

## Online Supplementary Material

Appendices to *Looking for compensation at multiple scales in a wetland bird community*. Barraquand F., Picoche C., Aluome C., Carassou L., and Feigné C.

### Appendix S1 - List of species

Among the 279 bird species which were observed throughout the monitoring, we focused on 2 functional groups (waterfowl and waders) and 2 phylogenetic groups (*Anatini*, *Calidris*) described in Table 1. In Table 2, we also present the most frequent birds present with the species we consider. The rest of the community (not detailed here) amount to 1% of the total number of observed birds.

Functional group	Species	Name	% occurrence	% abundance
Waterfowl	<i>Anas acuta</i>	Northern pintail	59.9	1.708
	<i>Anas crecca</i>	Eurasian teal	64.2	6.614
	<i>Anas platyrhynchos</i>	Mallard	63.8	3.388
	<i>Mareca penelope</i>	Eurasian wigeon	36.5	0.055
	<i>Mareca strepera</i>	Gadwall	48.7	0.308
	<i>Spatula clypeata</i>	Northern shoveler	63.5	1.580
	<i>Spatula querquedula</i>	Garganey	26.0	0.032
	<i>Anser anser</i>	Greylag goose	47.3	1.135
	<i>Aythya ferina</i>	Common pochard	57.1	1.053
	<i>Aythya fuligula</i>	Tufted duck	45.8	0.467
	<i>Aythya marila</i>	Greater scaup	6.5	0.005
	<i>Branta bernicla</i>	Brant	2.3	0.001
	<i>Branta canadensis</i>	Canada goose	5.1	0.002
	<i>Cygnus olor</i>	Mute swan	50.0	0.618
	<i>Fulica atra</i>	Eurasian coot	64.3	16.007
	<i>Netta rufina</i>	Red-crested pochard	27.0	0.030
	<i>Tadorna tadorna</i>	Common shelduck	53.1	0.870
Waders	<i>Actitis hypoleucos</i>	Common sandpiper	25.3	0.054
	<i>Arenaria interpres</i>	Ruddy turnstone	14.7	0.020
	<i>Calidris alba</i>	Sanderling	4.1	0.004
	<i>Calidris alpina</i>	Dunlin	37.2	26.394
	<i>Calidris canutus</i>	Red knot	22.6	0.406
	<i>Calidris ferruginea</i>	Curlew sandpiper	14.8	0.067
	<i>Calidris minuta</i>	Little stint	25.1	0.129
	<i>Calidris pugnax</i>	Ruff	11.4	0.010
	<i>Calidris temminckii</i>	Temminck's stint	4.6	0.001
	<i>Charadrius dubius</i>	Little ringed plover	18.2	0.040
	<i>Charadrius hiaticula</i>	Common ringed plover	34.2	0.921
	<i>Gallinago gallinago</i>	Common snipe	23.1	0.184
	<i>Himantopus himantopus</i>	Black-winged stilt	12.1	0.079
	<i>Limosa lapponica</i>	Bar-tailed godwit	18.4	0.327
	<i>Limosa limosa</i>	Black-tailed godwit	29.7	1.802
	<i>Numenius arquata</i>	Eurasian curlew	17.0	1.167
	<i>Numenius phaeopus</i>	Whimbrel	11.1	0.102
	<i>Pluvialis apricaria</i>	European golden plover	5.0	0.002
	<i>Pluvialis squatarola</i>	Grey plover	32.9	0.669
	<i>Recurvirostra avosetta</i>	Pied avocet	25.0	0.775
	<i>Tringa erythropus</i>	Spotted redshank	23.9	0.133
	<i>Tringa glareola</i>	Wood sandpiper	9.6	0.008
	<i>Tringa nebularia</i>	Common greenshank	25.0	0.173
	<i>Tringa ochropus</i>	Green sandpiper	15.4	0.014
	<i>Tringa totanus</i>	Common redshank	32.4	0.670
	<i>Vanellus vanellus</i>	Northern lapwing	22.8	0.265

Table 1: Composition of the two main functional groups considered in the manuscript. The genera on which we focused for our taxonomy-based comparisons are written in colour. The percentage of occurrence corresponds to the number of dates when a species was observed, compared to the total number of observation dates. The percentage of abundance corresponds to the ratio of the abundance of a given species to the total abundance of all birds observed during the monitoring.

