



Supplement of

Diatom–environment relationships and limnological variability: an updated quantitative tool for palaeoclimatology on sub-Antarctic Macquarie Island

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Table S1: Environmental parameters for lake sites included in the diatom dataset, including 2022 (LK) and 2006 (S) sampling. Mean values are shown for 2022 sampling. Site location refers to p = plateau or c = coastal sites, Si = silicate, PO₄⁻³ = phosphate, TON = total oxidised nitrogen, < indicates measurements were below detection limits. Nutrient variables for 2022 (LK) sites were measured with ICP-AES and 2006 (S) sites were measured using an Alpkem Autoanalyser (Continuous Flow Solution Analyser).

Lake ID	Easting	Northing	Site location	Temperature (°C)	DO (mg L ⁻¹)	Conductivity (µS cm ⁻¹)	pH	Si (mg L ⁻¹)	PO ₄ ⁻³ (mg L ⁻¹)	TON (mg L ⁻¹)
LK1	494110	3959140	p	8.4	11.49	180	7.65	1.067	< 0.010	< 0.060
LK2	492797	3957444	p	8.6	11.88	172	7.28	0.767	< 0.010	<0.060
LK3	492869	3958492	p	10.3	10.49	253	6.60	1.400	< 0.010	<0.060
LK4	494224	3956568	p	6.8	12.31	145	7.45	1.933	< 0.010	<0.060
LK6	492282	3955664	p	8.4	11.67	232	7.26	0.300	< 0.010	<0.060
LK7	494295	3955246	p	7.5	11.87	164	7.59	2.000	< 0.010	<0.060
LK8	490596	3946005	p	8.4	11.14	143	6.94	<0.100	< 0.010	<0.060
LK9	493581	3953224	p	8.7	12.61	246	9.14	0.600	< 0.017	<0.060
LK10	491985	3953033	p	7.6	12.24	248	7.07	<0.100	< 0.010	<0.060
LK11	493195	3952126	p	9.3	11.19	163	6.64	<0.100	< 0.010	<0.060
LK12	493150	3951470	p	10.2	10.88	156	6.22	<0.100	< 0.010	<0.060
LK15	493674	3950878	p	9.2	10.80	158	6.55	0.100	< 0.010	<0.060
LK18	490230	3948626	p	16.0	8.64	206	6.79	0.450	0.013	<0.060
LK20	493012	3948146	p	9.9	11.03	148	7.32	0.600	< 0.010	<0.060
LK21	491019	3948767	p	8.1	11.93	153	6.65	<0.100	< 0.010	<0.060
LK22	492706	3947350	p	10.8	11.49	168	7.21	1.233	< 0.010	<0.060
LK23	491879	3947314	p	8.3	12.05	170	7.46	2.833	< 0.010	<0.060
LK24	490162	3947027	p	10.0	11.20	200	7.50	1.433	< 0.010	<0.060
LK28	490470	3944833	p	7.5	11.88	126	6.38	0.233	0.013	<0.060
LK29	490159	3945158	p	7.3	11.26	162	7.19	0.267	< 0.010	<0.060
LK30	490821	3947661	p	8.0	11.94	144	6.37	<0.100	< 0.010	<0.060
LK31	489927	3942832	p	9.0	11.30	172	6.94	<0.100	< 0.010	<0.060

