Supplementary Information for **Strong self-regulation and widespread facilitative interactions between groups of phytoplankton -** Picoche, C. & Barraquand F.

Data collection

We analyzed phytoplankton time series from 10 sites, located in 4 regions in France (Supplementary Fig. 1). Distance between sites did not exceed 92 km in a region. Phytoplankton dynamics in each site were determined by both interactions within the planktonic communities and environmental parameters which could be partly captured by temperature and salinity (Supplementary Table 1). The mean temperature in each region mostly depended in its latitude while salinity in one can site could be considered as a proxy for terrestrial inputs from rivers, evaporation (mostly for the Mediterranean sea) and variation of sea height due to the tidal regime (mostly for the Atlantic ocean).

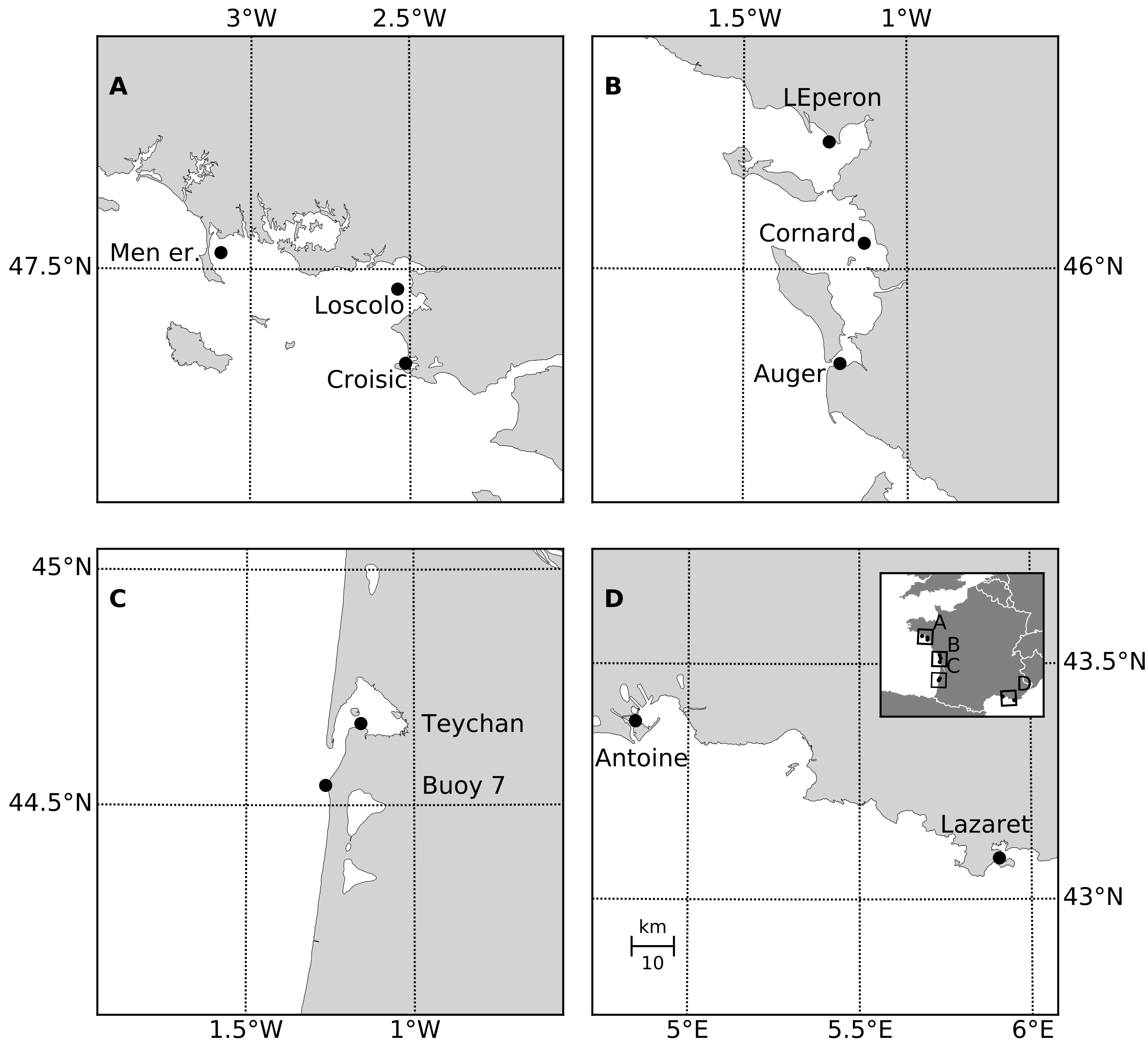

Figure 1: **Location of each study site in their region**: Brittany (A), Oléron (B), Arcachon (C) and the Mediterranean Sea (D). The common scale of the panels in given in the left corner of D.

Name of site	Location	Region	N. samples	Temperature (°C)	Salinity (g/L)
Men Er Roue	47°32' N / 3°5' W	Brittany	503	14.4 +/- 3.7	33.5 +/- 1.9
Loscolo	47°27' N / 2°32' W	Brittany	463	14.9 +/- 4.0	32.0 +/- 3.0
Croisic	47°18' N / 2°30' W	Brittany	500	14.7 +/- 3.9	31.8 +/- 3.1
L'Eperon	46°16' N / 1°14' W	Oléron	460	15.3 +/- 4.8	32.1 +/- 3.2
Cornard	46°3' N / 1°7' W	Oléron	491	15.6 +/- 4.8	32.7 +/- 2.4
Auger	45°47' N / 1°12' W	Oléron	524	15.4 +/- 4.4	32.7 +/- 1.8
Buoy 7	44°32' N / 1°15' W	Arcachon	311	15.2 +/- 3.8	34.7 +/- 0.7
