

Supplementary information

**Experimental evidence of high-dimensional elementome shifts
due to coexistence and its effects on growth rates**

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11 **Table S1:** Water chemistry at the beginning and end of the experiment. Three replicates were taken from the initial solution, from which the mean
12 per compound was calculated. The mean concentration of the 20 microcosmos was also calculated and was used to estimate the average change
13 per compound. Positive values in the mean change indicate higher concentrations at the end of the experiment compared to the beginning.

	NO ₃ ⁻ (ppm)	Cl ⁻ (ppm)	Na (ppm)	K (ppm)	Ca (ppm)	SO ₄ ²⁻ (ppm)	Mg (ppm)	P (ppm)	PO ₄ ³⁻ (ppb)	B (ppb)	Zn (ppb)	Fe (ppb)	Mn (ppb)
Initial 1	14.38	11.40	6.65	6.03	3.15	3.28	0.97	0.08	78.57	63.81	53.01	1.70	0.40
Initial 2	12.63	9.92	7.45	6.59	3.46	2.64	1.04	0.05	78.14	67.82	105.13	2.75	0.49
Initial 3	12.44	9.38	6.72	6.31	3.37	2.28	1.02	0.06	94.63	61.66	19.81	0.63	0.36
Mean Initial	13.15	10.24	6.94	6.31	3.33	2.73	1.01	0.06	83.78	64.43	59.32	1.69	0.42
Microcosmos 1	<0.20	12.37	8.81	3.24	4.04	0.20	0.87	0.07	145.42	63.38	20.62	4.94	0.61
Microcosmos 2	<0.20	12.45	9.53	0.95	9.37	3.17	1.12	0.00	32.12	51.75	5.23	2.97	0.13
Microcosmos 3	<0.20	13.93	8.96	2.72	3.76	0.20	0.77	0.04	64.25	66.87	16.27	6.03	0.61
Microcosmos 4	<0.20	11.55	9.25	3.65	3.78	0.65	0.81	0.03	103.75	61.90	12.70	9.48	0.70
Microcosmos 5	<0.20	12.37	10.14	1.35	9.22	1.82	1.14	0.00	55.13	51.51	9.34	4.84	0.38
Microcosmos 6	<0.20	19.17	13.25	5.42	14.76	1.67	1.43	0.02	61.64	54.61	8.03	3.09	1.95
Microcosmos 7	<0.20	12.95	8.80	3.97	4.03	1.29	0.84	0.00	53.83	51.44	10.18	3.75	0.42
Microcosmos 8	<0.20	4.79	6.36	0.98	4.62	0.20	0.65	0.01	59.90	42.49	9.21	4.30	0.38
Microcosmos 9	<0.20	13.05	10.60	4.09	6.50	2.37	1.09	0.00	31.25	58.62	5.95	1.07	0.17
Microcosmos 10	<0.20	13.02	8.71	3.49	4.78	2.17	0.95	0.00	42.54	59.18	9.36	1.59	0.39
Microcosmos 11	<0.20	11.71	8.80	4.82	3.97	0.20	0.83	0.01	58.60	54.95	10.41	9.38	0.89
Microcosmos 12	<0.20	15.15	10.70	3.69	5.01	3.97	0.88	0.00	67.72	68.82	48.87	3.17	1.51
Microcosmos 13	<0.20	16.58	9.65	3.80	5.91	2.31	1.13	0.00	30.39	65.51	7.62	1.67	0.51
Microcosmos 14	<0.20	8.99	5.80	2.34	3.14	0.20	0.63	0.00	60.77	43.53	11.41	5.34	0.55
Microcosmos 15	<0.20	13.06	9.08	4.74	3.55	0.20	0.72	0.02	72.93	52.46	10.57	3.62	1.48
Microcosmos 16	<0.20	13.40	8.21	3.71	3.81	0.20	0.77	0.03	100.71	64.91	11.34	11.13	1.14
Microcosmos 17	<0.20	11.37	7.18	4.13	2.81	0.20	0.62	0.00	70.32	49.65	9.70	6.40	1.12
Microcosmos 18	<0.20	7.76	5.59	1.57	1.89	0.20	0.39	0.01	72.06	42.17	8.19	5.68	0.80
Microcosmos 19	<0.20	11.00	7.21	3.39	5.05	0.20	0.80	0.00	73.36	49.55	13.40	2.85	1.60
Microcosmos 20	<0.20	11.52	7.52	1.45	4.92	0.20	0.68	0.00	84.65	46.81	7.17	3.51	1.25
Mean Final	<0.20	12.31	8.71	3.17	5.25	1.08	0.86	0.01	67.07	55.00	12.28	4.74	0.83
Mean Change (%)	-98%	20%	26%	-50%	58%	-60%	-15%	-80%	-20%	-15%	-79%	180%	98%

15 **Table S2:** Species composition of each microcosm.