Lake ID	Easting	Northing	Site location	Temperature (°C)	DO (mg L ⁻¹)	Conductivity (µS cm ⁻¹)	pH	Si (mg L ⁻¹)	PO ₄ ⁻³ (mg L ⁻¹)	TON (mg L ⁻¹)
LK35	489712	3940573	p	8.3	11.97	214	7.74	0.667	< 0.010	<0.060
LK36	488705	3940234	p	9.1	11.12	230	7.14	0.233	< 0.010	<0.060
LK37	488304	3940093	p	9.5	10.89	261	6.42	1.000	0.007	<0.060
LK38	488541	3938984	p	9.5	11.22	198	6.33	0.200	< 0.010	<0.060
LK39	490086	3938527	p	10.2	11.86	177	8.01	0.133	0.013	<0.060
LK40	489342	3936465	p	9.1	11.09	164	6.88	<0.100	< 0.010	<0.060
LK42	488615	3932846	p	7.3	12.01	157	5.73	<0.100	< 0.010	0.100
LK43	487915	3930746	p	7.7	11.63	169	6.73	<0.100	< 0.010	<0.060
S9	489342	3936465	p	7.4	11.35	224	7.46	0.066	0.002	0.006
S11	488324	3933951	p	6.9	11.52	215	6.35	0.006	0.001	0.008
S16	494029	3958628	p	5.9	11.66	179	6.98	0.070	0.024	0.015
S18	492797	3957444	p	5.5	11.80	179	7.01	0.092	0.004	0.005
S22	493222	3950937	p	6.4	11.61	164	6.79	0.003	0.003	0.001
S37	490859	3953144	c	8.6	9.17	1136	6.73	0.074	1.029	0.181
S38	490756	3953694	c	6.3	11.91	1482	7.47	0.170	0.527	0.636
S45	490982	3957320	c	6.0	10.75	1244	6.66	0.505	9.890	0.160
S46	491353	3958630	c	8.0	11.48	693	7.32	2.459	1.250	0.188
S47	491553	3958564	c	8.7	12.03	698	7.46	0.291	1.558	2.540
S48	491557	3958671	c	8.9	14.43	603	8.12	2.706	0.217	0.029
S49	491956	3959447	c	13.1	13.59	732	8.13	0.441	0.415	0.085
S50	491979	3959468	c	10.0	11.21	1265	7.85	1.064	0.774	0.625
S51	492008	3959442	c	8.2	9.55	1094	7.28	0.989	0.672	1.947
S52	492158	3959475	c	7.8	11.98	710	7.41	0.696	0.571	0.126
S54	487570	3939965	c	6.8	11.51	1179	6.77	0.100	0.808	1.052
S55	487545	3939906	c	6.9	10.44	1478	5.50	0.079	0.101	0.117
S56	488208	3940384	c	7.6	10.97	646	6.61	0.096	2.249	1.936

Table S2: Environmental parameters and stable water isotopes for 2022 lake water samples. Lake type refers to Meredith et al. (2022) lake clusters, 1 = Sea-spray dominated, 2 = catchment dominated, 3 = rainfall dominated, *indicates lakes also included in the diatom dataset.

Lake ID	Easting	Northing	Lake type	Distance from west coast (km)	Elevation (m)	Temperature (°C)	DO (mg L ⁻¹)	Conductivity (µS cm ⁻¹)	pH	δ ² H (‰)	δ ¹⁸ O (‰)	d-excess (‰)
LK1*	494110	3959140	3	2.48	217	8.6	11.7	191	7.5	-26.83	-3.87	4.10
LK2*	492797	3957444	3	1.31	216	8.1	12.0	179	7.2	-24.47	-3.60	4.36
LK3*	492869	3958492	1	2.14	185	9.2	11.5	214	6.7	-29.90	-4.63	7.14
LK4*	494224	3956568	3	3.27	314	6.4	12.6	151	7.3	-27.87	-4.24	6.05
LK6*	492282	3955664	1	1.01	169	7.5	11.8	240	7.2	-15.27	-1.99	0.65
LK7*	494295	3955246	3	2.86	256	7.1	12.4	172	7.5	-29.87	-4.62	7.12
LK8*	490596	3946005	3	2.03	188	8.3	11.4	153	6.4	-23.17	-3.01	0.89
LK9*	493581	3953224	2	2.79	138	8.6	12.9	260	9.1	-28.27	-4.11	4.61
LK10*	491985	3953033	1	1.49	198	6.8	12.3	231	7.1	-15.57	-1.81	-1.11
LK11*	493195	3952126	3	2.87	173	8.9	11.4	171	6.6	-23.57	-2.99	0.38
LK12	493150	3951470	3	3.25	163	10.3	10.9	168	6.2	-17.73	-2.15	-0.53
LK14	493222	3950937	3	3.51	163	7.9	11.4	159	7.0	-23.07	-3.50	4.96
LK15*	493674	3950878	3	4	163	9.6	10.6	170	6.5	-16.57	-2.18	0.87
LK16	493174	3948589	2	3.66	95	9.4	10.5	168	7.2	-16.05	-2.22	1.71
LK18*	490230	3948626	1	1	214	16.1	8.7	211	7.0	-19.35	-3.06	5.09
LK19	491403	3948287	3	2.21	230	7.4	12.5	165	7.1	-27.23	-4.03	5.03
LK20*	493012	3948146	3	3.82	126	10.0	11.3	156	7.3	-23.80	-4.05	8.57
LK21*	491019	3948767	3	1.9	251	7.6	12.3	161	6.6	-25.87	-4.37	9.12
LK22*	492706	3947350	3	4.14	103	10.9	11.8	186	7.3	-22.33	-2.97	1.40
LK23*	491879	3947314	2	3.32	201	7.8	12.3	176	7.3	-35.93	-5.19	5.59
LK24*	490162	3947027	2	1.51	144	9.8	11.1	209	7.4	-28.10	-4.15	5.10
LK25	489858	3946831	2	1.42	141	10.2	11.9	225	8.2	-26.23	-3.72	3.53
LK26	493186	3946456	2	4.69	9	10.4	12.0	210	7.6	-36.47	-5.46	7.19
LK27	490046	3944396	3	2.01	189	6.8	11.5	188	7.1	-31.77	-4.54	4.58
LK28*	490470	3944833	3	1.88	223	7.6	11.9	135	6.4	-22.13	-2.65	-0.93

