

Chromophoric Dissolved Organic Matter (CDOM) and Dissolved Organic Carbon (DOC) in Lakes Across An Elevational Gradient from the Mountains to the Sea.

Kyle Juetten, Angela L. Strecker, Aaron Harrison, Zachary Landram, Warren J. De Bruyn, Catherine D. Clark*

*Corresponding author information:

Catherine.Clark@wwu.edu

Department of Chemistry, College of Science and Engineering, Western Washington University, 516 High St., Bellingham, WA 98229, USA

Table of Contents:

Supporting Information Table 1. Sampling dates, coordinates and lake physical and landscape characteristics sorted from low to high elevation.

Supporting Information Table 2. Study lake water quality parameters sorted from low to high elevation.

Supporting Information Table 3. Detailed information on redundancy analysis, including a) importance of each component, b) species scores (i.e., response variable scores), and c) site scores.

Figure S1. Land use/land cover data for study lakes using categories from the 2019 National Land Cover Database (Multi-Resolution Land Characteristics Consortium 2021).

Figure S2. Core consistency plots for 2-, 3- and 4-component fits

Figure S3: Residual plots for PARAFAC fit

Figure S4. Lake names corresponding to RDA (Figure 6).

Figure S5. Elevation (m asl) and a) % forest, b) % wetland, c) % agriculture, and d) % herb-shrub.

Supporting Information Table 1. Sampling dates, coordinates and lake physical and landscape characteristics sorted from low to high elevation.

Lake	Sampling date	Latitude	Longitude	Surface area (ha)	Elevation (m)	Watershed area (ha)	% developed	% forest	% herbaceous + shrub	% agriculture	% wetland
Cranberry	23-Jul	48.5004	-122.6445	54.2	3	54.5	11.2	66.0	0.8	0.0	4.6
Lone	1-Aug	48.0208	-122.4623	36.5	6	641.1	17.9	66.1	7.7	2.1	1.4
Tennant	27-Jun	48.8299	-122.5782	32.4	7	224.7	45.3	4.3	1.4	5.3	42.8
Honeymoon	1-Aug	48.0515	-122.5525	2.6	8	452.6	13.0	67.4	13.0	2.3	3.1
Beaver	9-Jul	48.4482	-122.2189	29.3	10	1055.6	9.8	66.8	9.4	2.8	5.8
Clear	9-Jul	48.4599	-122.2236	89.2	11	422.3	15.3	35.9	13.7	7.0	10.5
Campbell	23-Jul	48.4399	-122.6146	158.2	15	622.8	10.4	58.1	4.3	7.7	7.3
Whistle	23-Jul	48.4604	-122.6052	15.0	17	195.4	1.1	91.5	0.3	0.0	1.3
Big	9-Jul	48.4029	-122.2413	217.0	25	4371.5	10.9	69.5	7.1	1.9	5.3
Sunset	16-Jul	48.7765	-122.4597	5.2	32	2907.0	27.5	42.2	2.6	19.9	7.4
Erie	23-Jul	48.4532	-122.6408	46.2	33	470.1	14.1	62.0	2.9	8.2	2.2
Bug	16-Jul	48.7765	-122.4724	2.9	34	82.6	58.1	11.4	1.3	1.0	27.1
Hoag	25-Jun	48.7082	-122.4825	1.0	35	22.4	40.2	57.0	0.0	2.0	0.0
Pass	23-Jul	48.4197	-122.6361	38.4	38	168.9	5.2	63.9	1.4	6.9	0.0
Fazon	27-Jun	48.8652	-122.3683	12.9	40	81.0	24.7	36.9	1.7	22.1	13.2
Armstrong	18-Jul	48.2263	-122.1239	12.2	42	122.3	5.0	64.7	13.6	0.3	6.5
Goss	1-Aug	48.0371	-122.4807	21.7	42	414.1	10.3	77.8	6.1	0.2	0.4
Ketchum	18-Jul	48.2845	-122.3440	9.7	58	166.3	41.9	31.6	1.4	15.5	3.4
Martha	6-Aug	48.1685	-122.3406	25.1	58	360.3	35.0	51.5	3.2	2.7	0.9
Sunday	18-Jul	48.2294	-122.2570	15.5	66	314.1	28.5	43.5	5.4	10.5	8.9
Terrell	27-Jun	48.8661	-122.6877	130.0	66	1244.7	10.0	19.2	2.0	29.4	28.5
McMurray	9-Jul	48.3154	-122.2325	62.9	69	864.3	17.5	61.2	9.5	2.5	2.5
Howard	6-Aug	48.1572	-122.3269	11.4	74	125.9	33.8	41.1	14.8	1.7	0.0