Microcosmos	Species identity	Richness
1	<i>C. filicinum</i>	1
2	<i>L. riparium</i> , <i>C. filicinum</i>	2
3	<i>R. riparioides</i> , <i>C. filicinum</i> , <i>F. grandifrons</i>	3
4	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>R. riparioides</i> , <i>C. filicinum</i>	4
5	<i>L. riparium</i>	1
6	<i>F. antipyretica</i> , <i>R. riparioides</i>	2
7	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>F. grandifrons</i>	3
8	<i>L. riparium</i> , <i>R. riparioides</i> , <i>C. filicinum</i> , <i>F. grandifrons</i>	4
9	<i>L. riparium</i>	1
10	<i>L. riparium</i> , <i>F. grandifrons</i>	2
11	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>R. riparioides</i>	3
12	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>R. riparioides</i> , <i>F. grandifrons</i>	4
13	<i>F. grandifrons</i>	1
14	<i>R. riparioides</i> , <i>F. grandifrons</i>	2
15	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>C. filicinum</i>	3
16	<i>F. antipyretica</i> , <i>R. riparioides</i> , <i>C. filicinum</i> , <i>F. Grandifrons</i>	4
17	<i>F. antipyretica</i>	1
18	<i>F. antipyretica</i> , <i>C. filicinum</i>	2
19	<i>F. antipyretica</i> , <i>R. riparioides</i> , <i>F. grandifrons</i>	3
20	<i>L. riparium</i> , <i>F. antipyretica</i> , <i>C. filicinum</i> , <i>F. grandifrons</i>	4

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Table S3: Summary table showing the goodness of fit of the best models explaining variability in moss growth rates at the sample level (N=50) as a function of a diversity metric, species (including their interaction to test overyielding), the elemental composition of mosses, and the percent of nutrients removed from water. Diversity metrics were species richness, Shannon's diversity index (H), functional dispersion (FDis), functional divergence (Fdiv), Rao's quadratic entropy index (RaoQ), elemental dissimilarity index (ED) and proportional elemental variability (PVe). Standardised versions are indicated with a "std" suffix. Marginal R^2 is the variance explained by fixed effects, and conditional R^2 is the variance explained by both fixed and random effects.

Diversity index	R^2_m	R^2_c	BIC	Δ BIC
Richness	0.77	0.77	83.2	0.0
FDiv	0.77	0.77	83.6	0.4
ED.std	0.76	0.76	86.4	3.2
H	0.75	0.75	87.7	4.5
ED	0.75	0.75	87.8	4.6
FDiv.std	0.70	0.70	93.4	10.2
RaoQ.std	0.72	0.72	94.8	11.6
RaoQ	0.70	0.70	97.6	14.4
FDis.std	0.68	0.68	100.0	16.8
FDis	0.68	0.68	100.2	17.0
PVe	0.68	0.68	100.7	17.5

Table S4: Model coefficients and ANOVA table showing the results of the model explaining growth rates when removing monocultures using species richness as a predictor. Results and their interpretation remained unchanged compared to those shown in **Figure S4**. Significance levels: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Model estimates	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.01524	0.35519	2.858	0.00426	**
B.ugg	0.37436	0.10223	3.662	0.00025	***
P.mgg	-0.3896	0.18656	-2.088	0.03677	*
especieFissiGran	-2.38398	0.55652	-4.284	1.84E-05	***
especieFontAnti	-1.0965	0.52576	-2.086	0.03702	*
especieLeptoRip	0.16589	0.32433	0.511	0.60902	
especiePlatyRipa	-1.63351	0.38865	-4.203	2.63E-05	***
Species Richness	-0.38664	0.15385	-2.513	0.01197	*
especieFissiGran:Species Richness	0.22598	0.21514	1.05	0.29356	
especieFontAnti:Species Richness	0.20055	0.21711	0.924	0.35563	
especieLeptoRip:Species Richness	1.10258	0.22191	4.969	6.74E-07	***
especiePlatyRipa:Species Richness	-0.02541	0.21269	-0.119	0.9049	
ANOVA table	Chisq	Df	Pr(>Chisq)		
(Intercept)	8.17	1	0.004259	**	
B.ugg	13.4109	1	0.0002502	***	
P.mgg	4.3611	1	0.0367679	*	
especie	89.9702	4	< 2.2e-16	***	
Species Richness	6.3153	1	0.0119699	*	
especie:Species Richness	32.9062	4	1.25E-06	***	