Teychan	44°40' N / 1°9' W	Arcachon	494	15.5 +/- 4.6	32.5 +/- 1.9
Antoine	43°22' N / 4°50' E	Mediterranean Sea	539	16.8 +/- 5.1	32.3 +/- 3.9
Lazaret	43°5' N / 5°54' E	Mediterranean Sea	512	17.4 +/- 4.2	35.9 +/- 2.4

Table 1: **Summary of the study site characteristics**, including the mean and standard deviation of the two main environmental parameters (temperature and salinity).

Among the 600 taxa which were identified at several taxonomic levels, we focused on the most frequent groups of species and gathered them in taxonomic units previously defined on the REPHY dataset(Supplementary Table 2, according to[1]). These taxonomic units, hereafter called 'groups', approximated genera or groups of genera, except for two families in the Arcachon region the euglenophytes and cryptophytes, which were considered abundant enough to be taken into account but could not be identified at a lower taxonomic level with optic microscopy. The dynamics of each group can be see in Fig. 2.

Code	Taxa
AST	Asterionella+Asterionellopsis+Asteroplanus
CHA	Chaetoceros
CRY	Cryptophytes
DIT	Ditylum
EUG	Euglenophytes
GUI	Guinardia
GYM	Gymnodinium+Gyrodinium
LEP	Leptocylindrus
NIT	Nitzschia+Hantzschia
PLE	Pleurosigma+Gyrosigma
PRO	Prorocentrum
PRP	Protoperidinium+Archaeperidinium+Peridinium
PSE	Pseudo-nitzschia
RHI	Rhizosolenia+Neocalyptrella
SCR	Scrippsiella+Ensiculifera+Pentapharsodinium+Bysmatrum
SKE	Skeletonema
THL	Thalassionema+Lioloma
THP	Thalassiosira+Porosira

Table 2: **Name and composition of the phytoplanktonic groups used in the paper**, based on[1]

Figure 2: **Time series of phytoplanktonic groups in each site**.

