8	39	0.04	0.12	0.20
<b>SN5</b>	7	40±19	482±106	33±13	1328±425	6365±857	689±165	1±1	0.13±0.03	0.12±0.04	178±55	53±7	0.07±0.04	1.6±0.5	6.3±3.2	48±22	0.05±0.01	0.07±0.02	0.36±0.11
<b>SN6</b>	15	90±36	356±66	35±8	1060±399	6563±891	658±120	1±0	0.15±0.02	0.16±0.02	131±65	50±18	0.04±0.01	0.8±0.2	4.7±1.7	56±16	0.06±0.01	0.06±0.02	0.46±0.13
<b>SN7</b>	7	23±9	347±34	26±8	1135±44	6752±586	632±99	1±0	0.10±0.02	0.13±0.01	84±32	36±6	0.03±0.02	0.4±0.1	3.5±0.9	35±6	0.04±0.02	0.07±0.01	0.29±0.15
<b>SN8</b>	16	42±25	395±103	40±12	1266±326	5892±305	699±231	1±1	0.12±0.02	0.15±0.03	68±32	44±9	0.04±0.02	0.5±0.2	3.3±1.2	45±13	0.05±0.02	0.07±0.02	0.33±0.11
<b>SN9</b>	12	69±35	593±154	65±23	2382±317	5910±608	557±138	4 ±3	0.19±0.05	0.22±0.08	68±31	75±28	0.13±0.06	0.8±0.3	4.3±1.0	43±14	0.09±0.03	0.05±0.02	0.56±0.31

**Table S4. Elemental concentration at each site for *Nephroma arcticum*.** Data are reported in µg of element per g of oven dry weight lichen (µg.g<sup>-1</sup>, dry weight) as median ± median absolute deviation for each site.

Sites	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>W400 - W100</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W50</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W25</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W12.5</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W6</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W3</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W1.5</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>EW0</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E50</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E100</b>	2	<13	359±5	33±8	1235±127	7541	449	3±2	0.22±0.05	0.21±0.01	389±220	47±5	0.08±0.02	0.5±0.2	3.3±0.9	93±47	0.05±0.01	0.51±0.49	0.57±0.20
<b>E200</b>	1	-	451	33	2028	-	-	2	0.18	0.12	77	39	0.06	0.6	3.0	40	0.03	0.04	0.60
<b>E400</b>	3	131±28	458±136	35±14	1713±62	6586±633	623±37	1±0	0.16±0.02	0.10±0.00	89±2	30±6	0.09±0.07	0.3±0.1	3.2±1.2	42±1	0.04±0.02	0.08±0.02	0.29±0.07
<b>SN1</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN2</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN3</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN4</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN5</b>	2	36±24	248±31	55±18	814±89	6085±279	471±216	1±0	0.19±0.06	0.18±0.02	113±65	71±18	0.06±0.02	0.4±0.1	2.8±0.6	36±10	0.06±0.02	0.09±0.03	0.54±0.20
<b>SN6</b>	5	54±21	250±52	43±11	767±36	6541±649	540±30	2±0	0.15±0.02	0.18±0.03	46±7	42±13	0.05±0.01	0.6±0.1	2.6±0.3	41±9	0.04±0.01	0.05±0.01	0.41±0.13
<b>SN7</b>	6	21±4	342±22	31±10	1131±30	6764±304	623±59	1±1	0.10±0.03	0.13±0.02	76±20	38±5	0.05±0.02	0.4±0.2	3.1±0.5	36±6	0.04±0.01	0.07±0.02	0.24±0.08
<b>SN8</b>	8	30±13	348±26	36±6	996±116	5884±66	599±181	1±0	0.11±0.01	0.13±0.01	47±23	42±4	0.04±0.01	0.4±0.1	2.9±0.3	35±13	0.04±0.01	0.06±0.02	0.33±0.11
<b>SN9</b>	4	39±5	439±30	134±72	1130±118	6298±304	477±55	6±3	0.25±0.09	0.23±0.08	37±3	114±58	0.29±0.10	0.5±0.1	2.9±0.3	37±4	0.09±0.01	0.06±0.01	0.47±0.14

**Table S5. Elemental concentration at each site for *Peltigera aphthosa* s.l..** Data are reported in µg of element per g of oven dry weight lichen (µg.g<sup>-1</sup>, dry weight) as median ± median absolute deviation for each site.