Table S5: Model coefficients and ANOVA table showing the results of the model explaining growth rates when removing monocultures using the elemental divergence index (Fdiv) as a predictor. Results and their interpretation remained unchanged compared to those shown in **Figure S3**. Significance levels: . $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.20198	0.37105	3.239	0.0012	**
B.ugg	0.32103	0.10749	2.987	0.00282	**
P.mgg	-0.50522	0.19506	-2.59	0.0096	**
especieFissiGran	-2.65873	0.58322	-4.559	5.15E-06	***
especieFontAnti	-1.41715	0.54721	-2.59	0.0096	**
especieLeptoRip	0.02076	0.34014	0.061	0.95133	
especiePlatyRipa	-1.81335	0.40642	-4.462	8.13E-06	***
Fdiv	0.32905	0.16876	1.95	0.0512	.
especieFissiGran:Fdiv	-0.16368	0.2342	-0.699	0.48462	
especieFontAnti:Fdiv	-0.11474	0.23121	-0.496	0.61971	
especieLeptoRip:Fdiv	-0.8938	0.22957	-3.893	9.89E-05	***
especiePlatyRipa:Fdiv	0.09171	0.23288	0.394	0.69374	

	Chisq	Df	Pr(>Chisq)	
(Intercept)	10.4938	1	0.0011977	**
B.ugg	8.9195	1	0.0028214	**
P.mgg	6.7085	1	0.0095953	**
especie	80.2727	4	< 2.2e-16	***
Fdiv	3.8019	1	0.0511956	.
especie:Fdiv	23.3497	4	0.0001078	***

Table S6: Model coefficients and ANOVA table showing the results of the model explaining growth rates when removing monocultures using the standardised elementome dissimilarity index (ED.std) as a predictor. Results and their interpretation remained unchanged compared to those shown in **Figure S4**. Significance levels: . $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.06276	0.37603	2.826	0.004709	**
B.ugg	0.33113	0.10318	3.209	0.001331	**
P.mgg	-0.40521	0.20054	-2.021	0.043327	*
especieFissiGran	-2.43873	0.59747	-4.082	4.47E-05	***
especieFontAnti	-1.1723	0.55276	-2.121	0.033938	*
especieLeptoRip	0.07396	0.34039	0.217	0.828002	
especiePlatyRipa	-1.71383	0.40829	-4.198	2.70E-05	***
ED.std	-0.34227	0.18171	-1.884	0.059622	.
especieFissiGran:ED.std	0.22416	0.23769	0.943	0.345629	
especieFontAnti:ED.std	0.1493	0.24281	0.615	0.538634	
especieLeptoRip:ED.std	0.92912	0.24638	3.771	0.000163	***
especiePlatyRipa:ED.std	-0.12748	0.23703	-0.538	0.590688	

	Chisq	Df	Pr(>Chisq)	
(Intercept)	7.9879	1	0.004709	**
B.ugg	10.2992	1	0.001331	**
P.mgg	4.0826	1	0.043327	*
especie	76.6207	4	9.05E-16	***
ED.std	3.5479	1	0.059622	.
especie:ED.std	23.5663	4	9.76E-05	***

Table S7: Summary table of the performance of the eleven diversity indices explaining variability in the within-species pairwise elemental distance between moss samples living in mixtures compared to their elemental composition living in monocultures. Diversity metrics were species richness, Shannon’s diversity index (H), functional dispersion (FDis), functional divergence (Fdiv), Rao’s quadratic entropy index (RaoQ), elemental dissimilarity index (ED) and proportional elemental variability (PVe). Standardised versions are indicated with a “std” suffix.

Diversity index	df	BIC	Δ BIC
RaoQ.std	6	136.30	0
FDis.std	6	136.96	0.66
ED.std	6	138.88	2.58
ED	6	141.12	4.82
PVe	6	141.32	5.02
H	6	142.43	6.13
Richness	6	143.33	7.03
RaoQ	6	143.36	7.06
FDis	6	144.02	7.72
FDiv	6	147.33	11.03
FDiv.std	6	148.19	11.89

Figure S1: Scheme showing the different parts of one of the experimental microcosms (out of 20). 1: Microcosm, including the moss contained within a mesh; 2: Aeration water pot; 3: Air pump; 4: Peristaltic water pump; 5: Full spectrum grow lights (12 in total for the entire experiment).