Lake ID	Easting	Northing	Lake type	Distance from		Elevation (m)	Temperature (°C)	DO (mg L ⁻¹)	Conductivity (µS cm ⁻¹)	pH	δ ² H (‰)	δ ¹⁸ O (‰)	d-excess (‰)
				west coast (km)									
LK29*	490159	3945158	3	1.61		206	7.2	11.2	171	7.1	-27.20	-4.15	5.97
LK30*	490821	3947661	2	2.02		176	8.1	12.0	150	6.0	-25.70	-3.84	5.05
LK31*	489927	3942832	3	1.24		260	8.7	11.6	178	6.7	-26.73	-4.14	6.39
LK32	491780	3943075	3	3.05		191	10.1	11.3	146	6.6	-24.70	-3.79	5.62
LK34	491707	3942016	3	2.8		126	12.7	11.3	183	8.7	-22.43	-2.72	-0.65
LK35*	489712	3940573	1	1.77		223	7.9	12.1	223	7.4	-23.67	-3.22	2.12
LK36*	488705	3940234	1	1.27		189	8.7	11.3	240	7.0	-25.60	-3.71	4.05
LK37*	488304	3940093	1	1.08		196	9.1	11.0	267	6.4	-16.75	-1.88	-1.75
LK38*	488541	3938984	1	1.27		185	9.2	11.2	204	6.3	-25.77	-3.58	2.85
LK39*	490086	3938527	2	2.58		184	10.4	11.6	189	7.7	-21.50	-2.99	2.45
LK40*	489342	3936465	3	1.63		208	9.1	11.3	173	7.0	-26.73	-3.90	4.49
LK41	488929	3934629	3	1.76		306	7.2	12.0	160	6.8	-29.00	-4.42	6.39
LK42*	488615	3932846	3	1.57		278	7.4	12.1	168	5.6	-22.20	-3.22	3.56
LK43*	487915	3930746	3	2.27		252	7.9	11.8	180	6.7	-25.93	-3.72	3.80
LK44	493546	3960364	1	1		200	9.5	11.5	233	6.4	-25.33	-3.35	1.49

Table S3: Anions and Cations for 2022 lake water samples (mmol L⁻¹)