Sites	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>W400- W100</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W50</b>	1	42	428	34	759	5227	867	1	0.11	0.13	74	36	<0.03	0.6	2.6	14	0.03	0.04	0.17
<b>W25</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W12.5</b>	2	386±37	521±76	90±36	1617±156	8163±1406	1497±511	4±2	0.38±0.05	0.22±0.04	277±59	110±45	0.16±0.11	0.6±0.1	3.5±1.3	33±3	0.04±0.00	0.12±0.01	0.46±0.20
<b>W6</b>	3	191±3	405±27	60±16	1508±154	6146±154	717±34	3±1	0.25±0.03	0.18±0.03	293±18	76±22	0.10±0.01	0.6±0.0	5.5±2.3	38±4	0.05±0.01	0.04±0.01	0.34±0.09
<b>W3</b>	3	135±39	469±26	62±6	842±138	6755±1662	912±163	3±0	0.21±0.06	0.18±0.03	224±52	78±5	0.04±0.00	0.6±0.2	2.6±0.5	20±3	0.05±0.01	0.04±0.01	0.27±0.05
<b>W1.5</b>	2	79±27	519±53	41±5	1702±4	7705±267	717±21	2±1	0.14±0.00	0.18±0.03	206±8	60±3	0.05±0.00	0.4±0.0	2.4±0.2	22±1	0.06±0.03	0.20±0.16	0.20±0.00
<b>EW0</b>	1	483	477	94	1386	6935	905	6	0.39	0.19	183	109	0.09	0.4	4.3	30	0.06	0.10	0.32
<b>E50</b>	1	188	518	36	824	7263	818	1	0.21	0.16	294	66	0.03	0.6	4.6	31	0.03	0.04	0.48
<b>E100</b>	3	109±26	449±121	22±6	1309±116	7189±1405	806±191	1±0	0.13±0.01	0.12±0.01	194±82	35±10	0.06±0.01	0.4±0.1	3.4±0.6	27±5	0.03±0.00	0.03±0.00	0.39±0.17
<b>E200</b>	3	91±37	508±68	28±5	1438±116	8044±364	1045±124	1±0	0.16±0.02	0.12±0.01	110±34	27±1	0.06±0.02	0.4±0.0	3.4±0.3	22±3	0.04±0.00	0.03±0.00	0.68±0.15
<b>E400</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN1</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN2</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN3</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN4</b>	1	-	533	22	1472	-	-	4	0.14	0.17	504	18	0.03	0.3	4.8	39	0.04	0.12	0.20
<b>SN5</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN6</b>	2	288	390±67	49±18	1334±165	6585	871	2±0	0.23±0.04	0.17±0.00	103±37	54±12	0.31±0.28	0.8±0.1	14.3±9.6	40±1	0.06±0.01	0.18±0.14	0.85±0.07
<b>SN7</b>	1	341	428	23	1362	5039	773	1	0.08	0.14	164	27	<0.03	0.4	23.7	29	0.03	0.05	0.57
<b>SN8</b>	4	155±17	585±102	44±6	1254±332	5385±697	1244±425	1±1	0.13±0.03	0.15±0.01	111±8	48±5	0.03±0.01	0.5±0.1	4.8±0.3	32±14	0.06±0.02	0.07±0.03	0.55±0.24
<b>SN9</b>	3	210	1107±397	107±49	2193±714	4432	1532	9±3	0.32±0.17	1.13±0.14	179±107	81±17	0.13±0.00	0.9±0.2	5.1±1.2	53±16	0.05±0.03	0.07±0.05	1.50±0.80

**Table S6. Elemental concentration at each site for *Peltigera neopolydactyla* s.l.** Data are reported in µg of element per g of oven dry weight lichen (µg.g<sup>-1</sup>, dry weight) as median±median absolute deviation for each site.