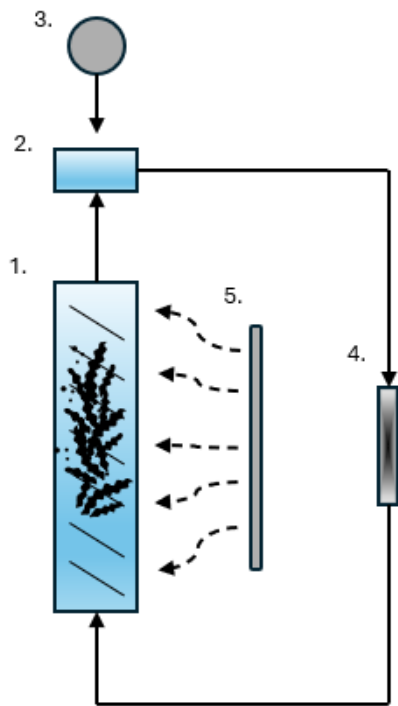


Figure S3: Partial residual plots showing the species-specific growth rate (logged) as a function of elemental divergence (panel a), and the effect of moss P (panel b) and B (panel c) elemental concentrations on growth rates across species. Beta indicates standardised parameter estimates ($\pm$ standard error of the mean).

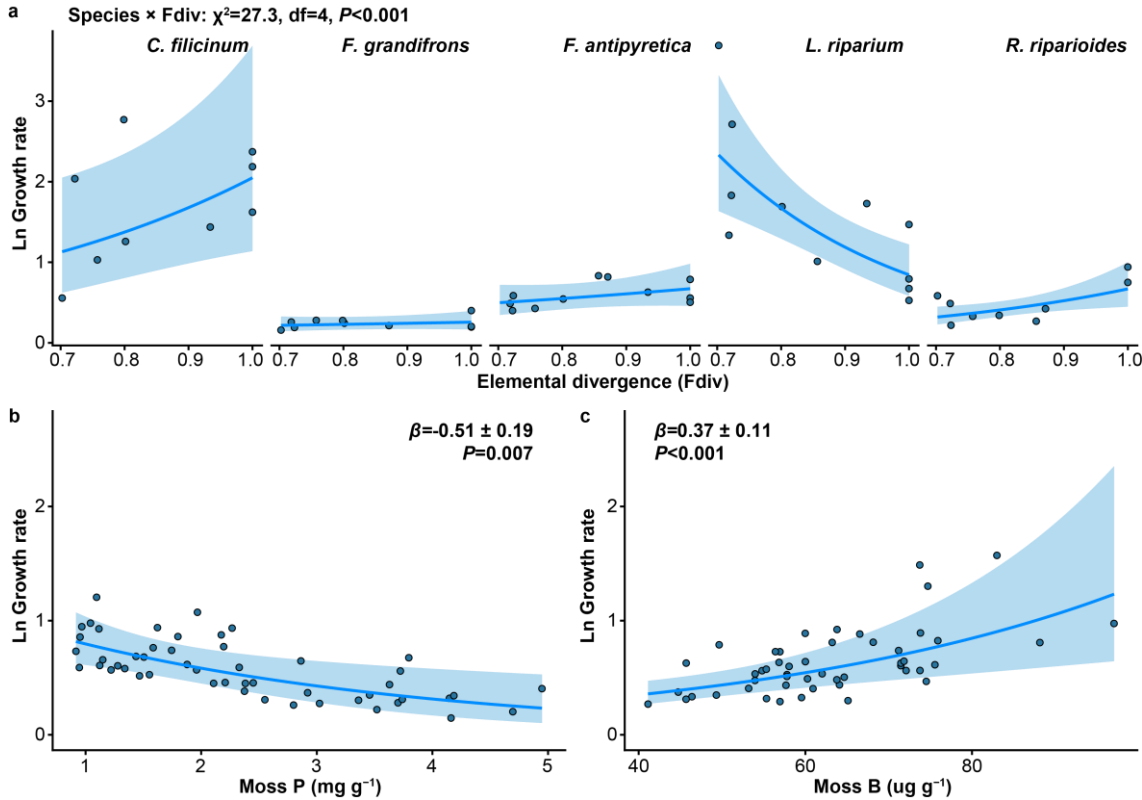


Figure S4: Partial residual plots showing the species-specific growth rate (logged) as a function of elemental dissimilarity index (panel a), and the effect of moss P (panel b), B (panel c), N (panel d) and Ca (panel e) elemental concentrations on growth rates across species. Results for N and Ca come from a candidate model with a difference in BIC of 2.9 units with respect to the best fitting model (which included P and B). Beta coefficients indicate standardised parameter estimates ($\pm$ standard error of the mean).