Functional group	Species	Name	% occurrence	% abundance
Other	<i>Accipiter nisus</i>	Eurasian sparrowhawk	12.8	0.003
	<i>Alcedo atthis</i>	Common kingfisher	12.1	0.017
	<i>Ardea alba</i>	Great egret	30.0	0.150
	<i>Ardea cinerea</i>	Grey heron	63.1	2.480
	<i>Bubulcus ibis</i>	Western cattle egret	37.9	0.381
	<i>Chroicocephalus ridibundus</i>	Black-headed gull	51.3	9.645
	<i>Ciconia ciconia</i>	White stork	51.3	0.905
	<i>Circus aeruginosus</i>	Western marsh harrier	23.3	0.017
	<i>Egretta garzetta</i>	Little egret	55.1	6.511
	<i>Falco peregrinus</i>	Peregrine falcon	13.8	0.003
	<i>Gallinula chloropus</i>	Common moorhen	42.2	1.106
	<i>Larus argentatus</i>	European herring gull	36.4	3.414
	<i>Larus fuscus</i>	Lesser black-backed gull	32.1	0.088
	<i>Larus marinus</i>	Great black-backed gull	38.9	0.039
	<i>Larus michahellis</i>	Yellow-legged gull	17.5	0.210
	<i>Milvus migrans</i>	Black kite	12.8	0.106
	<i>Nycticorax nycticorax</i>	Black-crowned night heron	58.4	0.160
	<i>Phalacrocorax carbo</i>	Great cormorant	57.7	3.616
	<i>Platalea leucorodia</i>	Eurasian spoonbill	48.2	0.720
	<i>Podiceps cristatus</i>	Great crested grebe	28.6	0.033
	<i>Podiceps nigricollis</i>	Black-necked grebe	12.0	0.008
	<i>Rallus aquaticus</i>	Water rail	40.4	0.594
	<i>Tachybaptus ruficollis</i>	Little grebe	44.8	0.403
	<i>Threskiornis aethiopicus</i>	African sacred ibis	12.5	0.019

Table 2: Most frequent birds (observed more than 75 times during the monitoring) which are not described in the previous functional groups (see previous legend for more details on the column signification).