Sites	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>W400- W100</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W50</b>	1	283	486	23	877	6790	954	2	0.21	0.08	50	39	0.04	2.2	4.7	21	0.03	0.20	0.08
<b>W25</b>	1	198	570	24	2615	9586	9190	1	0.24	0.11	345	50	0.09	1.4	5.5	37	0.04	0.08	0.21
<b>W12.5</b>	2	180	513±9	52±21	3021±361	5065	771	2±0	0.32±0.04	0.14±0.06	139±28	78±13	0.28±0.09	2.3±0.2	6.6±0.3	44±4	0.04±0.01	0.07±0.02	0.23±0.01
<b>W6</b>	2	88	439±87	32±10	1667±692	8349	818	5±3	0.23±0.07	0.14±0.05	515±184	48±5	0.13±0.10	1.2±0.4	3.3±0.9	31±10	<0.03	0.04±0.00	0.21±0.10
<b>W3</b>	1	27	482	25	1417	8349	818	2	0.25	0.07	238	64	0.09	1.4	4.5	32	0.04	0.04	0.05
<b>W1.5</b>	1	68	320	36	749	4067	743	2	0.16	0.21	366	57	0.04	0.6	1.8	21	0.06	0.03	0.68
<b>EW0</b>	3	91±1	521±27	37±2	1282±56	7175±931	807±63	3±1	0.33±0.03	0.15±0.02	136±3	76±12	0.20±0.07	1.5±0.2	3.7±0.3	24±1	0.03±0.00	0.06±0.02	0.20±0.02
<b>E50</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E100</b>	3	67±2	436±21	27±2	853±175	5365±678	751±41	1±0	0.16±0.01	0.07±0.00	121±5	45±0	0.08±0.04	1.0±0.2	2.0±0.2	27±4	0.03±0.00	0.03±0.00	0.15±0.05
<b>E200</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E400</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN1</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN2</b>	2	170±20	1198±161	1162±393	1718±265	8425±1420	1794±340	72±8	4.57±1.94	1.88±0.66	288±119	3069±1155	1.17±0.33	2.5±0.4	7.6±0.9	30±2	0.21±0.03	0.06±0.00	0.68±0.20
<b>SN3</b>	2	90	687±164	586±182	1462±213	586	1462	63±12	2.02±0.29	1.35±0.32	301±126	978±222	0.61±0.11	2.5±0.0	6.9±0.0	51±19	0.15±0.06	0.12±0.10	0.40±0.13
<b>SN4</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN5</b>	1	58	360	33	743	3942	1097	1	0.11	0.07	122	46	0.08	1.1	3.1	21	0.04	0.05	0.25
<b>SN6</b>	1	54	356	19	648	4466	718	1	0.08	0.10	91	30	0.55	0.8	2.4	22	0.16	0.10	0.15
<b>SN7</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN8</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN9</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

**Table S7. Elemental concentration at each site for *Peltigera scabrosa* s.l.** Data are reported in µg of element per g of oven dry weight lichen (µg.g<sup>-1</sup>, dry weight) as median ± median absolute deviation for each site.