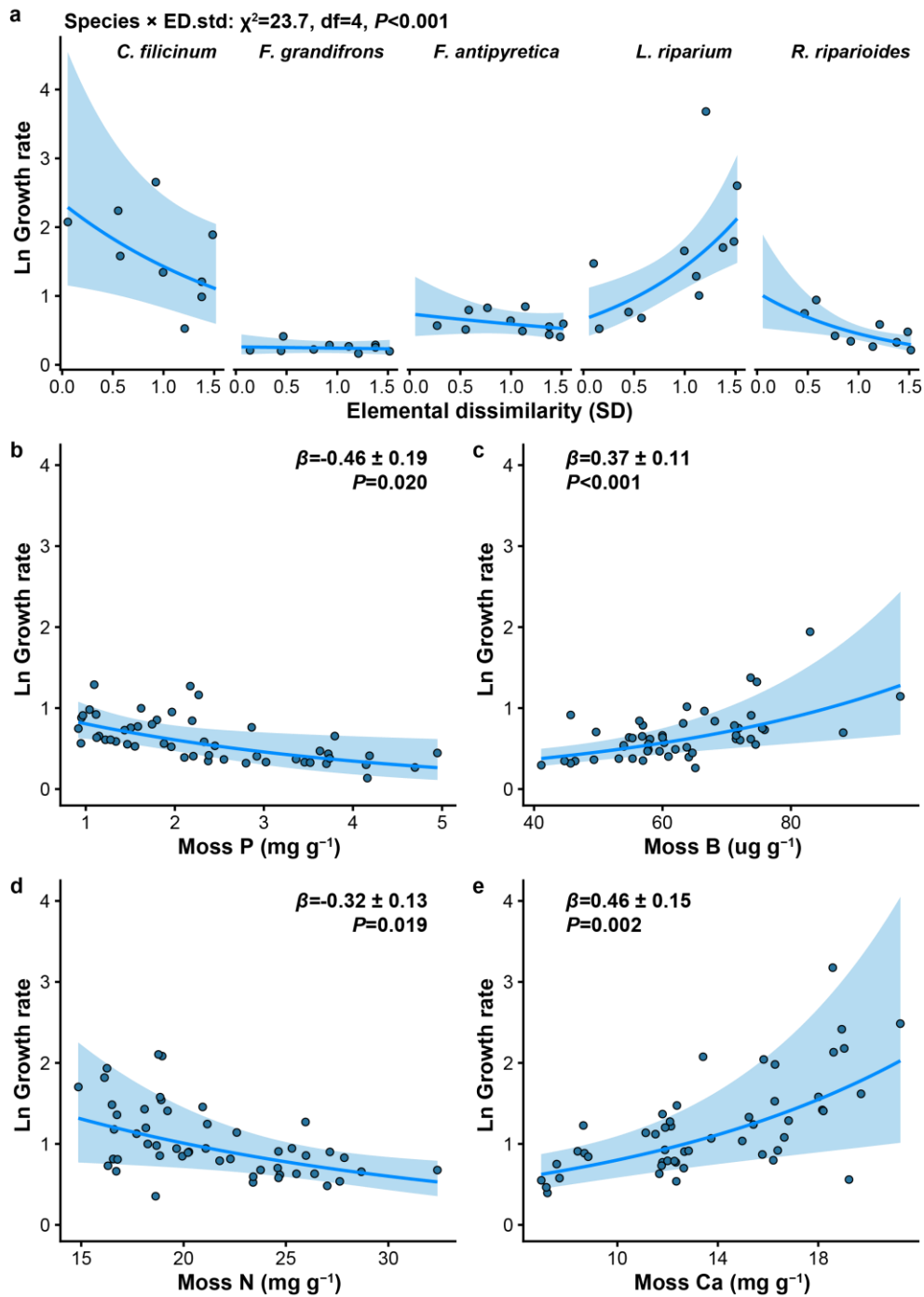


Figure S5: Values and pairwise comparisons of the bioelemental space occupied by the experimental species. The blue shading represents the 95% confidence intervals of the means. Non-overlapping arrows indicate statistically significant differences between species at the 0.05 level.