Lake	Sampling date	Latitude	Longitude	Surface area (ha)	Elevation (m)	Watershed area (ha)	% developed	% forest	% herbaceous + shrub	% agriculture	% wetland
Samish	11-Jul	48.6592	-122.3798	327.8	83	3258.0	6.6	77.0	5.7	0.4	0.5
Goodwin	16-Aug	48.1390	-122.2796	216.7	100	7.5	39.0	54.9	3.7	2.4	0.0
Shoecraft	6-Aug	48.1292	-122.3027	53.3	100	1226.3	31.8	40.2	3.5	2.0	0.7
Heart	23-Jul	48.4758	-122.6306	25.7	103	185.5	7.8	75.5	0.5	0.0	2.4
Deer	1-Aug	47.9739	-122.3832	33.1	108	307.6	28.4	52.3	4.8	4.3	0.0
Mirror	11-Jul	48.6629	-122.2196	4.7	111	46.1	5.3	78.5	4.0	1.0	3.2
Cain	11-Jul	48.6492	-122.3292	28.8	121	410.5	23.9	72.8	1.0	0.7	0.1
Reed	11-Jul	48.6632	-122.3258	10.0	122	130.2	17.1	81.4	0.0	0.5	0.6
Shannon	22-Aug	48.5842	-121.7237	833.7	124	76383.3	1.0	67.3	14.0	0.0	0.4
Crabapple	6-Aug	48.1318	-122.2724	14.4	126	317.4	44.4	38.3	5.4	4.2	1.9
Ki	6-Aug	48.1522	-122.2647	38.7	127	175.8	36.4	39.4	1.3	0.5	0.0
Sixteen	9-Jul	48.3440	-122.2895	17.5	130	439.0	5.0	73.5	15.8	0.0	1.7
Squires	11-Jul	48.6456	-122.3535	3.1	133	58.0	1.4	90.6	0.8	0.0	4.1
Wiser	27-Jun	48.9037	-122.4803	47.0	134	965.6	22.8	1.4	0.7	68.0	2.4
Padden	25-Jun	48.7022	-122.4519	59.8	137	701.8	30.5	51.3	8.4	0.6	0.9
Squalicum	16-Jul	48.7978	-122.3507	12.6	147	3.8	4.8	57.1	0.0	0.0	21.4
Beaver Pond	11-Jul	48.7321	-122.3759	3.1	158	0.5	20.0	80.0	0.0	0.0	0.0
Geneva	11-Jul	48.7326	-122.3754	1.5	158	91.5	7.2	73.8	16.3	0.2	2.6
Summer	9-Jul	48.3332	-122.1682	2.8	170	47.3	8.5	40.1	24.6	2.6	18.7
Loma	6-Aug	48.1340	-122.2530	8.6	173	14.5	56.6	18.9	15.1	0.6	0.0
Everett	22-Aug	48.5424	-121.7251	3.5	201	516.3	3.4	87.7	7.5	0.0	0.9
Toad	16-Jul	48.7911	-122.3953	11.5	219	191.9	16.5	76.6	2.2	0.0	0.0
Silver	15-Aug	48.9781	-122.0694	63.7	233	695.6	3.1	85.6	2.6	0.0	0.4
Grandy	22-Aug	48.5655	-121.8002	22.9	243	858.8	6.5	72.8	13.0	0.0	5.6
Cavanaugh	9-Jul	48.3262	-122.0210	337.2	308	1881.9	6.3	67.2	7.1	0.0	1.6
Vogler	22-Aug	48.5706	-121.7735	5.9	325	742.1	9.9	79.7	5.8	0.0	1.6

Lake	Sampling date	Latitude	Longitude	Surface area (ha)	Elevation (m)	Watershed area (ha)	% developed	% forest	% herbaceous + shrub	% agriculture	% wetland
Monte Cristo	8-Aug	48.0534	-121.4300	3.1	593	4811.2	0.4	70.2	15.2	0.0	0.3
Myrtle Canyon	8-Aug	48.0536	-121.4260	2.9	606	8.9	3.1	79.6	0.0	0.0	2.0
	20-Aug	48.8332	-122.0710	2.1	708	986.2	0.1	94.6	3.9	0.0	0.2
Evan	8-Aug	48.0311	-121.6880	1.8	843	44.4	0.8	89.3	0.0	0.0	0.0
Bear	8-Aug	48.0586	-121.7430	11.9	847	71.8	0.1	88.2	0.4	0.0	0.0
Coal	8-Aug	48.1123	-121.5170	2.7	1031	137.6	0.8	91.1	6.8	0.0	0.0
Highwood	15-Aug	48.8646	-121.6750	0.7	1253	8.2	24.4	61.1	14.4	0.0	0.0
Picture	15-Aug	48.8655	-121.6770	1.2	1255	19.3	33.6	53.0	3.2	0.0	0.0
L. Bagley	15-Aug	48.8599	-121.6840	3.1	1276	69.0	3.6	36.8	56.9	0.0	0.0
Sunrise	15-Aug	48.8626	-121.6800	0.4	1292	13.2	38.1	53.1	8.2	0.0	0.0
U. Bagley	15-Aug	48.8541	-121.6920	1.5	1321	232.7	1.4	8.7	48.3	0.0	0.0
L. Twin	20-Aug	48.9510	-121.6380	7.4	1574	44.9	4.2	22.7	58.2	0.0	0.0
U. Twin	20-Aug	48.9529	-121.6330	6.6	1574	41.6	0.4	36.2	38.3	0.0	0.0

Supporting Information Table 2. Study lake water quality parameters sorted from low to high elevation.