Sites	n	Na	Mg	Al	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Cd	Pb
<b>W400- W100</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W50</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W25</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>W12.5</b>	1	284	591	48	1763	8046	950	2	0.28	0.15	274	69	0.07	1.0	3.5	91	0.05	0.08	0.26
<b>W6</b>	1	50	507	36	1954	8828	757	2	0.19	0.13	530	67	0.07	1.1	4.7	90	0.03	0.07	0.26
<b>W3</b>	1	213	528	43	1624	8088	728	2	0.24	0.17	157	69	0.07	1.2	4.5	70	0.07	0.05	0.21
<b>W1.5</b>	3	54	479±32	28±7	1474±531	7916±23	597±307	2±2	0.15±0.03	0.17±0.02	206±84	60±4	0.04±0.01	0.9±0.0	2.8±0.7	64±19	0.03±0.00	0.04±0.01	0.29±0.01
<b>EW0</b>	5	-	540±113	48±10	1564±395	6717±685	815±55	2±0	0.23±0.05	0.14±0.01	195±16	88±10	0.08±0.03	1.6±0.3	5.1±0.8	106±14	0.04±0.00	0.05±0.00	0.24±0.03
<b>E50</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E100</b>	2	-	381±111	19±4	1054±37	4517±379	431±87	<1	0.16±0.03	0.06±0.01	100±35	38±5	0.03±0.00	0.6±0.1	2.4±0.1	50±9	0.05±0.00	<0.03	0.32±0.00
<b>E200</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>E400</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN1</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN2</b>	1	198	1283	1448	2026	8496	2121	63	6.48	2.46	184	4562	1.25	2.4	6.3	61	0.16	0.05	0.83
<b>SN3</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN4</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN5</b>	4	23	569±12	20±1	1510±177	7397±440	771±84	<1	0.12±0.01	0.10±0.02	224±53	50±7	0.08±0.05	1.9±0.2	8.4±1.9	96±40	0.08±0.04	0.08±0.01	0.37±0.09
<b>SN6</b>	7	92±5	422±70	28±6	1459±186	6669±958	758±159	1±0	0.14±0.02	0.14±0.03	187±35	57±3	0.04±0.01	1.5±0.5	5.9±0.4	104±27	0.06±0.01	0.07±0.01	0.46±0.08
<b>SN7</b>	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>SN8</b>	4	-	742±86	48±28	2185±837	6064±294	521±117	2±1	0.21±0.10	0.19±0.05	42±6	96±47	0.14±0.08	3.2±0.9	8.6±2.1	56±5	0.08±0.02	0.07±0.01	0.31±0.04
<b>SN9</b>	5	221	600±39	47±15	1685±392	5260±631	626±81	2±1	0.15±0.05	0.14±0.06	66±11	69±34	0.10±0.03	1.2±0.5	4.9±1.3	46±19	0.05±0.02	0.04±0.01	0.36±0.14