MAR(1) models

We focused on the most parsimonious community matrices in each site to avoid over-parameterization. Interactions scenarios were compared in each site, based on phylogenetic proximity of each group (see Methods in main paper). The ranking of scenario BIC was remarkably consistent between sites for 3 scenarios among 5 (Fig. 3): BIC was lowest for the null scenario, i.e. with no interaction between groups, then minimized by the pennate-centric model which implied interactions only within pennate diatom, centric diatoms or dinoflagellates groups, and no interaction between them. The highest BIC was always reached for the unconstrained scenario, which estimated all interaction strengths. The two other scenarios (diatom-dinoflagellate and inter-group scenarios) differentiated between diatoms and dinoflagellates, to allow interactions within (respectively between) those groups and forbid interactions between (respectively within) them. The diatom-dinoflagellate scenario had a lower BIC than the inter-group scenario in Arcachon and the Mediterranean Sea, and a higher BIC in Brittany and Oléron.

Based on these results, we focused on the pennate-centric scenario to analyze community matrix as they corresponded to the best fitted model which still allowed interactions between groups.

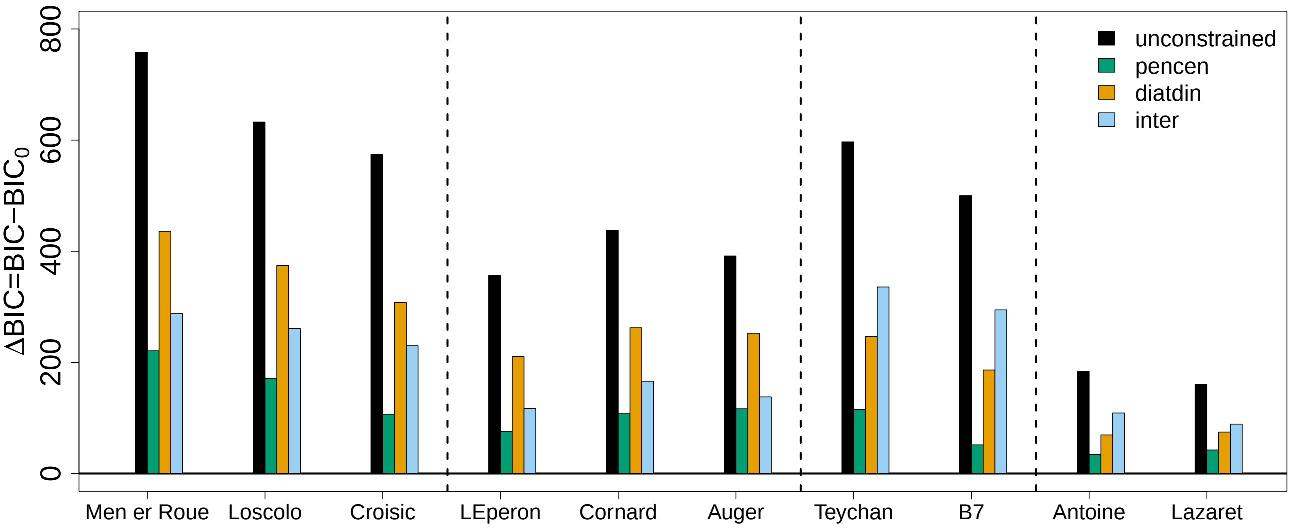

Figure 3: **Comparison of the BIC of different interaction scenarios**, compared to the null scenario (diagonal interaction matrix, allowing only intragroup interactions), for 10 sites in 4 different regions, separated by dashed lines (Brittany, Oléron, Arcachon and the Mediterranean Sea). Different interaction matrices may allow interactions between all taxa (unconstrained), only interactions within pennate diatoms, centric diatoms, dinoflagellates, or other phytoplanktonic taxa (pencen), only interactions within diatoms, dinoflagellates or other taxa (diatdin), or only interactions between taxa belonging to these different groups. As model structures (length of the times series taken into account) are different between sites and regions, groups of bars should not be compared.