Lake ID	Cl	SO ₄	Br	Na	Ca	Mg	K	SiO ₂	Fe	F-	Al
LK1	1.347	0.074	0.0010	1.195	0.082	0.182	0.025	0.038	0.0006	0.0033	0.0033
LK2	1.305	0.076	0.0015	1.115	0.073	0.174	0.025	0.027	0.0001	0.0006	0.0006
LK3	1.492	0.099	0.0011	1.305	0.053	0.147	0.029	0.050	0.0005	0.0042	0.0042
LK4	1.171	0.072	0.0013	0.996	0.088	0.152	0.022	0.069	0.0002	0.0009	0.0009
LK6	2.045	0.107	0.0025	1.762	0.062	0.191	0.038	0.011	0.0010	0.0057	0.0057
LK7	1.220	0.084	0.0015	1.076	0.114	0.181	0.020	0.071	0.0003	0.0010	0.0010
LK8	1.241	0.062	0.0013	1.044	0.025	0.116	0.029	0.004	0.0003	0.0014	0.0014
LK9	1.772	0.085	0.0014	1.531	0.290	0.257	0.009	0.021	0.0007	0.0011	0.0011
LK10	2.003	0.115	0.0023	1.712	0.051	0.186	0.040	0.004	0.0003	0.0017	0.0017
LK11	1.299	0.068	0.0018	1.083	0.033	0.121	0.028	0.004	0.0001	0.0004	0.0004
LK12	1.264	0.073	0.0018	1.054	0.033	0.120	0.027	0.004	0.0001	0.0007	0.0007
LK14	1.248	0.060	0.0016	1.045	0.034	0.119	0.023	0.004	0.0001	0.0003	0.0003
LK15	1.249	0.064	0.0016	1.064	0.031	0.120	0.031	0.004	0.0005	0.0017	0.0017
LK16	1.207	0.048	0.0012	1.059	0.075	0.158	0.023	0.030	0.0028	0.0037	0.0037
LK18	1.413	0.085	0.0020	1.279	0.031	0.113	0.040	0.016	0.0026	0.0126	0.0126
LK19	1.248	0.061	0.0013	1.074	0.067	0.143	0.025	0.005	0.0006	0.0019	0.0019
LK20	1.151	0.057	0.0016	0.982	0.050	0.128	0.026	0.021	0.0010	0.0026	0.0026
LK21	1.288	0.069	0.0017	1.102	0.030	0.120	0.028	0.004	0.0002	0.0007	0.0007
LK22	1.202	0.055	0.0016	1.038	0.122	0.133	0.029	0.044	0.0035	0.0025	0.0025
LK23	1.275	0.066	0.0014	1.096	0.165	0.148	0.025	0.101	0.0001	0.0005	0.0005
LK24	1.532	0.074	0.0019	1.324	0.166	0.176	0.022	0.051	0.0016	0.0030	0.0030
LK25	1.651	0.077	0.0019	1.419	0.187	0.174	0.021	0.019	0.0009	0.0031	0.0031
LK26	1.332	0.085	0.0019	1.338	0.251	0.104	0.012	0.154	0.0042	0.0018	0.0018
LK27	1.516	0.079	0.0018	1.283	0.097	0.156	0.027	0.032	0.0001	0.0004	0.0004
LK28	1.102	0.064	0.0015	0.928	0.027	0.105	0.023	0.008	0.0018	0.0080	0.0080
LK29	1.361	0.066	0.0017	1.170	0.093	0.145	0.027	0.009	0.0003	0.0011	0.0011
LK30	1.196	0.068	0.0015	0.999	0.026	0.109	0.024	0.004	0.0001	0.0007	0.0007
LK31	1.469	0.074	0.0020	1.245	0.037	0.136	0.029	0.004	0.0001	0.0004	0.0004

