Supporting Information: *Rare earth elements in freshwater, marine, and terrestrial ecosystems in the eastern Canadian Arctic*

Gwyneth Anne MacMillan (1), John Chételat (2), Joel Heath (3), Raymond Mickpegak (4), Marc Amyot (1, *)

1) Centre for Northern Studies, Department of Biological Sciences, University of Montreal, Montreal, QC, Canada, H2V 2S9

2) Environment and Climate Change Canada, National Wildlife Research Centre, Ottawa, ON, Canada, K1A 0H3

3) Arctic Eider Society, St. John's, NL, Canada, A1C 3Z6

4) Sakkuq Landholding Corporation, Kuujjuaraapik, QC, Canada, J0M 1G0

*Corresponding author: Marc Amyot. Phone: 514-343-7496. E-mail: m.amyot@umontreal.ca.

KEYWORDS:

Metals, Rare Earth Elements (REE), Lanthanide, Arctic, Subarctic, Bioaccumulation, Stable Isotope

TABLE S1: Mean detection limits for REEs based on 4 separate ICP-MS analytical runs.

Element	ICP-MS Detection Limits		
	µg/L	ng/g	nmol/g
Y	0.0002	0.1976	0.0022
La	0.0001	0.1442	0.0010
Ce	0.0001	0.1452	0.0010
Pr	0.0001	0.0604	0.0004
Nd	0.0003	0.2684	0.0019
Sm	0.0003	0.2576	0.0017
Eu	0.0001	0.1125	0.0007
Gd	0.0001	0.1398	0.0009
Tb	0.0000	0.0449	0.0003
Dy	0.0002	0.1540	0.0009
Ho	0.0000	0.0325	0.0002
Er	0.0000	0.0478	0.0003
Tm	0.0000	0.0315	0.0002
Yb	0.0001	0.0825	0.0005
Lu	0.0000	0.0143	0.0001

TABLE S2: REE concentrations in certified reference materials (with uncertainty) and measured values in standards (with standard deviations).

	STSD-1 (Creek Sediment)				**BCR 668 (Mussel Tissue)**				**BCR 670 (Aquatic Plant)**			
	nmolg-1 d.w.				pmolg-1 d.w.				pmolg-1 d.w.			
	Certified		**Measured (n=16)**		**Certified**		**Measured (n=16)**		**Certified**		**Measured (n=10)**	
Element	Mean	CI	Mean	SD	Mean	CI	Mean	SD	Mean	CI	Mean	SD
Y	472	± na	273	± 23	662	± 58	584	± 25	5196	± 776	4068	± 167
La	216	± na	163	± 16	578	± 48	476	± 35	3506	± 338	2705	± 284
Ce	364	± na	271	± 29	633	± 83	496	± 45	7044	± 443	5631	± 547
Pr	-	±	45	± 4.4	87	± 8.5	71	± 5.5	859	± 106	667	± 45
Nd	194	± na	183	± 18	378	± 41	321	± 27	3279	± 208	2764	± 229
Sm	40	± na	36	± 3.4	74	± 6.7	67	± 5.1	626	± 67	566	± 39
Eu	11	± na	7.5	± 0.7	18	± 1.6	16	± 1.2	153	± 16	177	± 6.0
Gd	-	±	37	± 3.1	82	± 6.0	82	± 8.2	622	± 85	622	± 26
Tb	8	± na	4.8	± 0.4	10	± 1.1	9.8	± 0.7	88	± 10	77	± 3.4
Dy	34	± na	25	± 2.0	55	± 3.7	45	± 3.1	486	± 54	406	± 24
Ho	-.	±	4.8	± 0.4	11	± 3.6	9.2	± 0.7	96	± 16	74	± 3.0
Er	-	±	14	± 1.2	27	± 2.9	24	± 2.0	263	± 27	218	± 14
Tm	-	±	1.8	± 0.2	2.8	± 0.4	2.5	± 0.4	34	± 5.5	27	± 1.0
Yb	23	± na	12	± 1.0	16	± 2.9	14	± 1.1	231	± 25	175	± 10
Lu	5	± na	1.9	± 0.2	2.2	± 0.2	2.1	± 0.2	36	± 3.9	24	± 0.9

