JOURNAL OF LIMNOLOGY

DOI: 10.4081/jlimnol.2014.965

Predicting aquatic macrophyte occurrence in soft-water oligotrophic lakes (Pyrenees mountain range)

Cristina PULIDO,[1*] Joan Lluís RIERA,[2] Enric BALLESTEROS,[1] Eglantine CHAPPUIS,[1] Esperança GACIA[1]

[1]Biogeodynamics and Biodiversity Group, Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Accés a la Cala St. Francesc 14, 17300 Blanes
[2]Departament d'Ecologia, Universitat de Barcelona, Diagonal 643, 08028 Barcelona, Spain

***Corresponding author:** cpulido@ceab.csic.es

Supplementary Tab. 1. Pearson correlation between environmental variables.

	Maximum depth	Catchment area	Lake area	Vegetation	Peat bog	Alkalinity	pH	Conductivity	TP	NH_4^+	NO_3^-	Cl^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Mean Slope
Altitude	-0.07	-0.53**	0.00	-0.27*	-0.49**	-0.02	0.03	-0.04	-0.26*	-0.13	0.14	-0.06	0.08	-0.09	-0.16	-0.04	-0.02	-0.01
Maximum depth		0.17	0.43**	0.01	-0.16	-0.27*	-0.27*	-0.35**	-0.09	-0.23*	-.025*	-0.14	-0.06	-0.31**	-.021	-0.30**	-0.23*	0.42**
Catchment area			0.13	0.14	0.25*	0.04	0.09	0.00	-0.05	-0.15	0.09	-0.07	0.03	0.13	0.00	0.02	-0.03	0.10
Lake area				-0.14	-0.16	-0.10	0.00	-0.09	-0.10	-0.06	0.16	-0.07	0.10	-0.17	-0.12	-0.08	-0.09	0.11
Vegetation					0.27*	-0.14	-0.06	-0.18	-0.15	-0.20	-0.31**	-0.22*	-0.15	0.24*	-0.21	-0.15	-0.09	0.10
Peat bog						0.01	-0.07	0.03	0.29**	0.21	0.00	0.10	-0.11	0.21	0.09	0.03	0.17	0.01
Alkalinity							0.72**	0.87**	-0.10	-0.02	-0.08	0.00	0.07	0.30**	-0.01	0.095**	0.71**	-0.14
pH								0.58**	-0.09	-0.05	0.05	0.02	-0.19	0.24*	0.04	0.70**	0.27*	-0.13
Conductivity									-0.06	0.13	-0.07	0.10	0.45**	0.26*	0.07	0.95**	0.75**	-0.27*
TP										0.64**	0.12	0.59**	-0.13	0.01	0.74**	-0.10	0.07	-0.23*
NH_4^+											0.15	0.53**	0.04	0.13	0.48**	0.03	0.11	-0.42**
NO_3^-												0.06	0.00	0.01	0.14	-0.08	-0.05	-0.18
Cl^-													0.02	0.28*	0.85**	-0.02	0.17	-0.35**
SO_4^{2-}														0.08	-0.01	0.23*	0.38**	-0.20
Na^+															0.16	0.21	0.41**	-0.27*
K^+																-0.03	0.14	-0.39**
Ca^{2+}																	0.68**	-0.17
Mg^{2+}																		-0.17

*P<0.5; **P<0.1

Supplementary Tab. 2. Maximum probability (*P*max) of occurrence and optimum ranges for the environmental variables (Env. variables) that significantly explain macrophyte occurrence. Estimates of the optimum (u), the tolerance (t), the inferior range (Inf. range) and the superior range (Sup. range) were obtained from the estimates of the parameters β_1 and β_2; $u= -\beta_1/2\ \beta_2$; $t= 1/\sqrt{-2\ \beta_2}$. For each model adjusted proportion of explained deviance (D^2_{adj}) is shown. See Table 1 for units of the variables .