Lake	Water temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductance ($\mu\text{S cm}^{-1}$)	Chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Total nitrogen ($\mu\text{g L}^{-1}$)	Total phosphorus ($\mu\text{g L}^{-1}$)
Cranberry	24.4	12.3	9.4	242.6	41.5	61.4	8.1	1203	22.6
Lone	24.0	10.4	9.5	167.9	30.1	62.1	4.56	939	246.8
Tennant	16.2	7.0	6.5	125.6	50.5	47.1	11	1431	168.8
Honeymoon	22.6	7.6	8.9	170.7	190.3	64.2	21.1	1994	90.2
Beaver	22.9	9.4	7.6	94.6	22.2	43.8	6.25	760	44.7
Clear	22.7	8.7	7.2	3.3	6.3	33.4	2.87	441	12.6
Campbell	24.0	9.0	8.3	247.3	16.2	85.7	4.15	785	33.4
Wiser	21.9	10.3	8.9	459.6	42	71.4	12.5	1294	118.9
Big	22.9	9.1	7.7	82.2	8.4	31.9	3.17	297	15.1
Sunset	24.8	10.6	9.2	183.9	2.3	57.9	1.53	326	14.8
Erie	23.6	9.6	8.6	241.1	54.5	81.1	20.3	1541	49.1
Bug	24.3	6.4	7.5	190.9	3.6	85.5	1.93	533	26.7
Hoag	19.0	6.5	7.4	142	26.7	65.2	4.35	1031	75.6
Pass	22.1	9.4	8.7	271.1	13.5	69.5	3.46	680	26.7
Fazon	21.3	9.3	7.6	243.9	46.1	45.7	5.09	1174	76.5
Armstrong	24.4	8.1	7.9	54.8	2.9	22.3	0.65	390	14.1
Goss	24.0	8.4	8.1	122.1	2.6	37.2	1.22	452	8.7
Ketchum	24.5	8.8	8.2	155	4.3	42.3	0.96	534	10.1
Martha	19.4	9.0	6.8	NA	2.1	32.2	0.49	429	7.8
Terrell	20.8	11.7	9.8	93.3	145.1	35.4	23.5	2073	62.5
Sunday	23.7	3.8	6.5	70.1	2.5	21.4	0.63	519	21.2
McMurray	22.2	9.4	8.3	93.2	5.1	27.8	1	338	12.2
Howard	23.6	8.5	7.9	118.4	1.8	46.6	0.53	425	7.9
Samish	21.4	9.6	8.2	62	1.7	20.5	0.39	309	<5
Shoecraft	23.6	8.5	7.8	95.3	2.5	34.5	1.24	372	5.5

Lake	Water temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductance ($\mu\text{S cm}^{-1}$)	Chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$)	Alkalinity (mg L ⁻¹)	Turbidity (NTU)	Total nitrogen ($\mu\text{g L}^{-1}$)	Total phosphorus ($\mu\text{g L}^{-1}$)
Goodwin	24.2	8.6	7.9	87.9	1.7	28.7	0.6	362	<5
Heart	22.8	9.1	8.3	250.9	7.1	72.3	1.17	728	16.4
Deer	24.6	8.6	NA	79.8	2.2	23.1	0.55	405	5.8
Mirror	21.5	9.1	7.5	40.2	2.1	19.3	0.74	249	8.7
Cain	22.4	9.8	8.7	51.2	4.5	18.8	1.74	554	7.4
Reed	21.4	8.9	7.2	54.5	2	22.7	1.29	363	23.8
Shannon	20.4	9.5	7.9	46.4	1.9	14.8	1.59	69.5	5.7
Crabapple	23.4	8.7	7.5	46	4.7	12.6	0.91	478	8.3
Ki	24.1	8.9	8.3	46.8	2.6	11.6	0.43	280	<5
Sixteen	22.9	8.9	8.0	76.9	1.7	27.9	1.06	298	11.6
Squires	22.0	8.2	NA	42.5	4	18.4	2.38	411	18.2
Whistle	21.6	9.5	8.3	156.3	4.6	47.1	0.75	372	17.5
Padden	22.1	9.5	8.6	91.4	3.8	25.9	0.88	251	10.2
Squalicum	22.6	6.5	7.5	67.3	2.8	25.9	1.74	745	26.8
Geneva	19.2	4.3	6.3	35.8	13.1	16	4.4	819	95.2
Beaver Pond	16.6	0.8	6.1	46.1	2.6	19.5	2.11	559	33.7
Summer	22.7	8.0	7.3	NA	16.2	11.2	1.73	493	23.1
Loma	24.0	7.9	7.2	45.1	11.8	10	0.69	655	25.8
Everett	21.3	9.4	7.9	136.6	1.8	67	1.15	205	5
Toad	23.5	9.5	8.6	115.4	4.8	45.2	2.47	707	17.4
Silver	23.5	9.4	8	140.5	5.4	53.3	1.02	260	9.4
Grandy	21.0	7.3	7.6	148.2	7.5	74.2	2.3	311	15.1
Cavanaugh	20.4	9.3	7.7	27.3	0.5	10.2	0.38	130	<5
Vogler	21.8	7.5	6.6	14.7	5.6	3.4	2.09	614	20.9
Monte Cristo	17.9	6.3	6.8	82.2	2.4	28.7	3.97	130	8.5
Myrtle	22.2	7.3	7	23.7	4.7	10.4	1.21	282	12