TABLE S3: Detection frequencies for 15 individual REEs are shown by sampled taxonomic group. Mean detection frequencies for all elements by group are also shown. Sample sizes (N) and tissues are shown. Tissues include gonads (GON), muscle (MU), liver (LIV), and kidney (KID).

		Marine						Terrestrial							
		Sea Urchin	Blue Mussel	Common Eider		Ringed Seal		All Plants	Snowshoe Hare		Willow Ptarmigan		Caribou		
	N	5	9	16	16	23	23	17	6	6	9	9	5	6	6
	Tissue	GON	All	MU	LIV	MU	LIV	Leaves	MU	LIV	MU	LIV	MU	LIV	KID
LREE	La	1	1	0.25	1	0.52	0.96	1	0.83	1	0.78	1	0.80	1	0.83
	Ce	1	1	0.25	1	0.48	0.96	1	0.33	1	0.56	1	0.40	1	0.83
	Pr	1	1	0.25	1	0.39	0.96	1	0.50	1	0.67	1	0.60	1	0.83
	Nd	1	1	0.25	1	0.52	0.96	1	0.67	1	0.56	1	0.80	1	0.67
	Sm	1	1	0.25	1	0.13	1	1	0.33	1	-	1	0.40	1	0.67
	Eu	1	1	0.13	1	0.04	0.91	1	-	1	-	0.89	-	1	0.83
	Gd	1	1	0.25	0.50	0.52	0.96	1	0.50	1	0.33	1	0.20	1	1
HREE	Y	1	1	0.94	1	0.57	0.96	1	0.83	1	0.78	1	1	1	0.83
	Tb	1	1	0.25	0.94	0.04	0.96	1	0.33	1	0.11	1	-	1	0.67
	Dy	1	1	0.25	0.75	0.17	0.83	1	-	1	-	1	0.40	1	0.50
	Ho	1	1	0.19	0.31	0.09	0.78	1	-	0.83	-	0.78	-	0.83	0.17
	Er	1	1	0.25	0.88	0.17	0.87	1	0.33	1	-	1	0.20	0.83	0.67
	Tm	1	1	0.06	0.50	-	0.57	1	0.17	0.50	-	0.22	-	0.17	0.17
	Yb	1	1	0.25	0.69	0.13	0.83	1	0.17	0.67	0.33	0.67	-	0.50	0.67
	Lu	1	1	0.25	0.19	0.17	0.70	0.94	0.33	0.50	-	0.22	-	0.50	0.17
	Mean	1	1	0.27	0.78	0.26	0.88	1	0.44	0.90	0.51	0.85	0.32	0.86	0.63

TABLE S3 (Continued).

		Freshwater (River)		Freshwater (Lake)				
		Brook Trout	Whitefish	Benthos	Zooplankton	Brook Trout		
	N	6	22	17	19	60	60	
	Tissue	MU	MU	All	All	MU	LIV	Mean
LREE	La	0.33	0.45	1	1	0.85	0.98	0.83
	Ce	-	0.18	1	1	0.73	0.98	0.74
	Pr	0.50	0.41	1	1	0.77	0.98	0.79
	Nd	0.50	0.50	1	1	0.80	0.98	0.81
	Sm	0.50	0.27	1	1	0.28	0.97	0.73
	Eu	0.17	0.14	1	1	0.13	0.90	0.64
	Gd	-	0.23	1	1	0.42	0.97	0.72
HREE	Y	0.83	0.55	1	1	0.78	0.95	0.90
	Tb	-	0.23	1	1	0.28	0.97	0.63
	Dy	-	0.23	1	1	0.23	0.87	0.68
	Ho	-	0.14	1	1	0.27	0.83	0.58
	Er	-	0.23	1	1	0.45	0.95	0.66
	Tm	0.17	0.09	1	1	0.13	0.68	0.44
	Yb	-	0.18	1	1	0.17	0.82	0.55
	Lu	-	0.09	1	1	0.23	0.57	0.48
	Mean	0.20	0.26	1	1	0.44	0.89	