## Appendix S2 - Temporal patterns of the Teich bird community

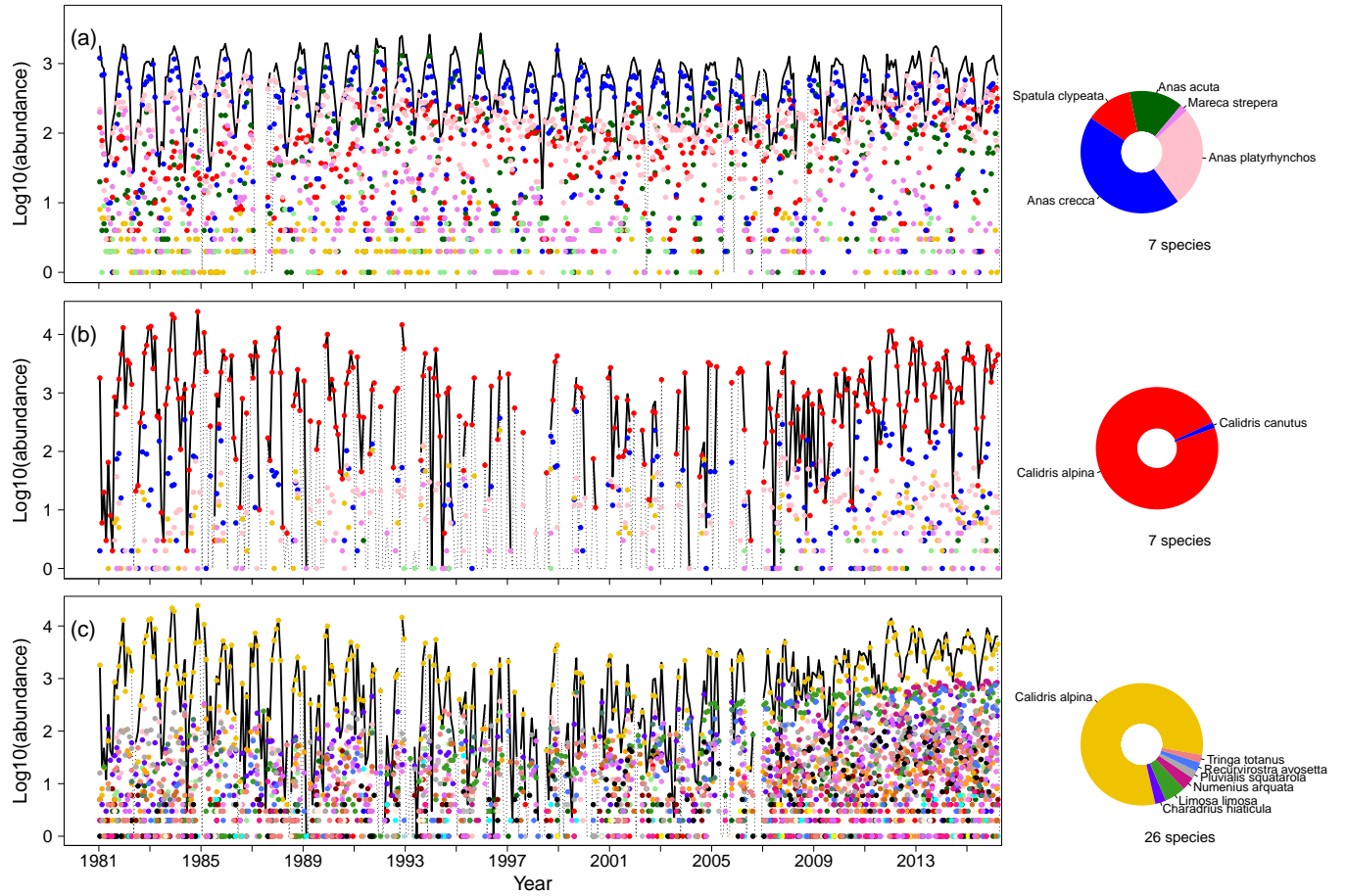


Figure S1: Time series of counts for ducks of the tribe *Anatini* (a), calidrids (b, *Calidris* genus), and all waders (c, including calidrids). The solid black lines represent trends in summed abundances for each guild when abundances are strictly positive, thin dotted lines connect positive to zero abundances. The coloured symbols below the curves represent each species abundances. Species composition on the donut plots (right) are given for species whose relative abundance is over 1% in the group considered. The total number of species constituting the group is given below the donut plot.