**Table S8. Baseline concentration of elements for *Nephroma arcticum*, *Peltigera aphthosa* s.l., *P. neopolydactyla* s.l. and *P. scabrosa* s.l. in Québec.** SN2 and SN3 were excluded from the dataset. Min: lowest value of the dataset, Max: highest value of the dataset, MED: median, MAD: median absolute deviation, GM: Geometric mean.

Lichen content ( $\mu\text{g.g}^{-1}\text{DW Lichen}^{-1}$ )																
	<i>N. arcticum</i> (n=31)				<i>P. aphthosa</i> s.l. (n=30)				<i>P. neopolydactyla</i> s.l. (n=16)				<i>P. scabrosa</i> s.l. (n=33)			
Element	Min	Max	MED±MAD	GM	Min	Max	MED±MAD	GM	Min	Max	MED±MAD	GM	Min	Max	MED±MAD	GM
<b>Na</b>	<13	213	36 ± 19	40	42	483	155 ± 55	156	27	395	89 ± 33	105	23	284	92 ± 42	98
<b>Mg</b>	133	593	347 ± 55	331	323	1597	493 ± 83	533	320	570	469 ± 67	439	271	1031	561 ± 79	547
<b>Al</b>	10	213	40 ± 13	40	17	176	46 ± 17	47	19	73	30 ± 7	31	15	515	34 ± 13	35
<b>P</b>	543	2028	1091 ± 195	1093	704	3435	1449 ± 265	1410	648	3382	1182 ± 383	1258	653	4995	1474 ± 305	1548
<b>K</b>	3748	9041	6365 ± 473	6297	4432	10898	6757 ± 1286	6665	3942	9586	6304 ± 1709	6101	4138	8828	6306 ± 1028	6414
<b>Ca</b>	255	1243	540 ± 108	550	615	2009	905 ± 166	963	710	1419	812 ± 81	872	290	1411	695 ± 148	666
<b>Ti</b>	<1	21	2 ± 1	2	<1	12	2 ± 1	2	1	8	2 ± 1	2	<1	80	1 ± 1	1
<b>V</b>	0.07	0.58	0.15 ± 0.04	0.15	0.08	0.6	0.18 ± 0.06	0.19	0.08	0.36	0.22 ± 0.06	0.21	0.10	2.2	0.16 ± 0.04	0.18
<b>Cr</b>	0.10	0.68	0.15 ± 0.03	0.16	0.10	1.27	0.17 ± 0.03	0.20	<0.08	0.21	0.09 ± 0.02	0.10	<0.08	1.43	0.14 ± 0.03	0.14
<b>Mn</b>	19	610	69 ± 29	71	58	1206	181 ± 74	174	50	699	137 ± 34	168	34	530	170 ± 55	140
<b>Fe</b>	24	311	42 ± 12	50	18	190	56 ± 20	55	30	102	55 ± 10	56	33	880	59 ± 10	67
<b>Co</b>	<0.03	0.65	0.06 ± 0.03	0.07	<0.03	0.59	0.05 ± 0.03	0.06	0.03	0.55	0.09 ± 0.05	0.11	0.03	0.79	0.05 ± 0.02	0.07
<b>Ni</b>	0.2	2.0	0.5 ± 0.2	0.5	0.2	1.1	0.5 ± 0.1	0.5	0.5	2.5	1.3 ± 0.5	1.2	0.5	4.7	1.5 ± 0.5	1.5
<b>Cu</b>	1.9	8.8	2.9 ± 0.4	3.0	2.1	23.8	4.1 ± 1.0	4.4	1.8	6.8	3.9 ± 1.2	3.6	2.1	16.7	5.6 ± 1.9	5.6
<b>Zn</b>	17	140	40 ± 8	41	12	68	30 ± 9	29	20	83	26 ± 5	30	27	166	70 ± 23	75
<b>Mo</b>	<0.03	0.20	0.04 ± 0.01	0.05	<0.03	0.16	0.04 ± 0.01	0.05	<0.03	0.16	0.03 ± 0.01	0.04	0.03	0.33	0.05 ± 0.01	0.06
<b>Cd</b>	<0.03	1.00	0.06 ± 0.02	0.07	<0.03	0.35	0.04 ± 0.02	0.06	<0.03	0.20	0.04 ± 0.02	0.05	<0.03	0.17	0.05 ± 0.02	0.06
<b>Pb</b>	0.14	1.10	0.37 ± 0.15	0.39	0.17	3.02	0.43 ± 0.23	0.46	0.05	0.68	0.21 ± 0.06	0.18	0.09	1.47	0.32 ± 0.07	0.33