Lake ID	Cl	SO ₄	Br	Na	Ca	Mg	K	SiO ₂	Fe	F-	Al
LK32	1.090	0.057	0.0013	0.912	0.033	0.105	0.022	0.004	0.0001	0.0004	0.0004
LK34	1.248	0.054	0.0014	1.073	0.081	0.132	0.020	0.004	0.0008	0.0016	0.0016
LK35	1.832	0.090	0.0022	1.540	0.133	0.192	0.031	0.024	0.0001	0.0016	0.0016
LK36	1.965	0.101	0.0026	1.630	0.081	0.192	0.034	0.008	0.0001	0.0005	0.0005
LK37	2.419	0.113	0.0044	2.012	0.050	0.218	0.048	0.036	0.0161	0.0317	0.0317
LK38	1.703	0.093	0.0025	1.430	0.036	0.151	0.034	0.007	0.0001	0.0007	0.0007
LK39	1.372	0.064	0.0015	1.169	0.079	0.176	0.015	0.005	0.0012	0.0020	0.0020
LK40	1.385	0.069	0.0019	1.148	0.034	0.129	0.026	0.004	0.0001	0.0004	0.0004
LK41	1.342	0.063	0.0021	1.118	0.053	0.130	0.025	0.009	0.0002	0.0007	0.0007
LK42	1.418	0.075	0.0024	1.163	0.030	0.128	0.028	0.004	0.0004	0.0020	0.0020
LK43	1.528	0.064	0.0025	1.266	0.039	0.133	0.033	0.004	0.0002	0.0008	0.0008
LK44	1.866	0.090	0.0021	1.573	0.041	0.174	0.041	0.005	0.0023	0.0049	0.0049

Table S4: Mean major ions (mmol L⁻¹) and stable water isotope (‰) results for the 40 lakes sampled in 2018 and 2022.

	Cl	SO ₄	Br	Na	Ca	Mg	K	SiO ₂	Fe	F ⁻	Al	δ ² H	δ ¹⁸ O
2018													
Mean	1.965	0.103	0.003	1.350	0.085	0.325	0.032	0.013	0.001	0.001	0.002	-20.1	-2.8
Min	1.379	0.065	0.001	0.987	0.025	0.219	0.005	0.001	0.000	0.001	0.000	-34.9	-5.3
Max	3.667	0.211	0.007	2.566	0.287	0.590	0.064	0.087	0.003	0.006	0.006	-1.9	0.7
2022													
Mean	1.593	0.083	0.002	1.272	0.080	0.197	0.029	0.020	0.001	0.002	0.002	-23.4	-3.3
Min	1.191	0.055	0.001	0.931	0.025	0.133	0.009	0.003	0.000	0.000	0.000	-35.6	-5.3
Max	2.779	0.155	0.005	2.073	0.289	0.369	0.052	0.130	0.011	0.021	0.022	-14.6	-1.7
E2 Mean	1.426	0.076	0.002	1.229	0.079	0.150	0.028	0.027	0.001	0.003	0.003	-30.1	-4.6
E3 Mean	1.436	0.075	0.002	1.228	0.081	0.150	0.027	0.022	0.001	0.002	0.002	-23.4	-3.2
E4 Mean	1.448	0.073	0.002	1.223	0.075	0.146	0.026	0.018	0.001	0.002	0.002	-20.7	-2.8

Table S5: Species-electrical conductivity response curve types. Type I: no response/flat; Type II: monotonic increasing; Type III: monotonic decreasing plateau; Type IV: plateau; Type V: plateau Type VI: symmetrical unimodal (Gaussian); Type VII: skewed unimodal (Gaussian). Corresponding species name and code can be found in Supplementary Materials: Diatom Catalogue.