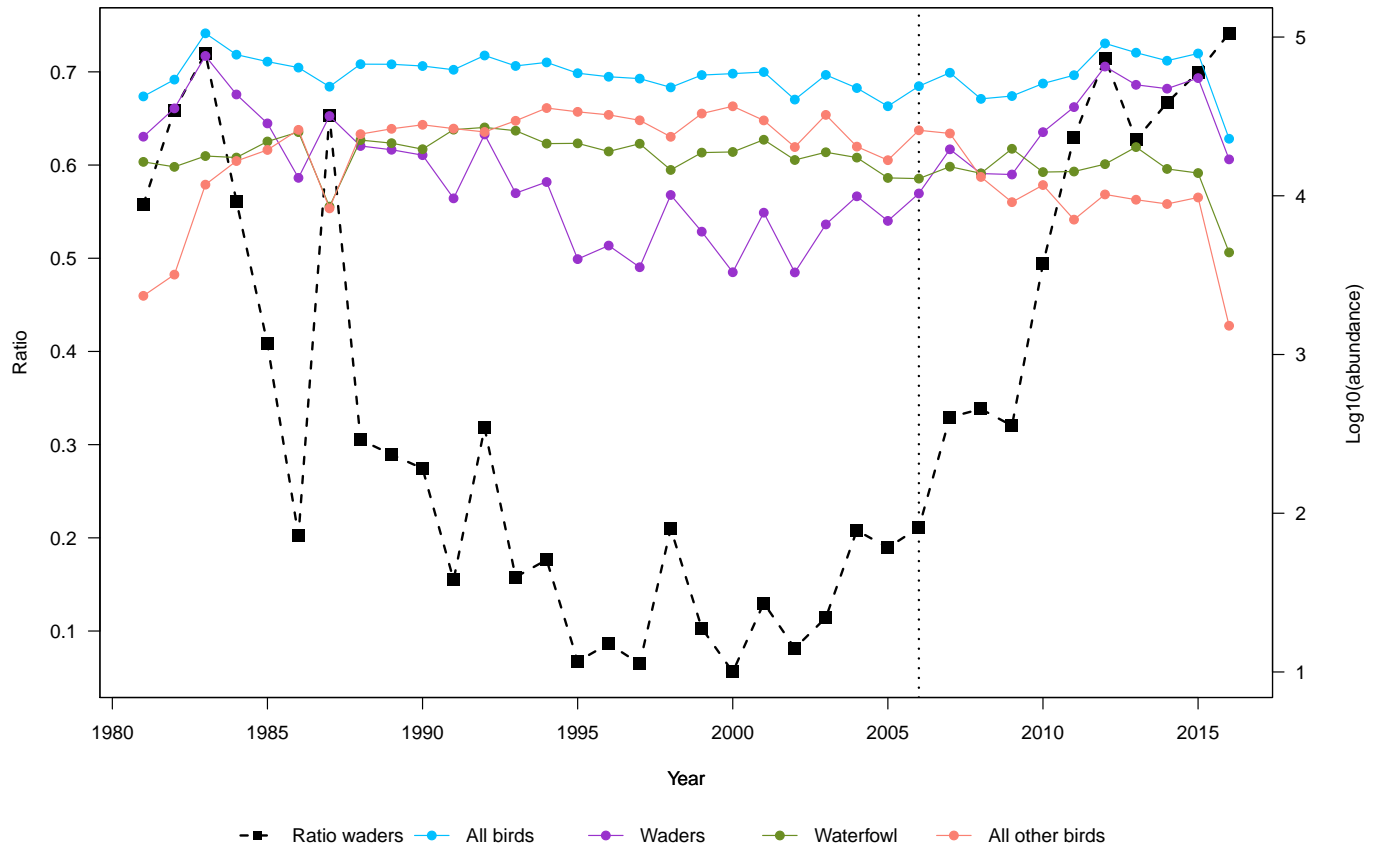


Figure S2: Temporal trends in the abundance of all birds and in the main functional groups (waders and waterfowl), with one point per year. The waterfowl category actually includes all species functionally similar to ducks (ducks, geese and swans, i.e. anatids, and the common coot). The dashed line presents the ratio of wader individuals in the whole community, i.e., their relative abundance, which changes markedly over time.