**Table S9. Comparison of metal content from the entire thallus versus the margin of the thallus for *Nephroma arcticum*, *Peltigera aphthosa* s.l., and *P. scabrosa* s.l. (see method section for details).** Results are expressed as median  $\pm$  median absolute deviation. Element contents are reported in  $\mu\text{g}$  of element per g of oven dry weight lichen ( $\mu\text{g}\cdot\text{g}^{-1}$ , dry weight). Percentages are expressed with regard to the value from the entire lichen thallus. An asterisk indicates when data for one element was missing (K and Ca in entire thallus).

<i>N. arcticum</i> n=6 (*n=5)			<i>P. aphthosa</i> n=4 (*n=3)			<i>P. scabrosa</i> n=4 (*n=3)			
Element	margin	entire	%	margin	entire	%	margin	entire	%
<b>Mg</b>	540 $\pm$ 105	362 $\pm$ 27	49	694 $\pm$ 201	468 $\pm$ 134	48	596 $\pm$ 54	526 $\pm$ 58	13
<b>Al</b>	14 $\pm$ 8	24 $\pm$ 3	-42	16 $\pm$ 6	22 $\pm$ 1	-27	14 $\pm$ 3	16 $\pm$ 2	-13
<b>P</b>	1896 $\pm$ 911	1018 $\pm$ 145	86	2027 $\pm$ 718	1400 $\pm$ 181	45	1896 $\pm$ 403	1512 $\pm$ 495	25
<b>K</b>	10294 $\pm$ 1228	6775 $\pm$ 1297*	52	8702 $\pm$ 1596	7680 $\pm$ 1356*	13	9589 $\pm$ 2465	7222 $\pm$ 521*	33
<b>Ca</b>	566 $\pm$ 129	632 $\pm$ 196*	-10	930 $\pm$ 433	921 $\pm$ 112*	1	676 $\pm$ 53	685 $\pm$ 250*	-1
<b>Ti</b>	1 $\pm$ 0	1 $\pm$ 0	0	1 $\pm$ 0	1 $\pm$ 0	0	<1 $\pm$ 0	<1 $\pm$ 0	-
<b>V</b>	0.07 $\pm$ 0.03	0.08 $\pm$ 0.01	-13	0.17 $\pm$ 0.11	0.12 $\pm$ 0.01	42	0.17 $\pm$ 0.04	0.12 $\pm$ 0.02	42
<b>Cr</b>	0.20 $\pm$ 0.05	0.13 $\pm$ 0.01	54	0.17 $\pm$ 0.05	0.12 $\pm$ 0.01	42	0.15 $\pm$ 0.06	0.08 $\pm$ 0.03	88
<b>Mn</b>	75 $\pm$ 43	72 $\pm$ 47	4	159 $\pm$ 118	137 $\pm$ 79	16	135 $\pm$ 62	169 $\pm$ 119	-20
<b>Fe</b>	26 $\pm$ 11	28 $\pm$ 4	-7	24 $\pm$ 9	26 $\pm$ 1	-8	34 $\pm$ 2	40 $\pm$ 5	-15
<b>Co</b>	0.01 $\pm$ 0.01	0.03 $\pm$ 0.01	-67	<0.03 $\pm$ 0.01	0.03 $\pm$ 0.00	-	0.05 $\pm$ 0.06	0.06 $\pm$ 0.04	-17
<b>Ni</b>	0.2 $\pm$ 0.0	0.3 $\pm$ 0.08	-33	0.6 $\pm$ 0.3	0.4 $\pm$ 0.1	50	3.0 $\pm$ 0.3	1.6 $\pm$ 0.8	88
<b>Cu</b>	4.5 $\pm$ 1.3	2.5 $\pm$ 0.4	80	5.1 $\pm$ 2.4	3.8 $\pm$ 1.3	34	9.3 $\pm$ 2.2	6.9 $\pm$ 5.9	35
<b>Zn</b>	36 $\pm$ 13	28 $\pm$ 8	29	29 $\pm$ 15	24 $\pm$ 6	21	93 $\pm$ 24	98 $\pm$ 64	-5
<b>Mo</b>	0.03 $\pm$ 0.01	0.04 $\pm$ 0.01	-25	0.03 $\pm$ 0.01	0.03 $\pm$ 0.00	0	0.04 $\pm$ 0.02	0.05 $\pm$ 0.02	-20
<b>Cd</b>	0.26 $\pm$ 0.15	0.06 $\pm$ 0.01	333	0.07 $\pm$ 0.04	0.03 $\pm$ 0.01	133	0.12 $\pm$ 0.07	0.07 $\pm$ 0.04	71
<b>Pb</b>	0.11 $\pm$ 0.03	0.19 $\pm$ 0.04	-42	0.22 $\pm$ 0.03	0.48 $\pm$ 0.26	-54	0.36 $\pm$ 0.05	0.37 $\pm$ 0.04	-3

**Table S10. Comparison of element concentrations for the whole thallus versus the  $\leq 5$  mm wide margin of the thallus.** (A) Data are averaged for all species (*Nephroma arcticum* n = 6 [\*n = 5], *Peltigera aphthosa* s.l. n = 4 [\*n = 3], *Peltigera scabrosa* s.l. n = 4 \*n = 3]). \* indicates that K and Ca were not analyzed in one sample (whole thallus). MED = Median. MAD = Median absolute deviation. Elements are sorted by increasing atomic weights. Element contents are expressed in  $\mu\text{g.g}^{-1}$ , dry weight. Percentages are expressed with respect to the entire lichen values. (B) P-values of a two-way ANOVA with interaction on clr transformed data with thallus part as first factor and species as the second factor. Only significant results for thallus part are shown.