	Env. variables	*P*max	Optimum (u)	Tolerance (t)	Inf. range	Sup. range	D^2_{adj}
Presence of macrophytes	Altitude	0.990	Na	Na	Na	Na	0.114
	Vegetation°	0.886	Na	Na	Na	Na	0.113
	NO_3^-	0.904	1.135	3.163	0.359	3.590	0.121
	SO_4^{2-}	0.949	Na	Na	Na	Na	0.065
S. angustifolium	Altitude	0.952	Na	Na	Na	Na	0.080
	C area	0.536	Na	Na	Na	Na	-0.010
	Mean slope	0.610	11.655	1.381	8.439	16.097	0.040
	Vegetation°	0.679	Na	Na	Na	Na	0.050
	NO_3^-	0.694	1.491	3.650	0.408	5.441	0.045
I. lacustris	L depth	0.791	Na	Na	Na	Na	0.051
	Slope	0.709	Na	Na	Na	Na	0.052
	Peat bog	0.738	30.944	16.524	14.420	47.468	0.152
	Alkalinity	0.746	82.880	-161.769	36.696	139.744	0.224
	Conductivity	0.954	Na	Na	Na	Na	0.209
	pH	0.847	Na	Na	Na	Na	0.073
	Cl^-	0.672	5.026	1.788	2.812	8.985	0.106
	SO_4^{2-}	0.738	10.554	1.444	7.310	15.237	0.198
	Na^+	0.856	Na	Na	Na	Na	0.129
	K^+	0.759	2.972	1.563	1.901	4.645	0.208
	Mg^{2+}	0.893	Na	Na	Na	Na	0.189
S. aquatica	C area	0.779	Na	Na	Na	Na	0.050
	L depth	0.560	7.445	1.875	3.971	13.957	0.047
	Vegetation°	0.578	4.578	1.165	3.413	5.743	0.094
	Conductivity	0.524	22.052	1.786	12.349	39.377	0.065
	pH	0.572	7.061	0.301	6.760	7.362	0.130
	NH_4^+	0.524	1.156	1.854	0.624	2.143	0.048
	Cl^-	0.529	7.553	1.670	4.524	12.610	0.061
	SO_4^{2-}	0.563	18.059	1.390	12.990	25.105	0.054
	Na^+	0.555	24.647	1.448	17.020	35.692	0.052
	K^+	0.605	5.436	1.464	3.714	7.957	0.141
Nitella spp.	C area	0.873	Na	Na	Na	Na	0.103
	L depth	0.728	Na	Na	Na	Na	0.043
	Conductivity	0.550	30.048	1.846	16.273	55.482	0.081

	Env. variables	*P*max	Optimum (u)	Tolerance (t)	Inf. range	Sup. range	D^2_{adj}
	Alkalinity	0.612	261.979	-161.622	145.370	422.684	0.093
	pH	0.617	7.137	0.255	6.883	7.392	0.170
	TP	0.550	0.274	1.766	0.155	0.485	0.071
	Cl^-	0.540	13.679	1.758	7.781	24.046	0.054
	SO_4^{2-}	0.595	Na	Na	Na	Na	0.011
	K^+	0.544	7.732	1.823	4.241	14.096	0.059
I. echinospora	L area	0.495	Na	Na	Na	Na	0.046
	L depth	0.359	4.937	1.605	3.075	7.926	0.080
	Vegetation°	0.418	Na	Na	Na	Na	0.063
	NO_3^-	0.600	Na	Na	Na	Na	0.036
	K^+	0.369	5.823	1.456	3.999	8.481	0.097
P. berchtoldii	L depth	0.746	Na	Na	Na	Na	0.051
	Conductivity	0.906	Na	Na	Na	Na	0.166
	Alkalinity	0.900	Na	Na	Na	Na	0.120
	pH	0.872	Na	Na	Na	Na	0.195
	Mg^{2+}	0.771	Na	Na	Na	Na	0.050
R. aquatilis	C area	0.616	Na	Na	Na	Na	0.035
	L area	0.484	1.737	1.896	0.916	3.295	0.136
	Vegetation°	0.481	Na	Na	Na	Na	0.073
	Conductivity	0.422	23.458	1.521	15.423	35.680	0.088
	pH	0.485	6.890	0.230	6.660	7.121	0.152
	SO_4^{2-}	0.531	19.804	1.264	15.664	25.038	0.136
	Na^+	0.452	33.814	1.420	23.805	48.031	0.113
	K^+	0.493	8.138	1.491	5.458	12.134	0.145
P. alpinus	Vegetation°	0.505	3.401	1.014	2.387	4.415	0.051
	Conductivity	0.835	Na	Na	Na	Na	0.175
	Alkalinity	0.865	Na	Na	Na	Na	0.172
	pH	0.942	Na	Na	Na	Na	0.354
C. palustris	Altitude	0.983	Na	Na	Na	Na	0.234
	Peat bog	0.636	Na	Na	Na	Na	0.220
	Conductivity	0.291	17.364	1.449	11.983	25.161	0.096
	pH	0.479	6.499	0.282	6.217	6.781	0.174
	Na^+	0.815	Na	Na	Na	Na	0.169
M. alterniflorum	Altitude	0.909	Na	Na	Na	Na	0.150
	C area	0.806	Na	Na	Na	Na	0.188
	Vegetation°	0.327	Na	Na	Na	Na	0.097
	Conductivity	0.317	26.720	1.341	19.924	35.833	0.120
	Alkalinity	0.328	240.363	-161.772	165.565	332.189	0.145
	pH	0.497	7.152	0.096	7.056	7.249	0.324