Lake	Water temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductance ($\mu\text{S cm}^{-1}$)	Chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$)	Alkalinity (mg L ⁻¹)	Turbidity (NTU)	Total nitrogen ($\mu\text{g L}^{-1}$)	Total phosphorus ($\mu\text{g L}^{-1}$)
Canyon	19.1	8.1	7.6	22.9	1.4	9.7	0.47	87.3	<5
Evan	24.7	7.8	6.8	9.9	3.8	2.1	0.85	341	12.8
Bear	25.1	7.6	7.2	5.6	1.5	1.2	1.45	159	6
Coal	17.2	9.2	7.9	53.1	0.9	25.4	0.42	48	<5
Highwood	19.7	8.0	7.4	24.9	1.6	5.5	0.69	126	6.9
Picture	19.8	7.8	7.4	22.3	1.3	5.3	0.56	144	7.1
L. Bagley	11.2	9.6	7.1	14.6	0.4	6.5	0.21	27.5	<5
Sunrise	19.1	8.5	8.2	48.1	6.8	18.2	1.24	244	10.7
U. Bagley	9.9	8.7	7.2	5.6	0.5	6.3	0.25	23.2	<5
U. Twin	15.1	9.0	8.0	73.5	0.3	24	0.17	16.2	<5
L. Twin	15.8	8.9	7.9	52.4	0.5	24	0.29	24.3	<5

Supporting Information Table 3. Detailed information on redundancy analysis, including a) importance of each component, b) species scores (i.e., response variable scores), and c) site scores.

<i>a) Importance of components</i>				
	RDA1	RDA2	RDA3	RDA4
Eigenvalue	3.0978	1.0234	0.1811	0.0469
Proportion Explained	0.3122	0.1031	0.0183	0.0047
Cumulative Proportion	0.3122	0.4154	0.4336	0.4384
<i>b) Species scores</i>				
	RDA1	RDA2	RDA3	RDA4
DOC	-0.9404	-0.8581	-0.2810	0.0044
Abs350	-1.1174	-0.3137	-0.1904	0.1794
S1	0.8062	-0.6842	0.3621	0.1902
S2	1.0298	-0.3243	-0.0498	-0.0368
S3	0.3091	-0.5930	0.0462	-0.0409
SR	0.8330	-0.0451	-0.0212	-0.0403
SUVA254	-0.9837	0.2723	0.1920	0.0476
FIX	-0.4320	-0.6607	0.2407	-0.1107
HIX	-1.0930	-0.2719	0.1854	-0.1617
BIX	0.8363	-0.4373	-0.2615	-0.0506
<i>c) Site scores</i>				
	RDA1	RDA2	RDA3	RDA4
Armstrong	-0.6657	0.9146	-0.3042	0.1557
Bear	0.0343	0.9258	1.0895	-0.3716
Beaver	-0.1420	-1.4835	1.8992	-0.0954
Beaver Pond	-1.0809	0.7067	0.1665	1.2215
Big	-0.0376	0.2370	1.2107	-0.5568
Bug	-0.1532	-0.2865	-0.3610	-1.4756
Cain	0.3893	0.1494	1.2534	-0.3571
Campbell	0.3092	-1.1668	-0.3020	0.2105
Canyon	-0.3073	0.8357	2.0801	-0.3475
Cavanaugh	0.9045	0.2589	-0.2829	0.5545
Clear	0.3848	-0.2965	0.1164	-1.6686
Coal	1.0685	0.9309	-0.8616	-0.5452
Crabapple	-0.1531	-0.0198	0.3405	0.2361
Cranberry	-0.5819	-1.0949	-2.2479	0.4524
Deer	0.5781	-0.8489	0.5918	-0.7864
Erie	0.2563	-1.3442	-0.6460	0.1719
Evan	-0.3664	0.8184	1.0956	0.6353
Everett	-0.3178	0.4491	1.3466	-2.5235
Fazon	-1.4387	-0.2087	-0.2248	1.4270
Geneva	-1.4249	0.0737	0.1787	2.0209
Goodwin	1.2301	-1.2318	0.3335	-0.1374