TABLE S4: Geometric means of individual elements (nmolg^{-1}) and total REE concentrations (∑REE, nmolg^{-1} and ngg^{-1}) for tissues of sampled taxonomic group from marine, terrestrial, and freshwater ecosystems. ∑REE concentrations are the sum of all REE, except scandium. Tissue type (muscle, liver) and samples sizes (N) are shown. Geometric means measure central tendency with high intra-group variation and are calculated as the antilog of the mean of the logarithmic values. Non-detected elements were included using values of 1/2 of the detection limit.

			nmol/g															nmol/g		mg/kg	
Ecosystem	**Tissue**	**N**	**Y**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	∑REE	SD	∑REE	SD
Marine																					
Sea Urchin	Gonad	5	2.929	5.017	4.323	0.699	2.392	0.331	0.053	0.353	0.035	0.164	0.032	0.098	0.012	0.074	0.011	16.67	7.57	2.21	0.99
Blue Mussel	Bulk	9	3.409	10.029	14.013	1.683	5.927	0.841	0.131	0.829	0.077	0.327	0.059	0.179	0.020	0.128	0.020	37.70	5.89	5.17	0.81
C. Eider	Muscle	16	0.005	0.007	0.013	0.002	0.005	0.003	0.001	0.003	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.055	4.938	0.008	0.693
C. Eider	Liver	5	0.009	0.129	0.102	0.012	0.044	0.007	0.001	0.005	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.332	0.304	0.046	0.043
Ringed Seal	Muscle	23	0.002	0.002	0.003	0.000	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.142	0.003	0.019
Ringed Seal	Liver	23	0.020	0.196	0.297	0.033	0.115	0.016	0.003	0.014	0.001	0.003	0.000	0.001	0.000	0.001	0.000	0.823	1.284	0.115	0.180
Terrestrial																					
Plants	Above ground	8	0.112	0.228	0.424	0.044	0.152	0.023	0.060	0.021	0.002	0.009	0.002	0.006	0.000	0.004	0.001	1.124	1.478	0.154	0.199
Lichen	Above ground	9	3.323	8.969	17.645	1.883	6.575	0.937	0.191	0.909	0.089	0.364	0.066	0.196	0.023	0.143	0.019	41.48	81.37	5.71	11.25
S. Hare	Muscle	6	0.003	0.004	0.002	0.001	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.160	0.003	0.023
S. Hare	Liver	6	0.030	1.723	2.119	0.181	0.551	0.048	0.006	0.049	0.002	0.004	0.000	0.003	0.000	0.001	0.000	4.729	5.995	0.663	0.841
Ptarmigan	Muscle	9	0.001	0.002	0.002	0.000	0.003	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.011	0.002	0.001
Ptarmigan	Liver	9	0.009	0.199	0.266	0.028	0.102	0.010	0.001	0.011	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.634	0.390	0.089	0.055
Caribou	Muscle	5	0.002	0.004	0.003	0.001	0.007	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.064	0.004	0.009
Caribou	Liver	6	0.012	0.135	0.211	0.023	0.076	0.010	0.002	0.010	0.001	0.002	0.000	0.001	0.000	0.001	0.000	0.487	0.367	0.068	0.052
River																					
Brook Trout	Muscle	6	0.006	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.089	0.002	0.008
Whitefish	Muscle	22	0.002	0.001	0.001	0.001	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.036	0.002	0.005
Lakes																					
Benthos	Bulk	17	2.280	9.943	11.886	1.552	4.912	0.605	0.157	0.634	0.059	0.219	0.040	0.125	0.013	0.085	0.012	33.54	85.05	4.62	11.67
Zooplankton	Bulk	19	9.187	28.349	34.786	5.383	17.980	2.190	0.423	2.106	0.210	0.896	0.164	0.519	0.060	0.376	0.054	103.8	484.6	14.24	66.30
Brook Trout	Muscle	60	0.003	0.006	0.010	0.002	0.004	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.041	0.153	0.006	0.021
Brook Trout	Liver	60	0.035	0.659	0.539	0.075	0.229	0.018	0.002	0.017	0.001	0.003	0.001	0.003	0.000	0.001	0.000	1.683	3.700	0.234	0.519