In additon to the coefficients of the interaction matrix, MAR(1) models allowed us to estimate the effect of environmental variables. Even though these variables are not the focus of this paper, they enable us to take into account the part of the phytoplankton dynamics which did not depend on interactions, such as phenology (temperature, related to insolation) or hydrological changes such as salinity variation (Fig. 4). Temperature always had a stronger impact than salinity on phytoplanktonic dynamics (XXX proportion of significant). The sign of significant temperature effects on a given species remained the same between regions, except for SKE, which was negatively affected by temperature in Brittany and Marennes-Oléron but positively affected by temperature in the Mediterranean Sea. Significant temperature effects were positive in XX % of the parameters. On the other hand, salinity rarely had a significant effect at the 95% threshold (XX) and it was negative in XX percent of the times in this case.

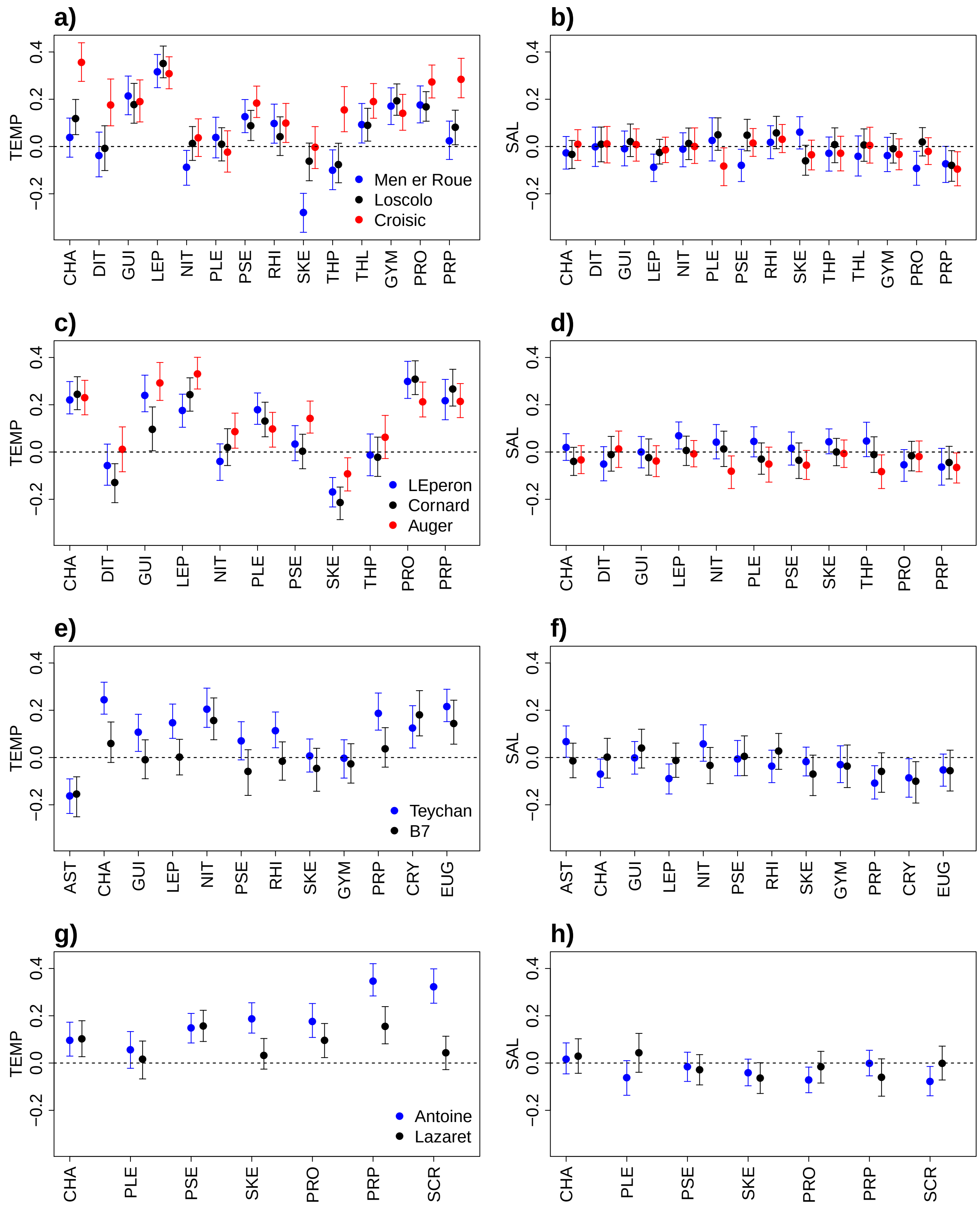

Figure 4: **Effect of environmental variables (temperature, TEMP or salinity, SAL) on phytoplankton group** in Brittany (a, b), Oléron (c, d), Arcachon (e, f) and in the Mediterranean Sea (g, h). Each color corresponds to a different site. Error bars correspond to the 95% confidence interval around the estimated coefficient. All variables were normalized before estimation.

Network analysis

Metrics

We characterized each interaction network with 4 quantitative descriptors: the mean and variance of the intra- and intergroup coefficients (i.e., on and off the matrix diagonal) and the linkage density and weighted connectance of **B–I**. Absolute values of intragroup coefficients were approximately XX times higher than the absolute effects of intergroup interactions while the intragroup interaction's deviation was about XX higher (Fig. 5), which is in line with previous results on theoretical matrices showing that richness increased with a decrease in mean and variance of the off-diagonal coefficients[2].