	RDA1	RDA2	RDA3	RDA4
Goss	0.2154	-0.5530	-0.3433	0.1148
Grandy	0.1976	0.4289	-0.0101	-2.0585
Heart	0.7315	-1.3523	-0.5962	-1.6835
Highwood	-0.1450	1.0840	0.6810	-0.4915
Hoag	-0.5985	-0.2322	-0.9878	-0.4715
Honeymoon	-1.4364	-0.9282	-1.8884	3.6700
Howard	0.5108	-0.1360	-0.5347	-1.0993
Ketchum	-0.0297	-0.5948	-0.0170	-1.5492
Ki	1.5382	-0.6850	-1.1532	-1.2220
L. Bagley	0.1290	2.6412	-0.9738	-0.8332
L. Twin	2.2208	1.1636	-6.0537	4.3783
Loma	-1.6336	0.1799	-0.1816	1.8840
Lone	-0.2076	-0.7286	-0.6490	0.3645
Martha	0.1585	-0.4676	-0.0161	-0.1154
McMurray	0.2129	0.0188	1.3308	-0.3225
Mirror	-0.8338	1.0336	1.0719	-0.1053
Monte Cristo	-0.3796	0.9604	1.0180	-1.8716
Myrtle	-0.5097	1.0141	0.4691	0.4359
Padden	0.4513	0.0502	0.8779	1.1767
Pass	0.7014	-1.2664	0.2526	-0.3426
Picture	0.1407	0.3756	1.0853	0.3138
Reed	-0.6126	0.3943	1.1209	-1.4112
Samish	1.2964	-1.1239	2.6912	4.3380
Shannon	1.0950	-0.2349	1.7737	2.9041
Shoecraft	0.7743	-0.3240	-0.3089	-0.6676
Silver	0.6085	0.2484	-0.3452	-1.2470
Sixteen	-0.3264	0.3680	0.6102	0.2636
Squalicum	-1.7360	0.0283	-0.3178	1.7029
Squires	-0.3420	0.7685	-0.4675	0.9758
Summer	-1.4616	0.7994	0.3847	1.6018
Sunday	-0.8063	0.4961	-0.5932	-0.4549
Sunrise	0.7196	-0.2138	-0.0830	-0.1260
Sunset	0.5236	-0.6592	-0.2212	-1.0889
Tennant	-0.8461	-0.3171	-0.4936	-1.1107
Terrell	-0.6283	-0.8180	-1.5993	-1.2553
Toad	0.9048	-0.7815	0.0080	-1.5670
U. Bagley	0.5358	1.4975	-1.3863	-1.5312
U. Twin	1.2692	0.2646	-0.7837	-0.0794
Vogler	-0.3988	0.7188	0.4101	0.4146
Whistle	0.3504	-0.6329	-0.2921	-0.4704
Wiser	-0.8395	-0.8029	0.0398	0.4163