Table S5. Summary of total rare earth elements concentrations [ΣREE, geometric means] and stable nitrogen isotope values ($\delta^{15}N$ and adjusted $\delta^{15}N$ or $\delta^{15}N_{adj}$*) in biota from marine, terrestrial, and freshwater subarctic ecosystems in Nunavik, Quebec. ΣREE concentrations are the sum of all REE, except scandium.

Ecosystem	[ΣREE] (nmol/g)				[ΣREE] mg/kg)				$\delta^{15}N$ (‰)				$\delta^{15}N_{adj}$ (‰)*			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Marine																
Sea Urchin	16.67	7.57	11.18	30.44	2.21	0.99	1.47	4.01	6.04	0.22	5.72	6.34				
Blue Mussel	37.70	5.89	27.05	45.49	5.17	0.81	3.71	6.23	6.19	0.36	5.67	6.79				
Common Eider	0.055	4.938	0.005	19.85	0.008	0.693	0.001	2.786	10.21	0.61	9.61	11.47				
Ringed Seal	0.021	0.142	0.005	0.651	0.003	0.019	0.001	0.088	14.90	0.69	13.62	16.36				
Terrestrial																
Plants	1.124	1.478	0.410	4.870	0.154	0.199	0.056	0.657	-5.15	1.71	-7.64	-2.42				
Lichen	41.48	81.37	5.395	258.7	5.71	11.25	0.737	35.7	-3.44	0.83	-4.78	-1.92				
Snowshoe Hare	0.022	0.160	0.007	0.407	0.003	0.023	0.001	0.057	0.14	0.68	-0.80	0.73				
Ptarmigan	0.016	0.011	0.007	0.038	0.002	0.001	0.001	0.005	1.51	0.44	0.97	2.15				
Caribou	0.027	0.064	0.008	0.160	0.004	0.009	0.001	0.022	4.21	0.77	3.33	5.25				
River																
Brook Trout	0.016	0.089	0.006	0.228	0.002	0.008	0.001	0.021	14.69	0.21	14.42	14.96				
Whitefish	0.013	0.036	0.005	0.135	0.002	0.005	0.001	0.018	11.81	0.84	9.92	12.97				
Lakes																
Benthos	33.54	85.05	1.624	305.4	4.62	11.67	0.223	41.89	2.61	0.98	1.02	4.58	1.99	1.29	0.16	4.97
Zooplankton	103.8	484.6	22.75	1395	14.24	66.30	3.12	190.8	3.41	0.72	2.14	4.24	2.61	0.86	1.53	4.26
Brook Trout	0.041	0.153	0.005	0.823	0.006	0.021	0.001	0.116	8.16	0.85	5.82	10.25	7.15	1.07	5.21	9.39

*See "Methods" for an explanation of $\delta^{15}N$ adjustment.
**SD = standard deviation; SD is shown only for results where $n \geq 3$.