Species code	Type	Species code	Type	Species code	Type
ACHmin	IV	BRAexi	IV	PSAobl	III
ACHmod	IV	NEIsp1	IV	PSAsta	I
ADLspp	III	NITgra	I	PSAsub	IV
AMPacu	I	NITsp1	I	PSAthe	III
AMPcop	I	NITsp5	I	STAacu	III
AMPven	I	NITunk	I	STAalp	I
AULdis	VII	STAspp	I	STAcri	I
CALsp1	I	PINspp	IV	STAexi	IV
CANpsu	VII	PINcar	I	STAlep	I
CAVhet	I	PINdec	I	STAmar	I
COCneo	I	PINdiv	I	STApin	IV
COCpla	IV	PINlec	I	STAsubg	I
CRAsub	I	PINobs	I	SURang	I
CYM	IV	PINrab	IV	SURR	IV
DIAbal	IV	PINrhom	I	UNK111	V
DIAspp.	I	PINsub-elo	IV	UNK119	III
DI Acomp	I	PLAaue	IV	UNK127	I
DIAlan	I	PLAcyc	I	UNK131-C	II
DIPsub	I	PLAdel	IV	UNK132	I
PSAinv.	II	PLAquad	IV	UNK18	I
EUNpal	IV	PLAren	IV	UNK21	IV
EUNsp2	III	PLAlan	IV	UNK21.b	I
FRAcap	VII	PSAabu	VII	UNK33	I
FRAsp2	I	PSAant	I	UNK44b	I
FRUsub	IV	PSAato	VII	UNK45	I
GOM11	I	PSAcon	VII	UNK54	I
GOMunk1	I	PSAger	III	UNK73	I
GOMunk2	I	PSAhod	II	UNK94	I
HANam	I	PSAinc	I	UNK94.b	I
NAVgre	I	PSAlev	I		
NAVsem	I	UNK37	IV		
NAVsp1	II	PSAman	I		

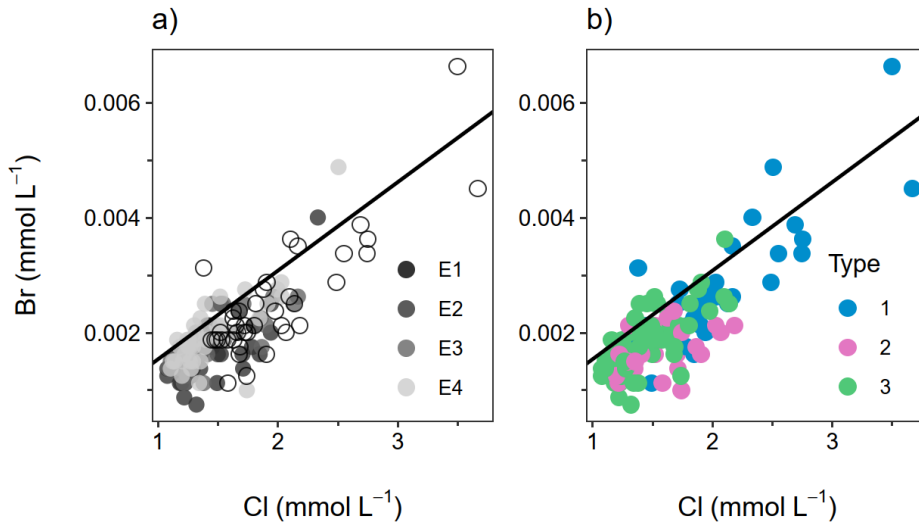


Figure S1: Cl/Br ratio of lake waters on Macquarie Island, black line shows the Cl/Br seawater ratio, classified by a) sampling event, b) lake type.

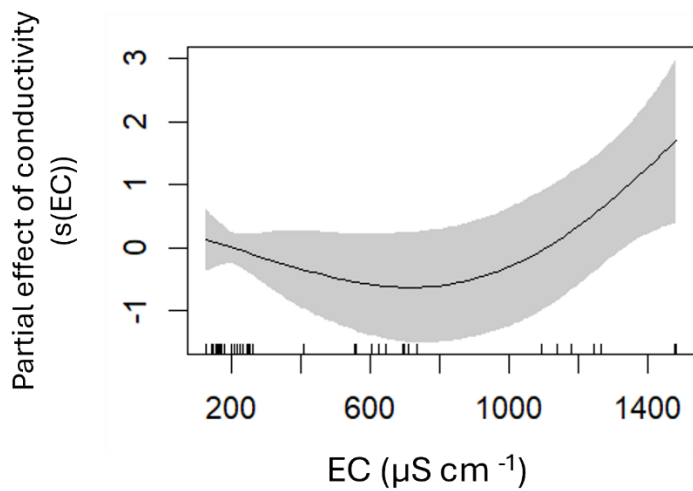


Figure S2: Generalised additive model (GAM) response curve for *Fragilaria capucina* along the electrical conductivity (EC) gradient. The fitted smooth term indicates a weakly non-linear response (edf = 2.19, $p = 0.054$), explaining ~15–16% of deviance, consistent with a broad ecological tolerance rather than a strongly defined unimodal response.