Supporting Information Figure 1

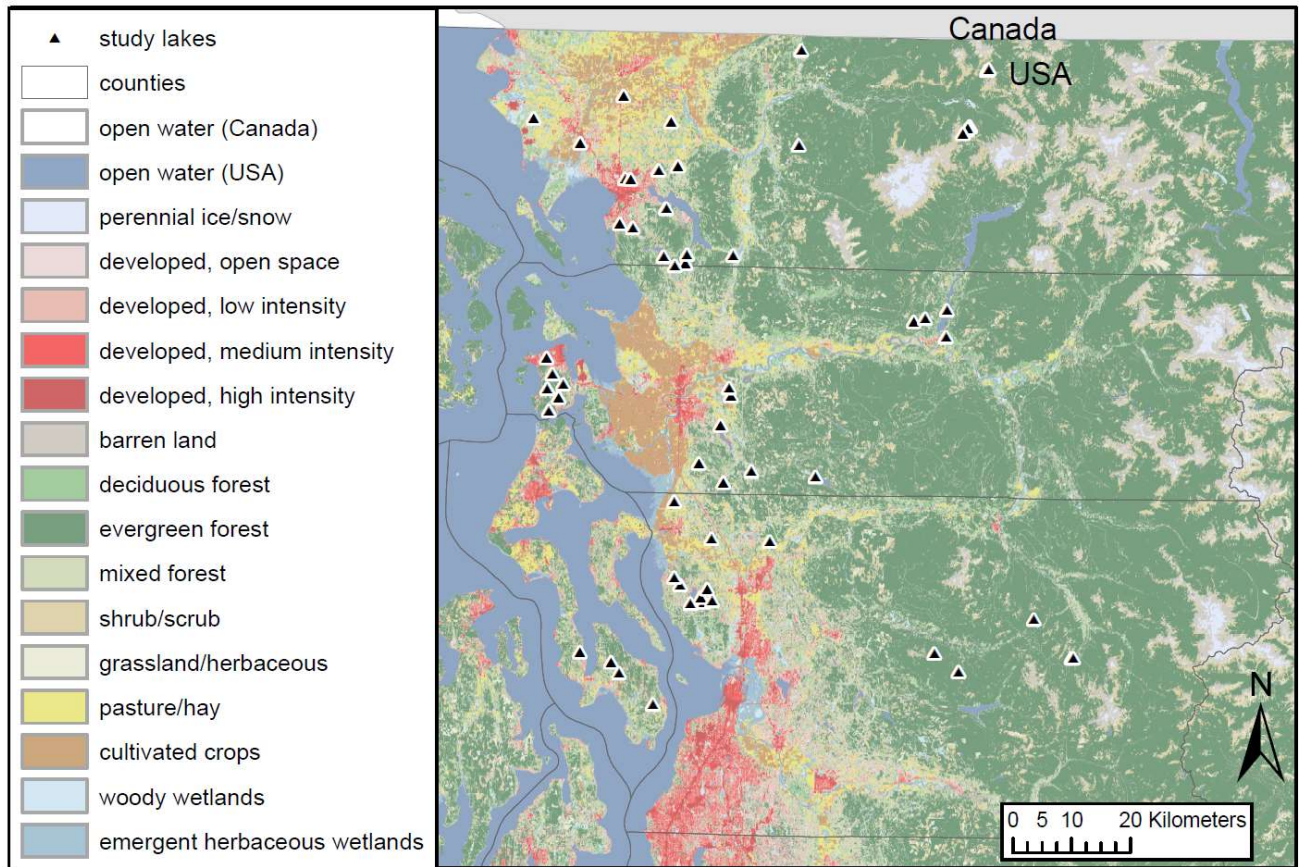


Figure S1. Land use/land cover data for study lakes using categories from the 2019 National Land Cover Database (Multi-Resolution Land Characteristics Consortium 2021).

Reference

Multi-Resolution Land Characteristics Consortium. 2021. NLCD 2019 Land Cover (CONUS).
<https://www.mrlc.gov/data/nlcd-2019-land-cover-conus>

Supporting Information Figure 2

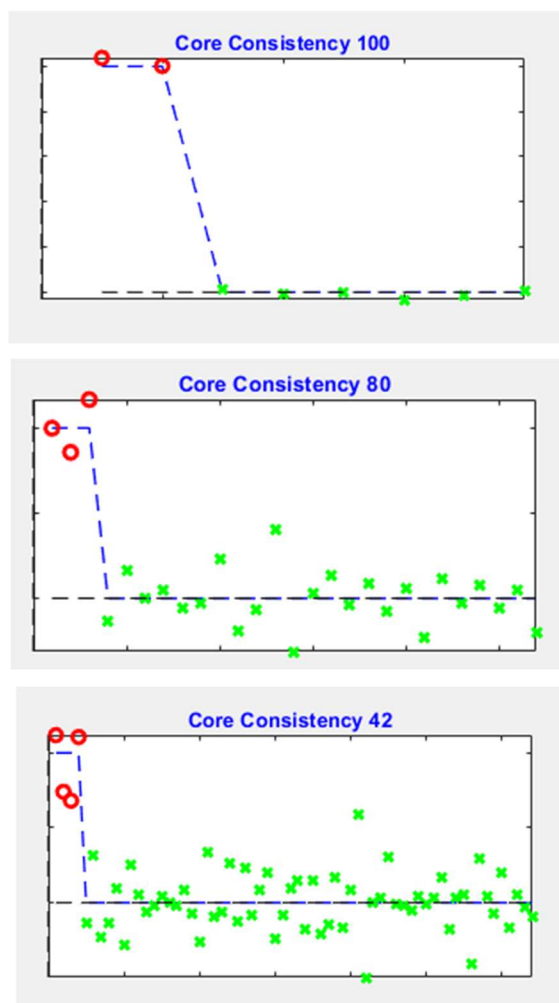


Figure S2. Core consistency plots for 2-, 3- and 4-component fits

Supporting Information Figure S3.