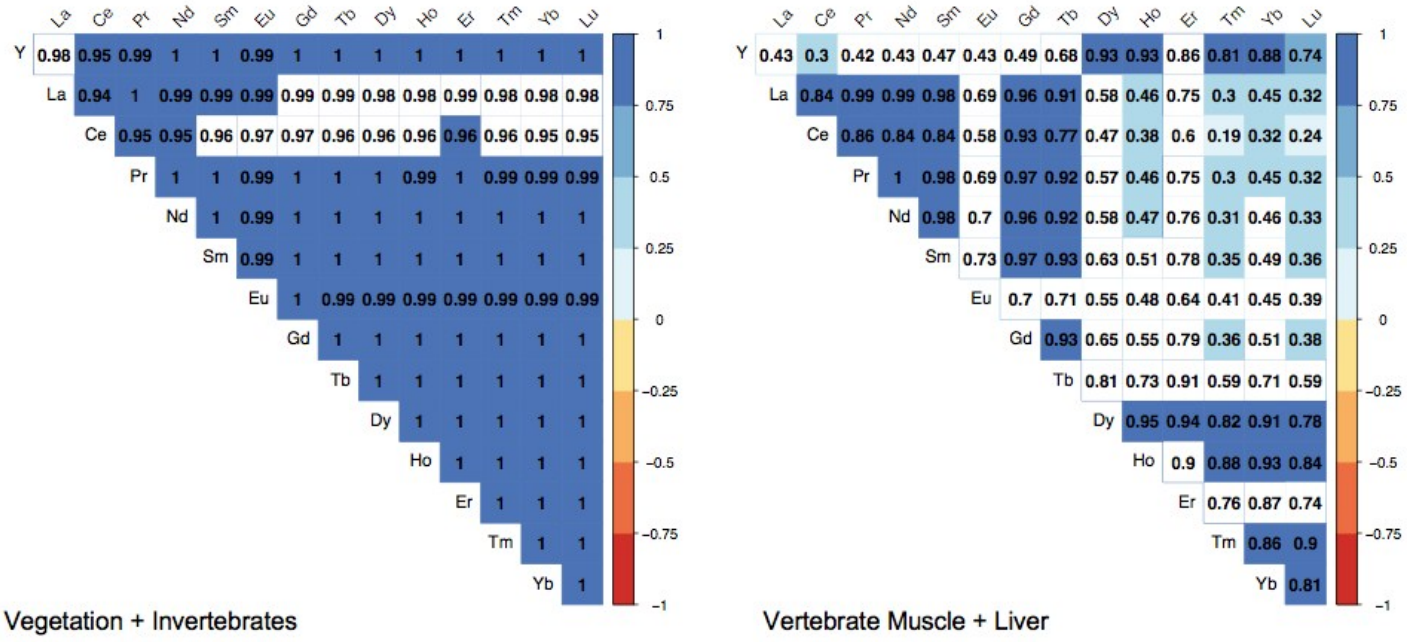