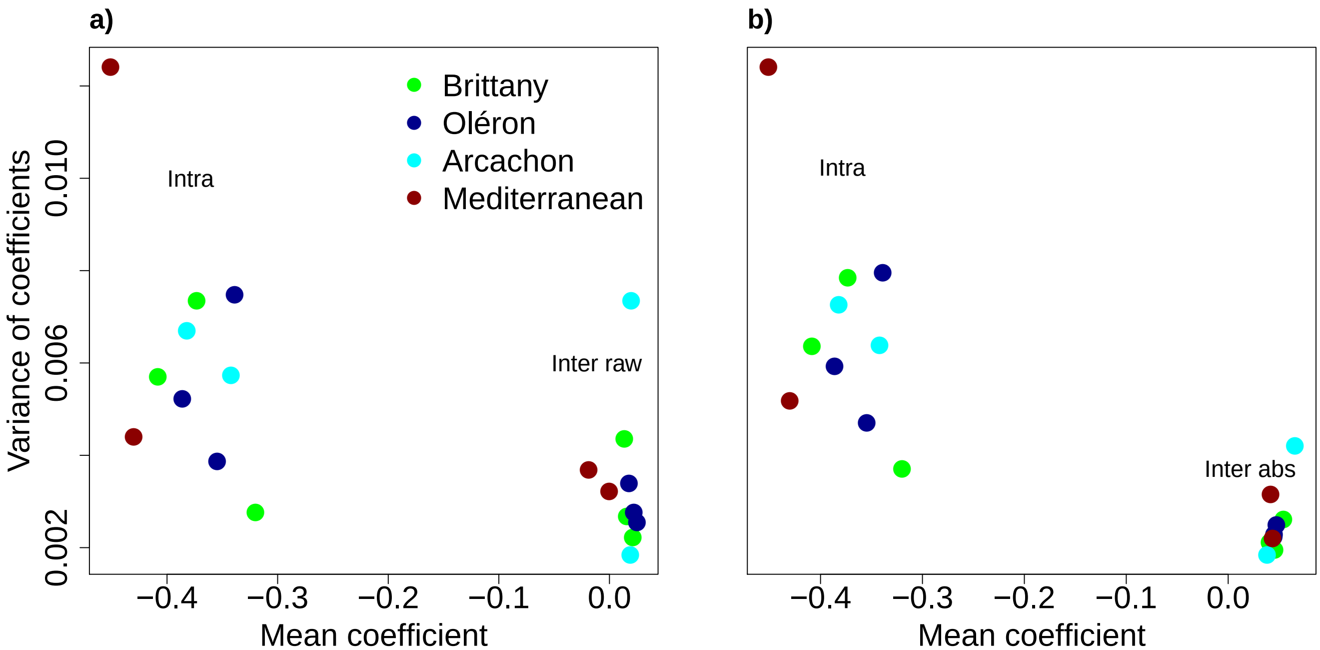

Figure 5: **Relation between mean and variance of the intra- and inter-group interaction coefficients**. Variance of the coefficient in the interaction matrix (**B**–**I**) is a function of their mean, for 10 sites in 4 regions, with a model allowing interactions only within clads (within centric or pennate diatoms, dinoflagellates, or other taxa). The mean-variance relation was either computed with raw values of intergroup interactions (a) or absolute values of the intergroup coefficients (b). Intragroup coefficients were not modified.

The intragroup interaction strength could be related to the mean abundance of each species as the most self-regulated species were also the least abundant (Fig. 6).

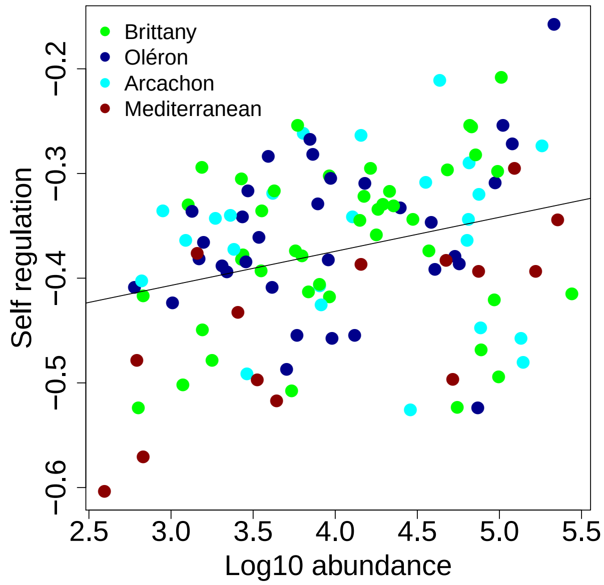

Figure 6: **Relation between abundance and self-regulation** (intra-group interaction coefficients). Mean abundance is computed for each species in each site in 4 regions and intra-group interaction strengths are the diagonal coefficients of the interaction matrix (**B**–**I**).

Linkage density and weighted connectance were described in ref[3]. Linkage density can be defined as the average of vulnerability and generality in the network. More precisely, diversity measures of the interactions from ($H_{P,k}$) and to ($H_{N,k}$) the phytoplanktonic group k can be computed as:

$$H_{N,k} = -\sum_{i=1}^{S} \frac{b_{ik}}{b_{\bullet k}} \log\left(\frac{b_{ik}}{b_{\bullet k}}\right) \tag{1}$$

$$H_{P,k} = -\sum_{i=1}^{S} \frac{b_{ki}}{b_{k\bullet}} \log\left(\frac{b_{ki}}{b_{k\bullet}}\right) \tag{2}$$

where b_{ik} is a coefficient of the interaction matrix (**B**–**I**), $b_{k\bullet} = \sum_{i=1}^{S} b_{ki}$ is the sum of all coefficients over row k and S is the number of species in the network. These indices are then averaged for the whole network as the linkage density LD (eq. 3).

$$LD = \frac{1}{2}\sum_{k=1}^{S} \frac{b_{\bullet k}}{b_{\bullet\bullet}} H_{N,k} + \sum_{k=1}^{S} \frac{\sum_{l=1}^{S} b_{k\bullet}}{b_{\bullet\bullet}} H_{P,k} \tag{3}$$

where $b_{\bullet\bullet} = \sum_{j=1}^{S}\sum_{i=1}^{S} b_{ji}$ is the sum of all coefficients of the interaction matrix (**B**–**I**).
Weighted connectance C is then defined as:

$$C = \frac{LD}{S} \tag{4}$$

Contrary to linkage density, weighted connectance accounts for the dimension of the interaction matrix and can be used to compare network in different regions, with different dimensions.