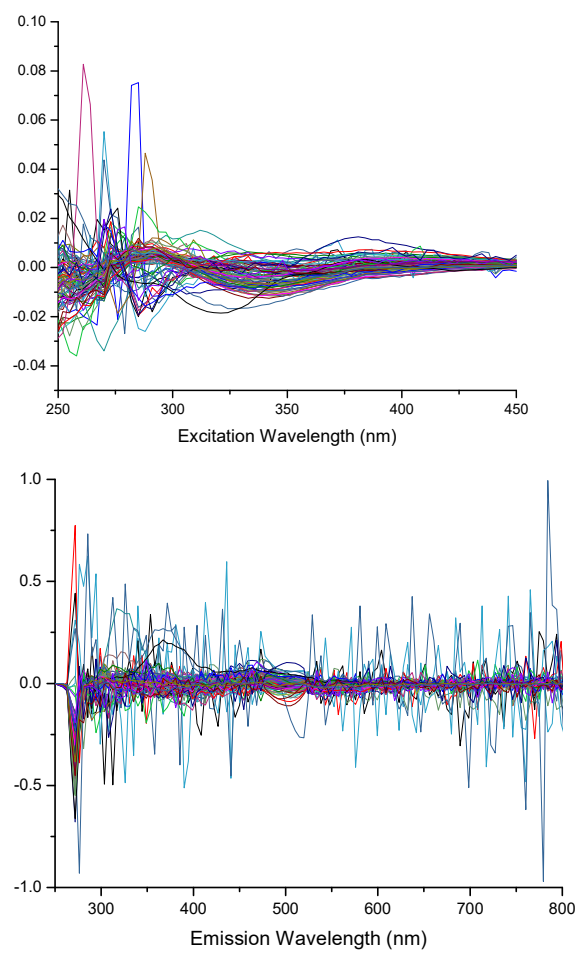


Figure S3: Residual plots for PARAFAC fit

Supporting Information Figure S4.

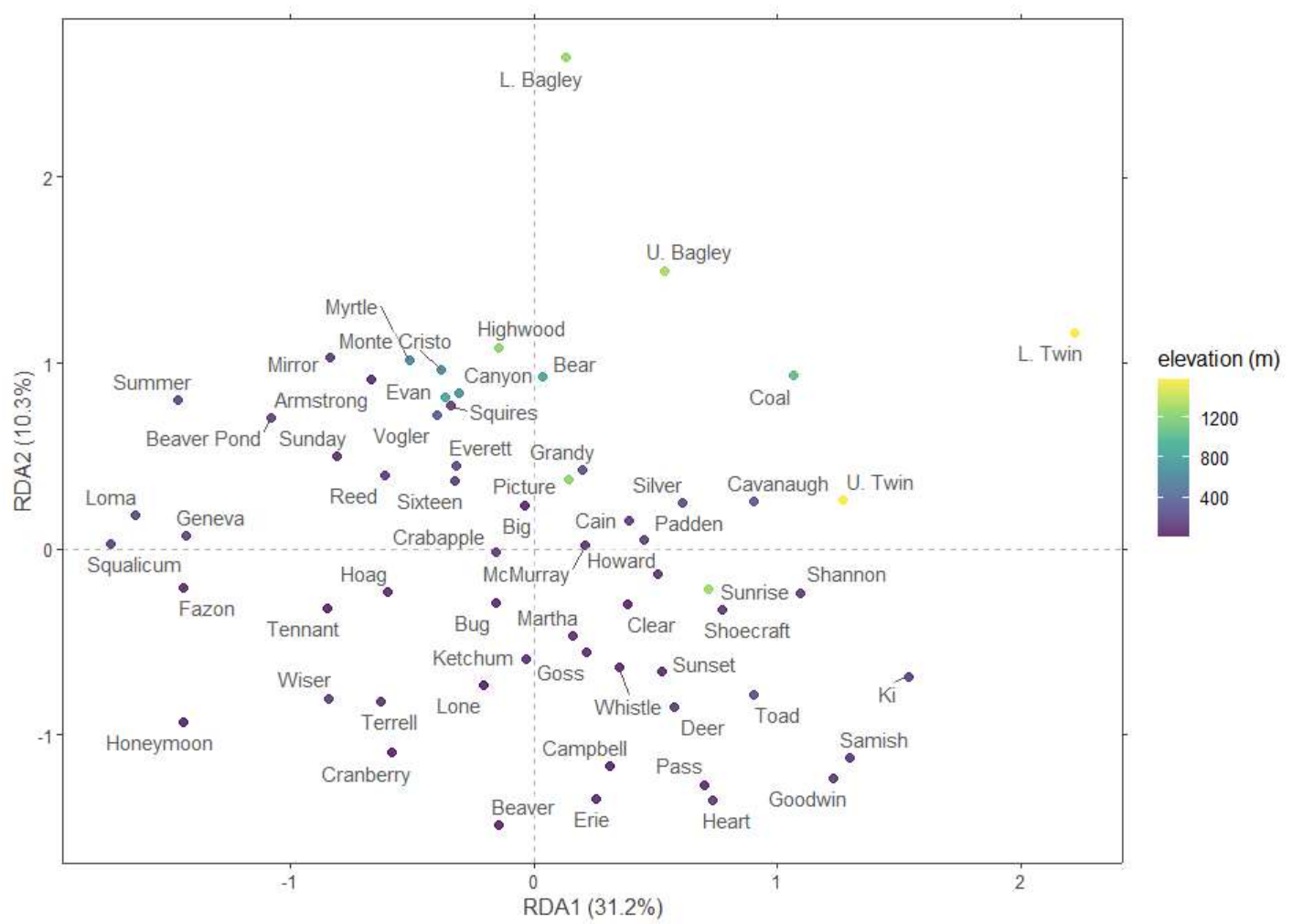


Figure S4. Lake names corresponding to RDA (Figure 6).