### Appendix S3 - Gross synchrony index at the whole community level

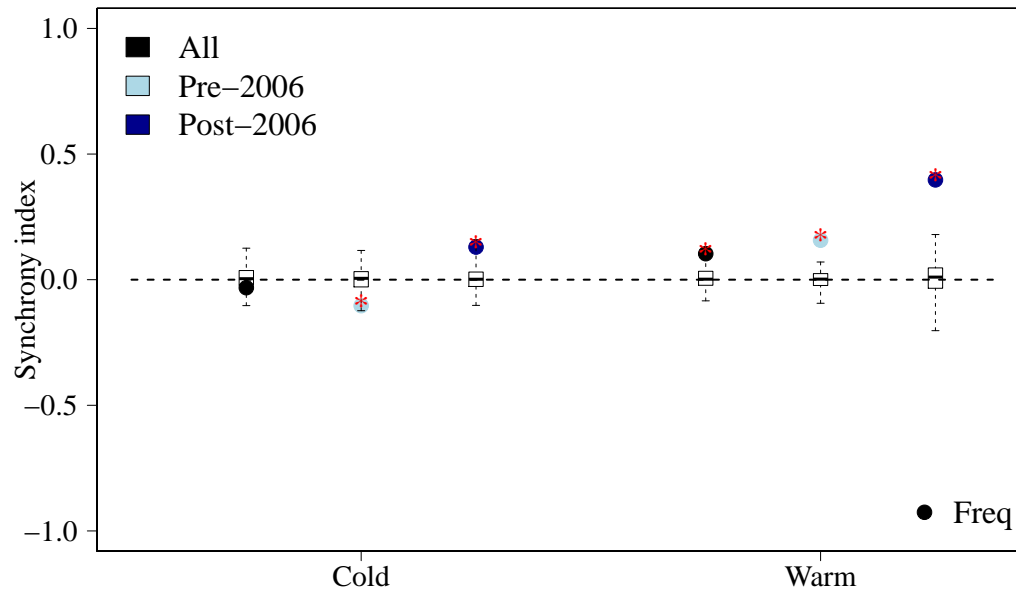


Figure S3: Gross' synchrony index as a function of the season (cold and warm seasons), calculated among the 60 most frequent species in the Teich reserve. The index was computed in each panel on the whole dataset (black) or using two periods: before and after 2006 (light and dark blue), the year of the change in water level management. Red stars correspond to synchrony values significantly different from the null model (independent species), at the 10% threshold, with the Benjamini-Hochberg correction.

## Appendix S4 - Additional plots concerning cormorant and heron+egret

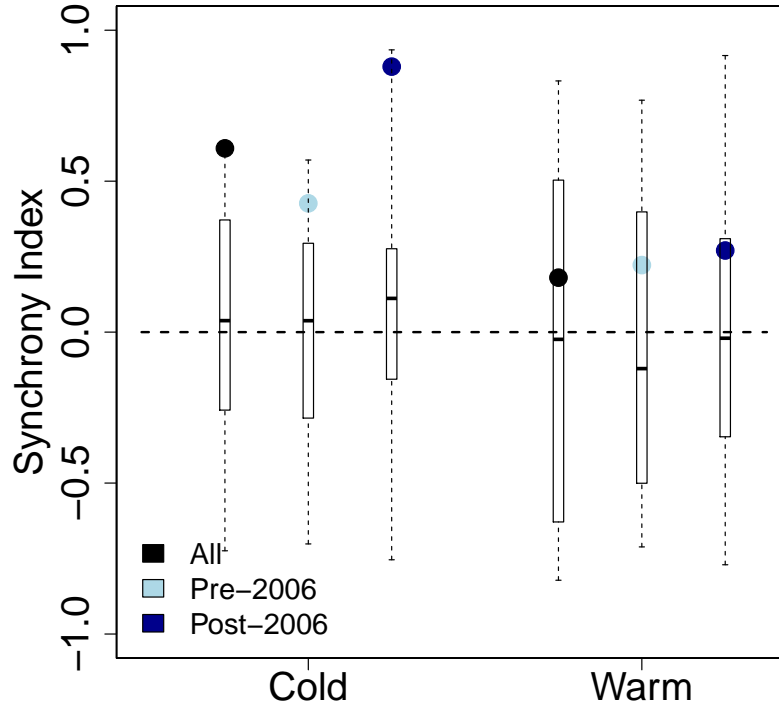


Figure S4: Gross' synchrony index as a function of the season (cold and warm seasons), calculated on log-transformed abundance data for the two groups formed by cormorant and heron+egret. The index was computed in each panel on the whole dataset (black) or using two periods: before and after 2006 (light and dark blue), the year of the change in water level management.