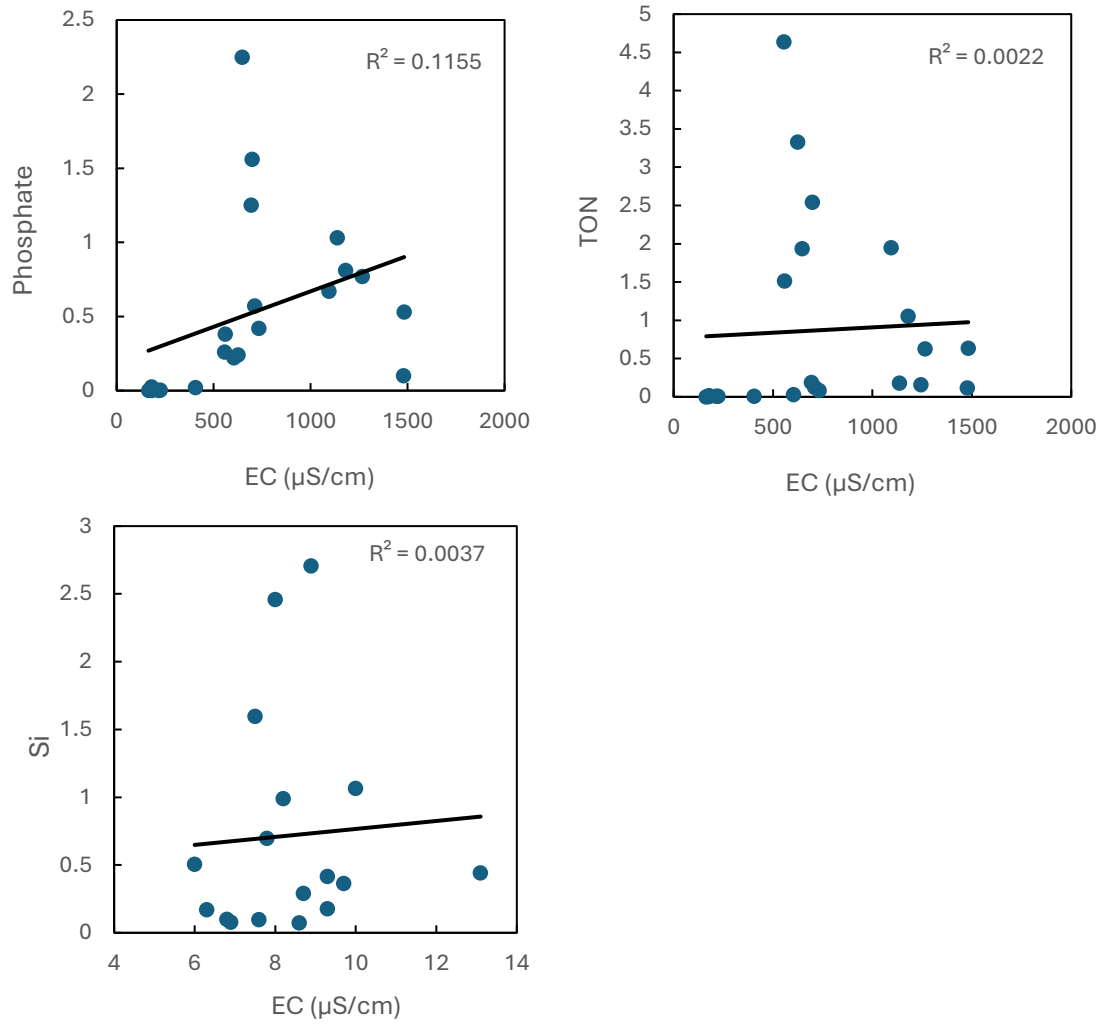


Figure S3: Linear correlations between electrical conductivity (EC) and nutrient variables from coastal lake sites.