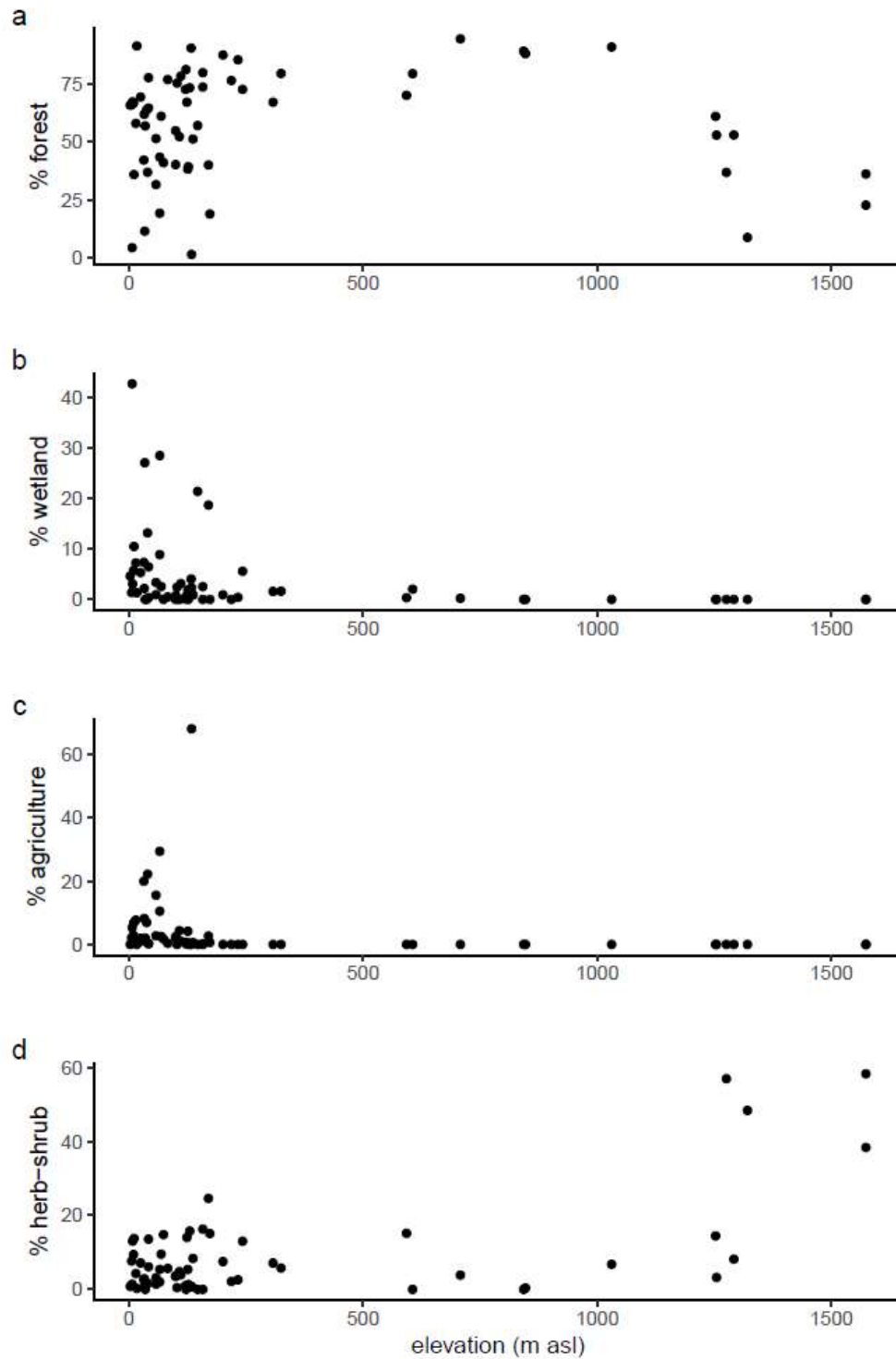


Figure S5. Elevation (m asl) and a) % forest, b) % wetland, c) % agriculture, and d) % herb-shrub. Spearman correlations and p-values were a) $\rho = -0.15$, $p = 0.261$; b) $\rho = -0.56$, $p < 0.001$; c) $\rho = -0.70$, $p < 0.001$; d) $\rho = 0.24$, $p = 0.062$.