In addition to these network-level metrics, we also considered metrics for each phytoplanktonic group. We measured both its vulnerability (mean strength of the interactions that are applied to a group, eq. X) and its impact (mean strength of the interactions the group applied to other groups, eq.) in each network.

$$v_k = \frac{1}{\sum_{i=1}^{S}(b_{ki} \neq 0)} \sum_{i=1}^{S} b_{ki} \tag{5}$$

$$i_k = \frac{1}{\sum_{i=1}^{S}(b_{ik} \neq 0)} \sum_{i=1}^{S} b_{ik} \tag{6}$$

where $\sum_{i=1}^{S}(b_{ki} \neq 0)$ is the number of interactions which are different from 0 in row k[1].

MAR references and analysis

We present here the MAR references we used to compare the effects of intra- and intergroup interactions (Supplementary Table 3, Supplementary Fig. 7). We add information on the type of system and dataset used in the study as they tend to be linked with the estimated parameters (Supplementary Fig. 8). Mean interaction strengths were computed as the mean absolute value of the coefficients which were deemed significant at the 95% threshold in the B-I matrix. The average value was either computed over the whole matrix (missing values in the matrix, or values which were not significant, were replaced by 0's, see Fig. 4 in the main text) or over the set of non-null coefficient only (Supplementary Fig. 7).

[1] I'm sure there's a proper way to write it but I can't find it right now

Code	Ref	Dimension	Type of organisms	Taxonomic level	System	T
1a	[4], CLS	9	Zooplankton	Species and functional groups	Lake	100
1b	[4], TLS	9	Zooplankton	Species and functional groups	Lake	100
2a	[5]	2	Phytoplankton	Class	Lake	100
2b	[5]	3	Zooplankton	Species	Lake	50
3a	[6]	4	Functional groups of plankton	NA	Lake	300
3b	[6]	5	Taxonomic groups of plankton	Class	Lake	300
4a	[7]	4	Plankton	Zooplankton v. phytoplankton, size classes	Lake	100
4b	[7]	4	Plankton	Zooplankton v. phytoplankton, size classes	Lake with high planktivory	100
4c	[7]	4	Plankton	Zooplankton v. phytoplankton, size classes	Lake with low planktivory	100
5a	[8]	14	Plankton	Class (phytoplankton), genus (zooplankton)	Lake	300
5b	[8]	14	Plankton, growing season	Class (phytoplankton), genus (zooplankton)	Lake	200
6a	[9]	13	Plankton	Class (phytoplankton), genus (zooplankton)	Lake	400
6b	[9]	7	Simpler web, plankton	Class (phytoplankton), genus (zooplankton)	Lake	400
7a	[10]	10	Ciliates	Genus and species	Lake	300
7b	[10]	10	Phytoplankton	Genus and species	Lake	300
8a	[11]	3	Insects	Species	Terrestrial	50
9a	[12]	2	Lynx/Hare	Species	Terrestrial	100
10a	[13]	3	Fish	Species	Baltic Sea	30
11a	[14]	7	Phytoplankton	Class	Coastal site	1000
11b	[14]	7	Phytoplankton	Class	Offshore site	700
12a	[15]	12	Phytoplankton	Genus	Outside a bay	300
12b	[15]	12	Phytoplankton	Genus	Inside a bay	500

Table 3: Studies used when comparing |intra|/|inter| ratios in Fig. 4 in main text and Supplementary Fig. 7. T is the approximate number of sampling dates in each time series.