**A**

	Margin of thalli		Whole thalli <sup>§</sup>		Difference
	MED $\pm$ MAD ( $\mu\text{g.g}^{-1}$ )		MED $\pm$ MAD ( $\mu\text{g.g}^{-1}$ )		
<b>Mg</b>	599	$\pm$ 140	424	$\pm$ 107	41
<b>Al</b>	14	$\pm$ 7	22	$\pm$ 5	-36
<b>P</b>	1896	$\pm$ 552	1266	$\pm$ 416	50
<b>K</b>	9646	$\pm$ 2300	7612	$\pm$ 1083*	24
<b>Ca</b>	666	$\pm$ 215	684	$\pm$ 168*	-3
<b>Ti</b>	1	$\pm$ 1	1	$\pm$ 0	0
<b>V</b>	0.12	$\pm$ 0.08	0.10	$\pm$ 0.04	20
<b>Cr</b>	0.19	$\pm$ 0.07	0.12	$\pm$ 0.03	58
<b>Mn</b>	102	$\pm$ 60	102	$\pm$ 79	0
<b>Fe</b>	33	$\pm$ 6	28	$\pm$ 5	-18
<b>Co</b>	0.02	$\pm$ 0.01	0.03	$\pm$ 0.01	-30
<b>Ni</b>	0.4	$\pm$ 0.4	0.4	$\pm$ 0.2	0
<b>Cu</b>	5.0	$\pm$ 2.7	3.2	$\pm$ 1.1	56
<b>Zn</b>	42	$\pm$ 27	29	$\pm$ 11	45
<b>Mo</b>	0.03	$\pm$ 0.01	0.03	$\pm$ 0.01	0
<b>Cd</b>	0.16	$\pm$ 0.13	0.06	$\pm$ 0.04	167
<b>Pb</b>	0.22	$\pm$ 0.17	0.30	$\pm$ 0.15	-27

**B**

Element	P value		
	Species	Thallus part	Interaction
<b>Mg</b>	0.18	<b>0.024</b>	0.43
<b>Al</b>	<0.001	<0.001	0.064
<b>P</b>	0.174	<b>0.004</b>	0.245
<b>K</b>	<b>0.002</b>	<b>0.019</b>	0.849
<b>Cr</b>	<0.001	<b>0.002</b>	0.819
<b>Fe</b>	0.022	<0.001	0.813
<b>Co</b>	0.326	0.005	0.776
<b>Cd</b>	<0.001	<0.001	0.060
<b>Pb</b>	<0.001	<0.001	0.198

## 5. Supplementary bibliography

- Aitchison J. A concise guide to compositional data analysis. 2nd CDA Work. Girona, Spain; 2003.
- Bergamaschi L, Rizzio E, Giaveri G, Profumo A, Loppi S, Gallorini M. Determination of baseline element composition of lichens using samples from high elevations. *Chemosphere*. 2004;55(7):933–9.
- Bindler R, Renberg I. Pb isotope ratios of lake sediments in West Greenland: inferences on pollution sources. *Atmos Environ*. 2001;35:4675–85.
- Buccianti A. Is compositional data analysis a way to see beyond the illusion? *Comput Geosci*. Elsevier; 2013;50:165–73.
- Filzmoser P, Hron K, Reimann C. Principal component analysis for compositional data with outliers. *Environmetrics*. 2009;20(6):621–32.
- Gouvernement du Québec. Cartes Minières [Internet]. 2013. Available from: <http://www.mrn.gouv.qc.ca/mines/publications/publications-cartes.jsp>
- Loppi S, Nelli L, Ancora S, Bargagli R. Accumulation of trace elements in the peripheral and central parts of a foliose lichen thallus. *Bryologist*. 1997;100(2):251–3.
- Monaci F, Fantozzi F, Figueroa R, Parra O, Bargagli R. Baseline element composition of foliose and fruticose lichens along the steep climatic gradient of SW Patagonia (Aisén Region, Chile). *J Environ Monit*. 2012;14(9):2309–16.
- Ranganathan Y, Borges RM. To transform or not to transform: That is the dilemma in the statistical analysis of plant volatiles. *Plant Signal Behav*. 2011;6(1):113–6.
- Simonetti A, Gariépy C, Carignan J. Pb and Sr isotopic compositions of snowpack from Quebec, Canada: inferences on the sources and deposition budgets of atmospheric heavy metals. *Geochim Cosmochim Acta*. 2000;64(1):5–20.
- Tolosana-Delgado R. Uses and misuses of compositional data in sedimentology. *Sediment Geol*. Elsevier B.V.; 2012;280:60–79.
- Ziembik Z, Dołęńczuk-Śródka A, Majcherczyk T, Wacławek M. Illustration of constrained composition statistical methods in the interpretation of radionuclide concentrations in the moss *Pleurozium schreberi*. *J Environ Radioact*. 2013;117:13–8.