	Env. variables	*P*max	Optimum (u)	Tolerance (t)	Inf. range	Sup. range	D^2_{adj}
R. trichophyllus	Cl^-	0.325	10.057	1.222	8.233	12.284	0.151
	Vegetation°	0.581	3.540	0.593	2.947	4.132	0.275
	Peat bog	0.157	Na	Na	Na	Na	-0.004
	Conductivity	0.642	Na	Na	Na	Na	0.166
	Alkalinity	0.607	Na	Na	Na	Na	0.137
	pH	0.695	Na	Na	Na	Na	0.241
	NO_3^-	0.282	6.572	1.416	4.641	9.308	0.119
	SO_4^{2-}	0.448	Na	Na	Na	Na	0.104
	Na^+	0.494	21.584	1.134	19.029	24.483	0.338
	K^+	0.250	6.645	1.370	4.850	9.104	0.115
	Mg^{2+}	0.439	Na	Na	Na	Na	0.066

C, catchment; L, lake; Na, not available. °Dominant catchment vegetation: 1, without vegetation; 2, *Festuca eskia,* 3, mixed meadows of *Festuca* spp. with shrubs of *Rhododendron ferrugineum;* 4, *Carex curvula,* 5, *R. ferrugineum;* 6, *Pinus uncinata.*

Supplementary Tab. 3. List of multiple logistic regression models for presence of macrophytes and for each macrophyte species within each confidence set (models with ΔAICc ≤ 2). For each model, the following statistics are shown Akaike information criteria corrected for the number of samples (AICc), delta Akaike information criteria corrected for the number of samples (ΔAICc) and Akaike weight (Weight). All environmental variables have been log transformed except altitude, vegetation, peat bog and pH. See Tab. 1 for units of the variables.

	N	Model	AICc	ΔAICc	Weight
Presence of macrophytes	1	15.523 Intercept -0.004 Altitude -1.560 SO_4^{2-} +0.245 Vegetation$^{\circ}$ +0.253 NO_3^- -0.417 NO_3^{-2}	86.750	0.000	1.000
S. angustifolium	1	-35.382 Intercept -0.004 Altitude +0.502 Vegetation$^{\circ}$ +35.110 Mean slope -7.093 Mean slope^2	104.067	0.000	0.563
	2	-33.979 Intercept -0.004 Altitude +34.139 Mean Slope -6.870 Mean Slope^2 +0.437 Vegetation$^{\circ}$ +0.150 NO_3^- -0.203 NO_3^{-2}	105.943	1.876	0.220
	3	-33.926 Intercept -0.004 Altitude -0.138 Catchment area +34.600 Mean slope -6.964 Mean slope^2 +0.530 Vegetation$^{\circ}$	105.980	1.913	0.216
I. lacustris	1	10.856 Intercept -3.890 Conductivity + 0.139 Peat bog -0.003 Peat bog^2	48.582	0.000	0.316
	2	14.766 Intercept -3.356 Conductivity +0.170 Peat bog -0.003 Peat bog^2 -1.782 Na	49.152	0.570	0.237
	3	-2.491 Intercept -5.327 Conductivity +0.131 Peat bog -0.003 Peat bog^2 +2.530 pH	49.765	1.182	0.175
	4	6.787 Intercept -3.637 Conductivity +0.131 Peat bog -0.003 Peat bog^2 +1.276 Mean slope	50.094	1.512	0.148
	5	4.387 Intercept -3.200 Conductivity +0.107 Peat bog -0.002 Peat bog^2 +8.020 K^+ -3.003 K^{+2}	50.453	1.871	0.124
S. aquatica	1	-218.698 Intercept +3.431 Vegetation$^{\circ}$ -0.375 Vegetation^2 +59.279 pH -4.147 pH^2	65.335	0.000	0.313
	2	-230.727 Intercept +63.395 pH -4.472 pH^2 +8.448 K^+ -2.586 K^{+2}	66.088	0.753	0.215
	3	-210.990 Intercept +57.058 pH -4.005 pH^2 +8.616 Cl^- -2.159 Cl^{-2}	66.103	0.768	0.213
	4	-185.596 Intercept +3.485 Vegetation$^{\circ}$ -0.3855 Vegetation^2 +49.925 pH-3.480 pH^2 + 0.303NH_4^+ -1.167 NH_4^{+2}	67.000	1.665	0.136
	5	-189.589 Intercept +0.218 Catchment area +3.3808 Vegetation -0.378 Vegetation^2 +50.925 pH -3.566 pH^2	67.224	1.890	0.122
P. berchtoldii	1	-13.783 Intercept +1.995 Lake depth +3.202 Conductivity	54.476	0.000	1.000
Nitella spp.	1	-435.602 Intercept +0.599 Catchment area +116.910 pH -8.133 pH^2 +10.115 Cl -1.837Cl^{-2}	60.603	0.000	0.457
	2	-434.833 Intercept +0.555 Catchment area +0.907 Lake depth +116.052 pH-8.071 pH^2 +10.601 Cl^- -1.898 Cl^{-2}	61.223	0.621	0.335
	3	-475.357 Intercept +1.004 Lake depth +129.046 pH -9.518 pH^2 +9.518 Cl^- -1.732 Cl^{-2}	62.183	1.581	0.207
I. echinospora	1	-12.600 Intercept -0.752 Lake area +0.421 Vegetation$^{\circ}$ +12.189 K^+ -3.427K^{+2}	79.848	0.000	0.502
	2	-11.942 Intercept -0.685 Lake area +0.363 Vegetation$^{\circ}$ -	80.931	1.083	0.292