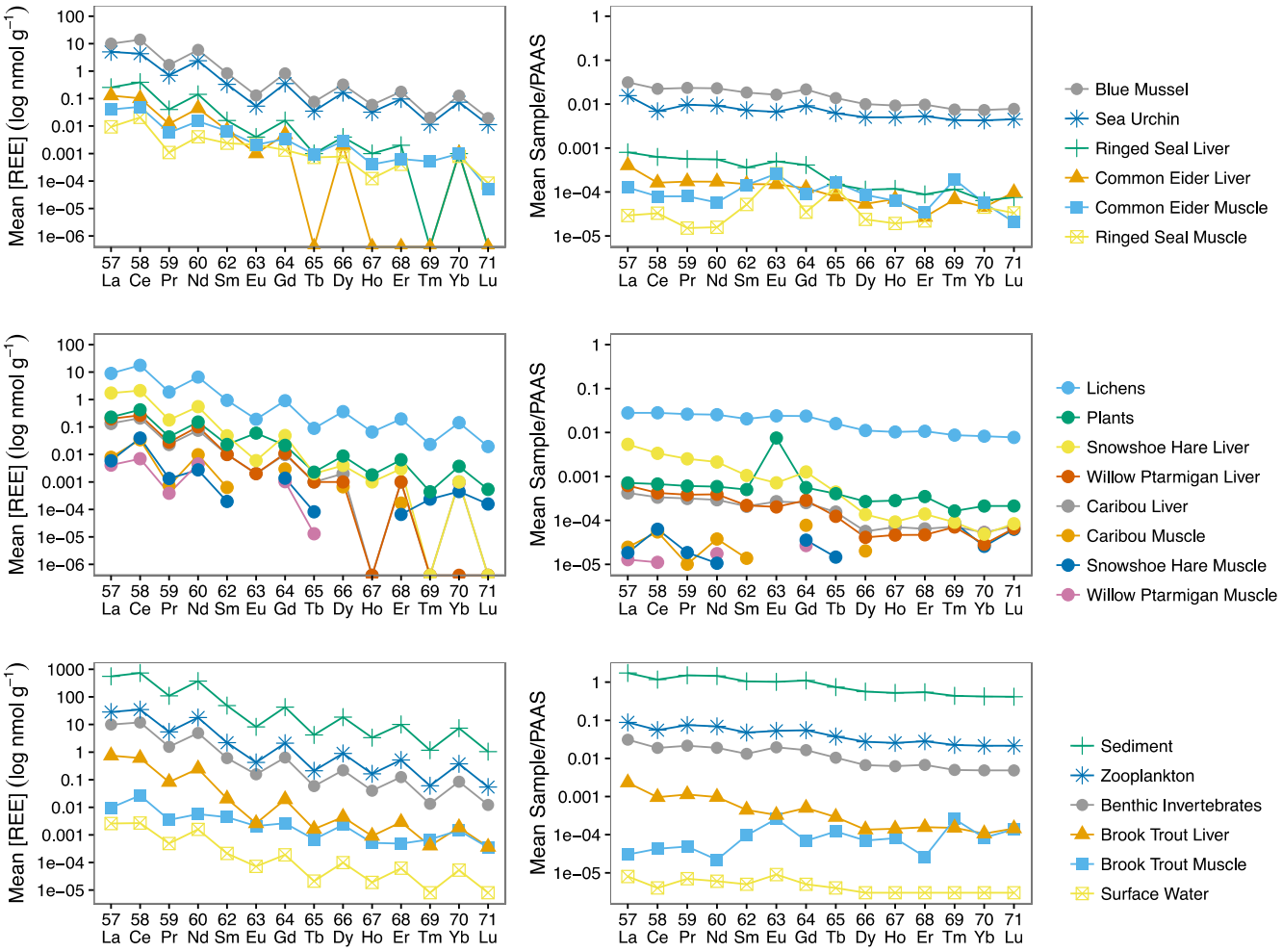