We noted on Fig. 4 in the main text that cormorants, herons and egrets seemed to compensate each other, at least for the first period of the time series. This compensation was seen on a log scale, and seemed conspicuous on that scale. We thus wondered if log-transforming the abundance would affect the values of the synchrony index observed for this group, and make compensation more likely. It appears to be the reverse: synchrony values are higher with log-transformed abundances. In fact, an annual representation of abundance (seasonal averages, Fig. S5) makes the correlation between the two groups less obvious, which is probably why it only appears at larger scales (>5 years).

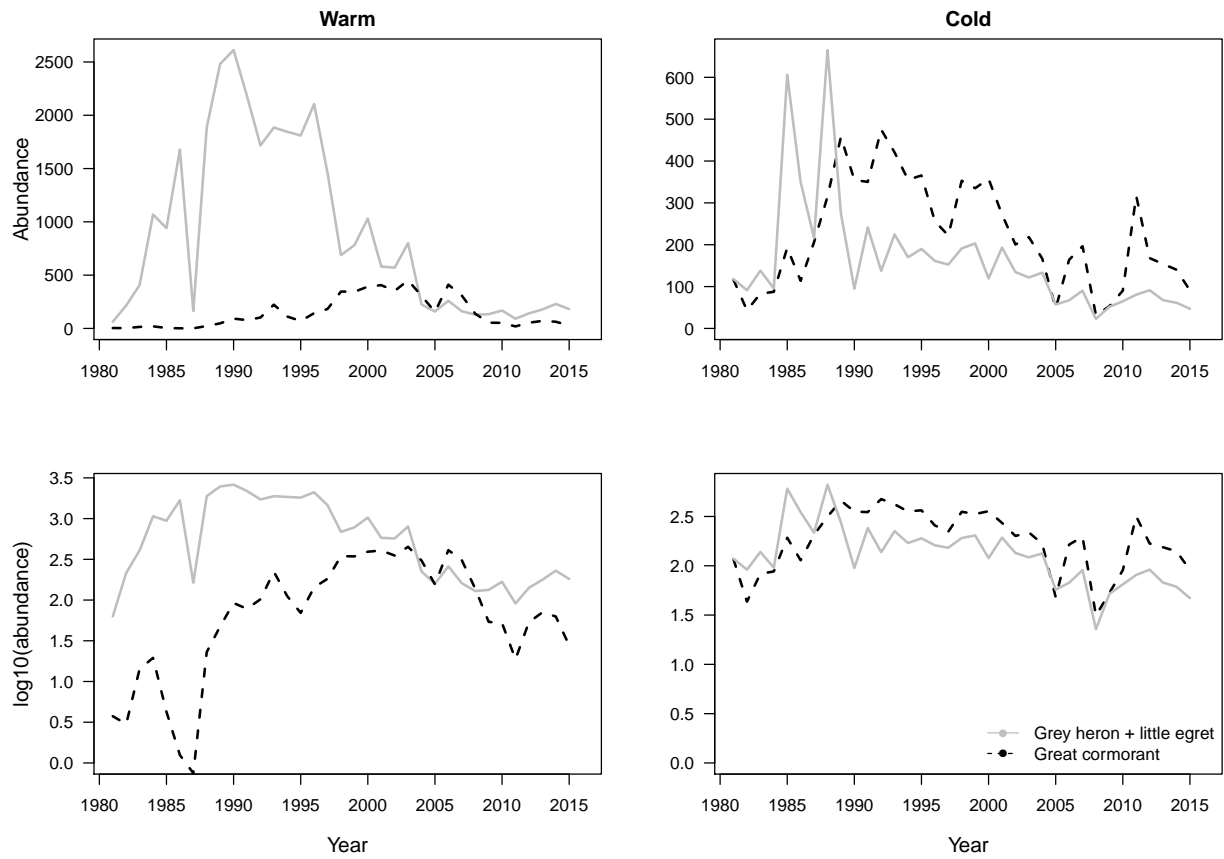


Figure S5: Time series of seasonally averaged abundances of the great cormorant (dashed black line) and the grey heron plus little egret group (solid grey line), differentiating between warm and cold seasons.