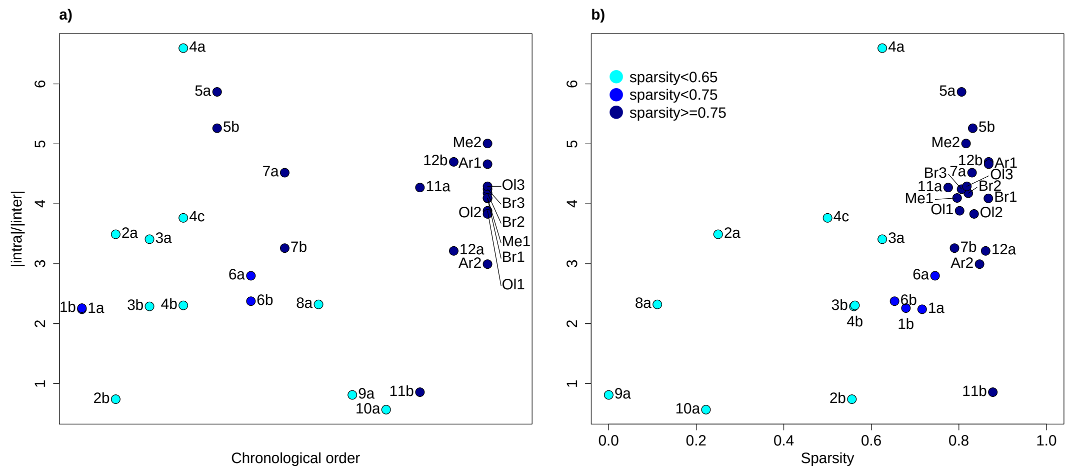

Figure 7: **Ratio of intra-to-intergroup interaction strength in MAR(1) studies.** Only significant values are taken into account and missing values in the matrix are not considered (e.g., not replaced by 0 as they are in the main text). The color of each point is a function of the sparsity of the interaction matrix B-I and the relation between the raio and the sparsity of the matrix is given in the right panel. Corresponding studies are described in Table 3.

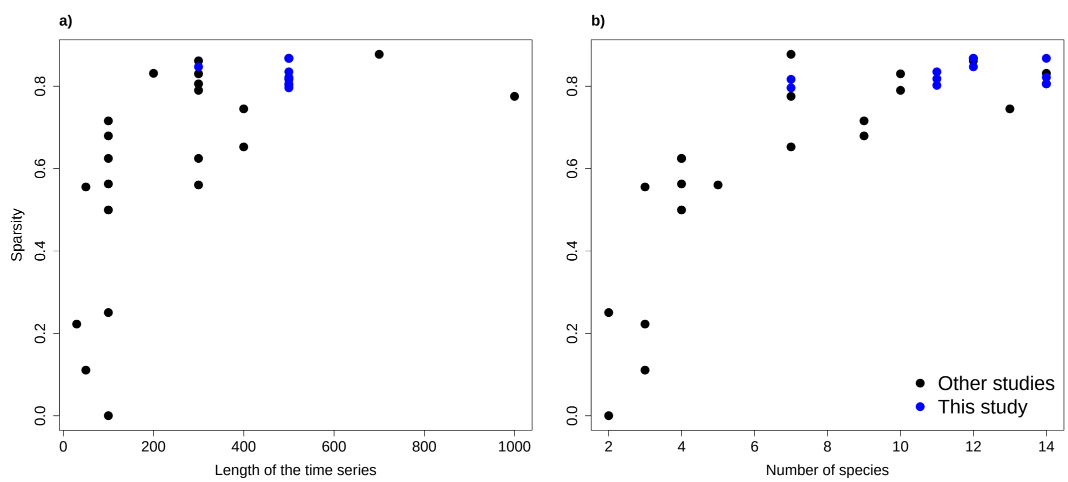

Figure 8: **Relation between interaction sparsity and study design** in studies described in Table 3. Blue points correspond to the present study.

References

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