FIGURE S1: Pearson correlation matrices with Holm adjusted probabilities. Positive correlations are shown in blue, negative correlations in red, and colour intensity is proportional to the correlation coefficients (which are shown in black). Non-significant correlations are shown in white ($p > 0.05$).) Samples are from vegetation and invertebrates (left panel, N = 70) and vertebrate muscle and liver tissues (right panel, N = 256).



FIGU

RE S2: REE concentration versus atomic number for biotic and abiotic component from all ecosystems. Left panels are mean [REE] (log-scaled geometric means, nmolg^{-1}) showing the pattern of log-linear or saw-tooth decrease with atomic number. Right panels are PAAS-normalized REE concentrations (log-scaled, geometric means nmolg^{-1}/PAAS nmolg^{-1}). Points show element means for each taxonomic group and samples below detection limits were excluded from figure (e.g. muscle tissues).

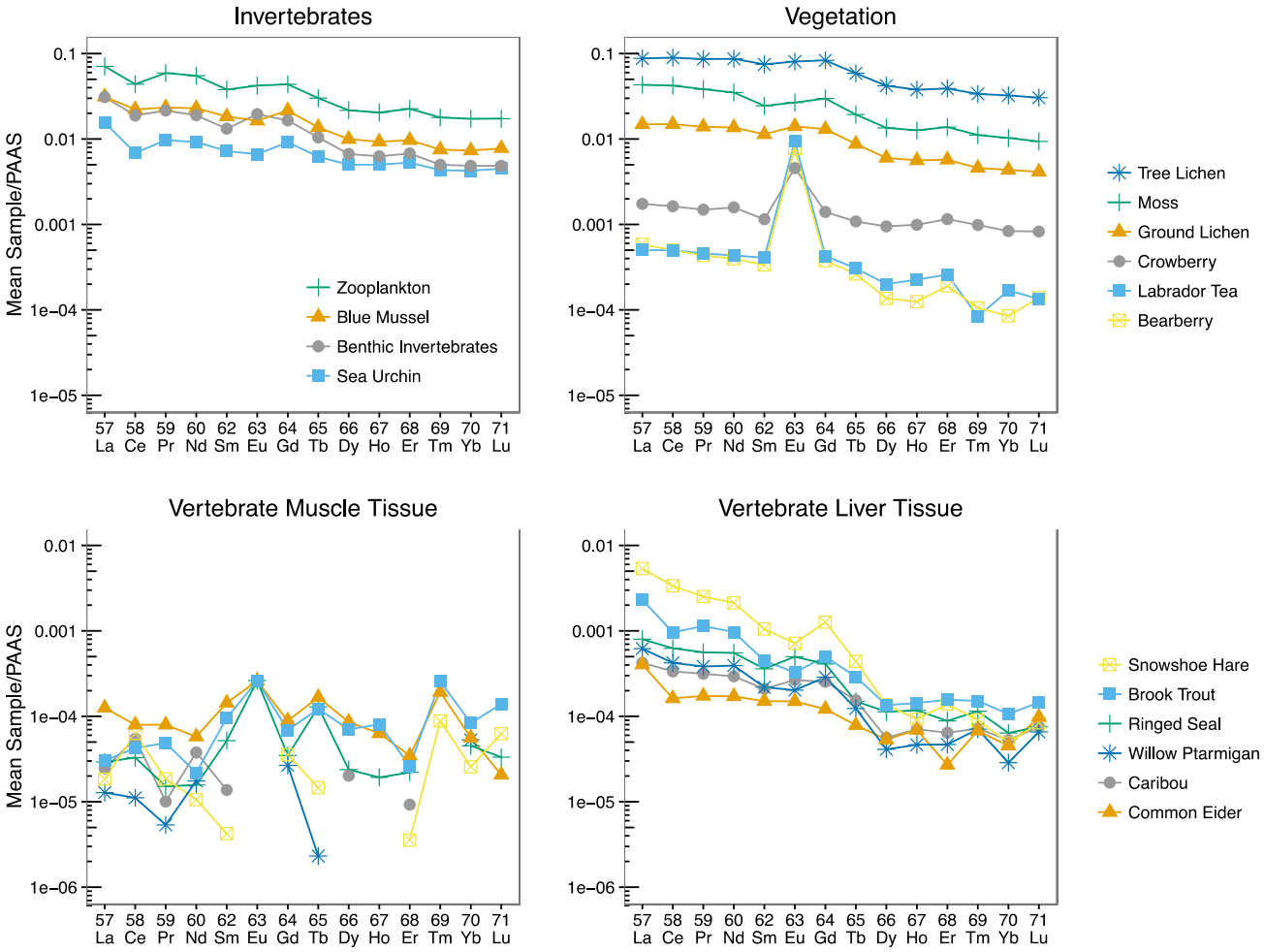


FIGURE S3: PAAS-normalized REE concentrations (geometric means, log nmolg^{-1}) versus atomic number for biotic components from all ecosystems including invertebrates, vegetation, vertebrate muscle and vertebrate liver tissues. Points show element means for each taxonomic group and samples below detection limits were excluded from the figure (e.g. muscle tissues).