## Appendix S5 - Synchrony indices using biomasses

We used the mean body mass of each species to compute observed biomasses from abundances and eventually the corresponding synchrony indices. This change in the state variable did not change our conclusions.



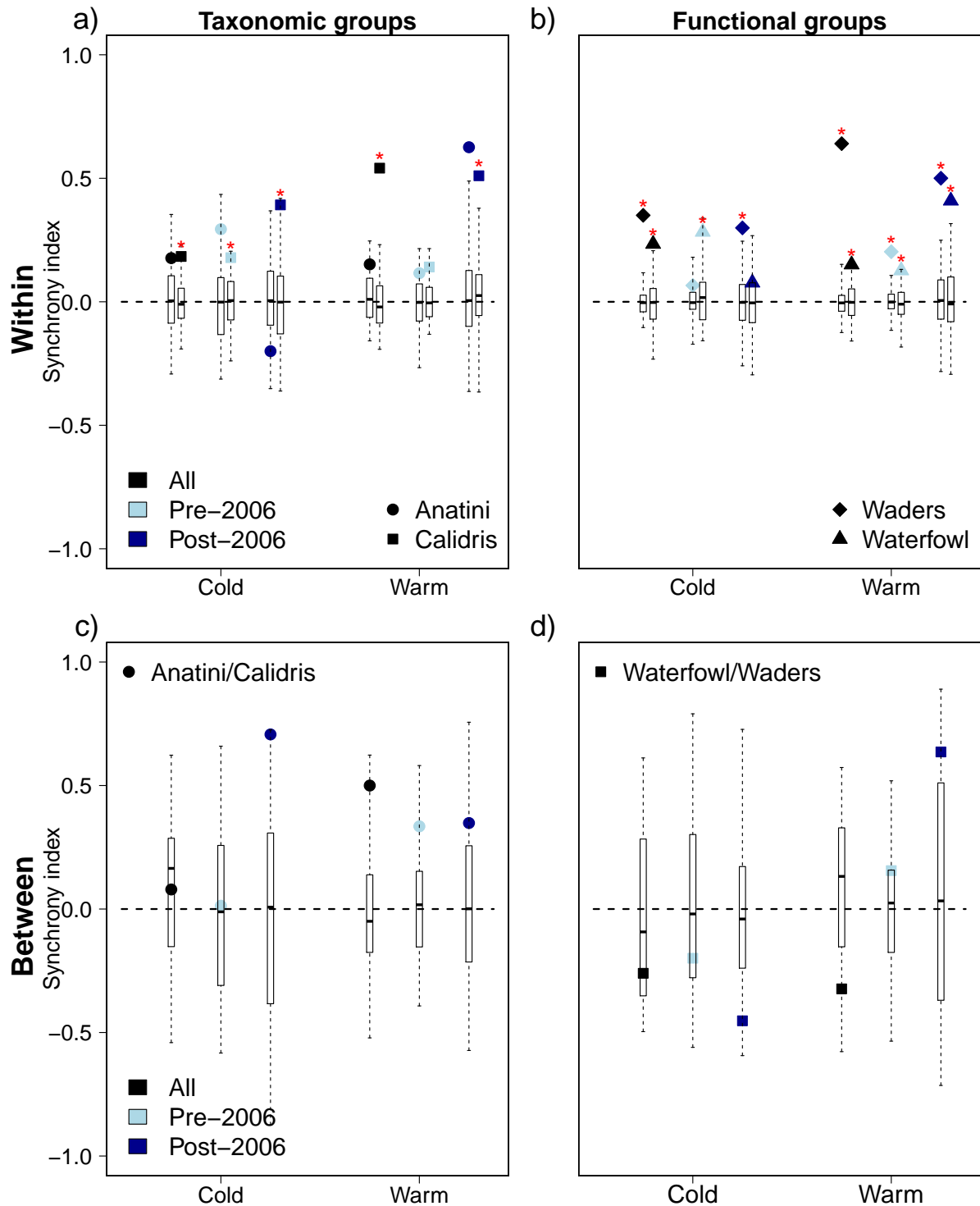


Figure S6: Gross' synchrony index ( $\eta$ ) as a function of the season (cold and warm seasons), calculated within (top, a-b) and between (bottom, c-d) groups, using biomasses instead of abundances. The groups considered were different functional groups (waterfowl - i.e. ducks, geese and swans - vs waders, right b-d) or taxonomic groups (*Anatini* tribe, *Calidris* genus, left a-b) groups. The index was computed in each panel on the whole dataset (black) or using two periods: before and after 2006 (light