	N	Model	AICc	ΔAICc	Weight
		$0.327NO_3^-$ +12.290 K^+ -3.441 $^{\circ}K^{+2}$			
	3	-10.367 Intercept -0.589 Lake area -0.469 NO_3^- +12.516 K^+ -3.531 K^{+2}	81.633	1.785	0.206
R. aquatilis	1	-2473.171 Intercept +2.191 Catchment area -6.377 Lake area -5.138 Lake area^2 +702.869 pH -50.988 pH^2 +41.102 K^+ -8.814 K^{+2}	35.070	0.000	1.000
P. alpinus	1	-80.035 Intercept -3.155 Conductivity +12.521 pH	43.010	0.000	0.596
	2	Intercept + pH	43.785	0.775	0.404
C. palustris	1	-491.720 Intercept -0.018 Altitude +162.653 pH -12.653 pH^2 +3.004 Na^+	28.792	0.000	0.232
	2	-518.077 Intercept +109.523 Conductivity -18.939 Conductivity^2 -0.035 Altitude +147.154 pH -12.184 pH^2	29.122	0.330	0.197
	3	-539.533 Intercept +148.976 Conductivity -25.599 Conductivity^2 -0.033 Altitude +0.046 Peat bog +132.767 pH -11.008 pH^2	29.424	0.631	0.169
	4	-21.895 Intercept +27.677 Conductivity -6.061 Conductivity^2 -0.0146 Altitude +6.726 Na^+	29.693	0.901	0.148
	5	-57.126 Intercept +44.541 Conductivity -8.553 Conductivity^2 -0.010 Altitude +0.037 Peat bog +5.708 Na^+	29.959	1.167	0.129
	6	-498.330 Intercept +81.065 Conductivity -14.798 Conductivity^2 -0.031 Altitude +143.132 pH -11.492 pH^2 +3.746 Na^+	30.026	1.234	0.125
M. alterniflorum	1	-7351.590 Intercept -0.0231 Altitude +2013.417 pH -149.922 pH^2 +191.817 Cl^- -42.927 Cl^{-2}	25.869	0.000	0.677
	2	-8833.000 Intercept -0.021 Altitude +0.506 Catchment area +242.300 pH -169.7 pH^2 +208.200 Cl^- -46.580 Cl^{-2}	27.347	1.478	0.323
R. trichophyllus	1	-604.403 Intercept +22.296 Conductivity +45.508 Vegetation -5.748 Vegetation^2 +483.850 K^+ -128.934 K^{+2}	21.788	0.000	0.346
	2	-1671.87 Intercept +51.640 Alkalinity + 120.270 Vegetation -15.110 Vegetation^2 +35.530 SO_4^{2-} +1136.140 K^+ -307.14 K^{+2}	22.788	1.000	0.210
	3	-258.033 Intercept +16.422 Conductivity -3.970 Na^+ -4.635 Na^{+2} +293.467 K^+ -80.666 K^{+2}	23.312	1.524	0.162
	4	-1438.143 Intercept +45.161Conductivity +99.522 Vegetation -12.307 Vegetation^2 +9.666 SO_4^{2-} +1157.874 K^+ -307.843 K^{+2}	23.451	1.663	0.151
	5	-720.902 Intercept +18.498 Conductivity +10.202 Alkalinity +52.022 Vegetation -6.501 Vegetation^2 +543.923 K^+ -145.078 K^{+2}	23.732	1.944	0.131

°Dominant catchment vegetation: 1, without vegetation; 2, *Festuca eskia,* 3, mixed meadows of *Festuca* spp. with shrubs of *Rhododendron ferrugineum;* 4, *Carex curvula,* 5, *R. ferrugineum;* 6, *Pinus uncinata.*