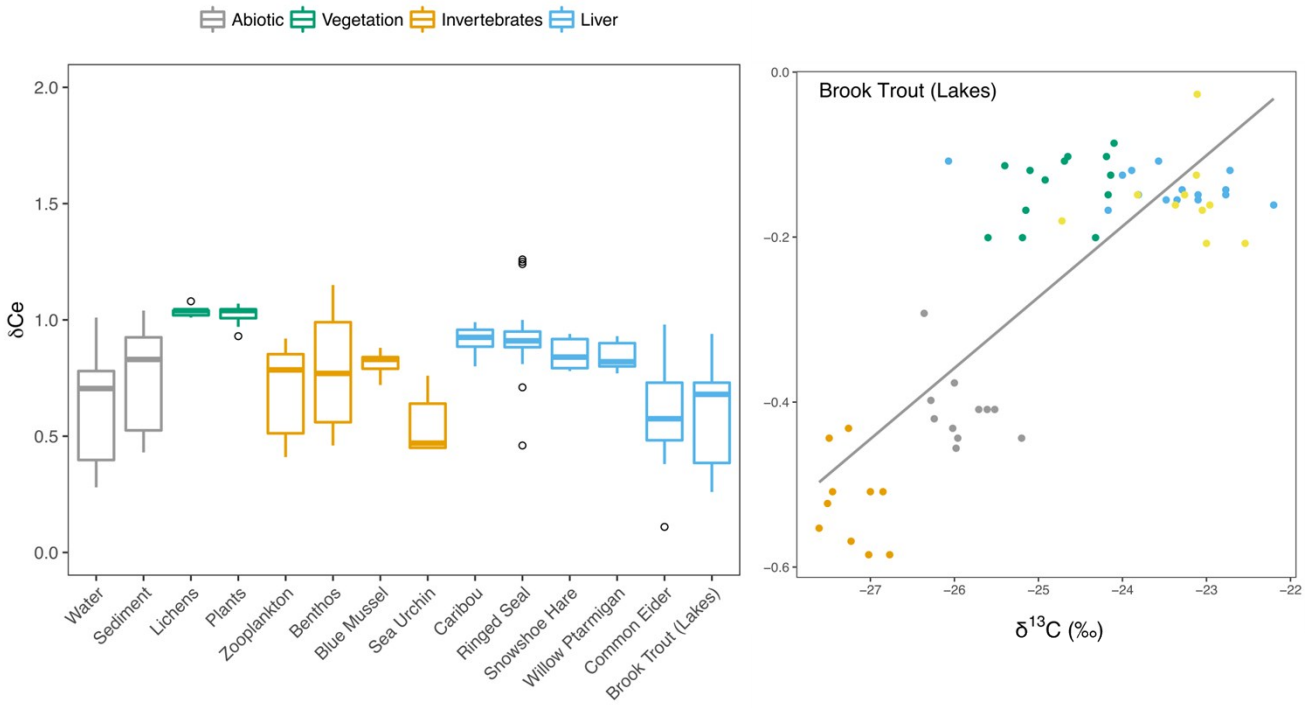


FIGURE S4: Boxplots showing the measured Ce anomaly in biota (∂Ce) by taxonomic group (left panel). Values close to 1 indicate no significant anomaly. Simple linear regression between ∂Ce (log_{10} - scaled) and carbon stable isotope ratios ($\partial^{13}C$, ‰) for freshwater brook trout: N = 54, $R^2_{adj} = 0.66$, $p < 0.001$. Coloured points indicate different sample lakes (geometric mean of 5 lakes). ∂Ce is calculated as $Ce_{PAAS} / (La_{PAAS} \times Pr_{PAAS})^{0.5}$ where PAAS indicated Post Archean Shale Standard normalized values.