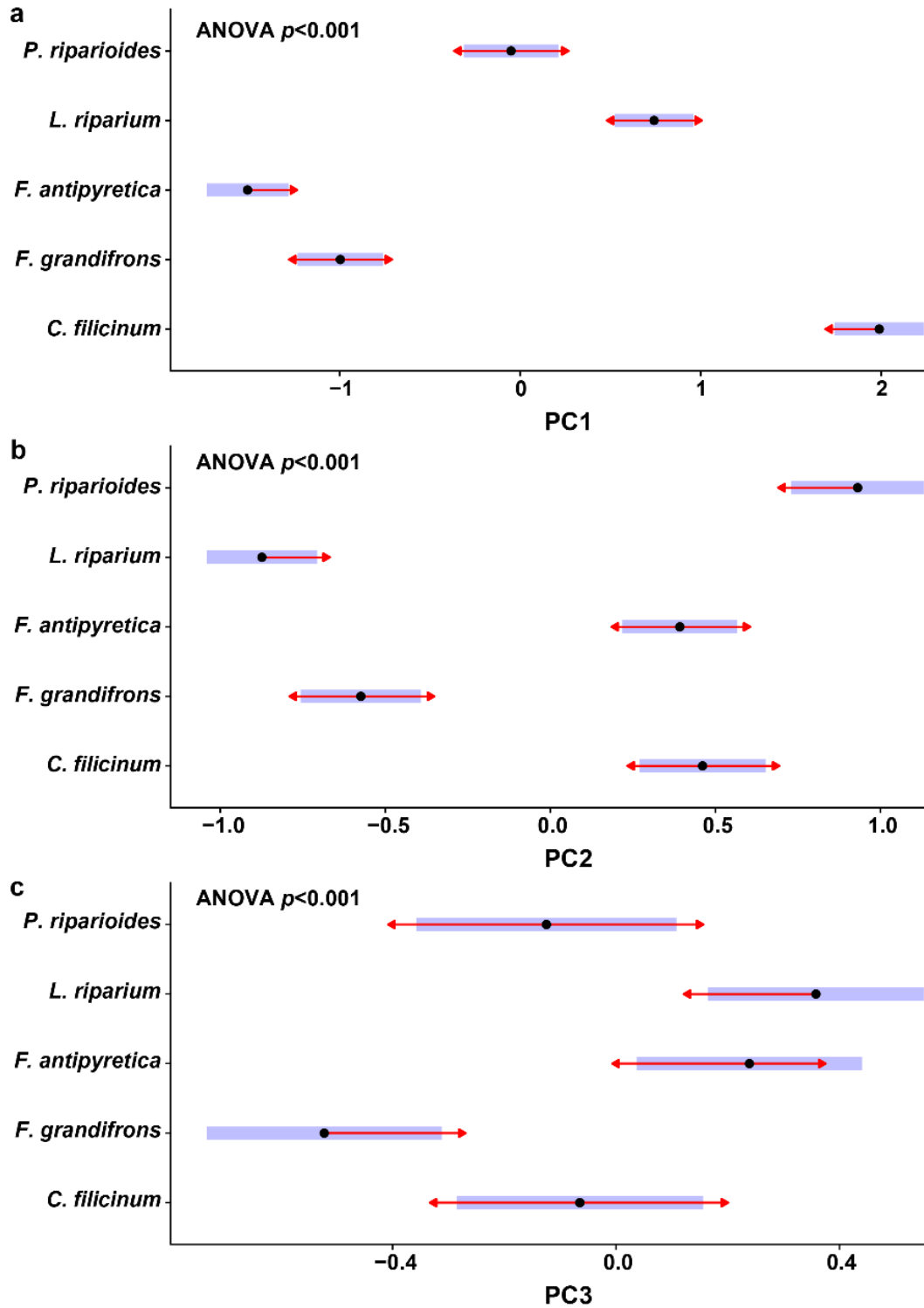


Figure S6: Partial residuals plots showing the relationship between growth rate and the N and P contents, at the sample level. The analyses were performed using mixed-effects models in which log growth rate was the response variable, and N or P content were the fixed effects together with species identity. The random factor was the microcosm identity.