and dark blue), the year of the change in water level management. Boxplots indicate the distribution of  $\eta$  under the null hypothesis (independent species) and filled symbols correspond to the observed values. Red stars correspond to synchrony values significantly different from the null model, at the 10% threshold with a Benjamini-Hochberg correction.

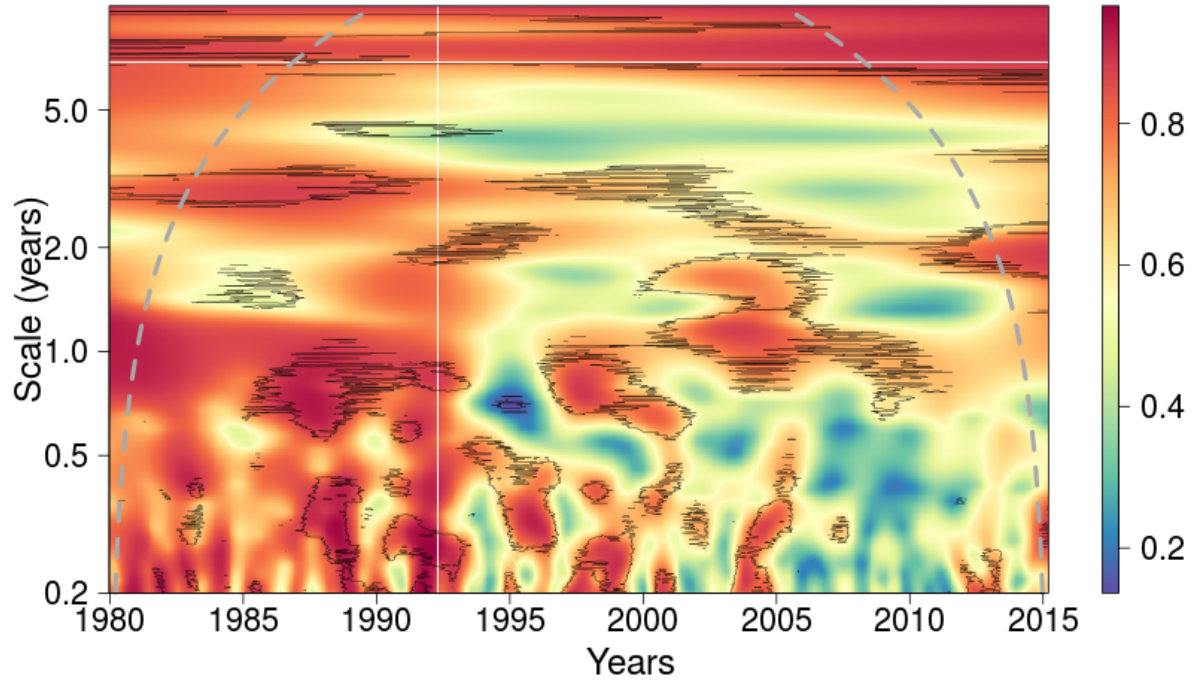


Figure S7: Wavelet modulus ratio for the wader community, scaling from 0 (compensation, blue color) to 1 (synchrony, red color), using the mean biomasses instead of the abundances of each species. Dashed black lines delineate regions significantly different from the null model (independently fluctuating species) with a false discovery rate controlled at the 10% threshold with a Benjamini-Hochberg correction.

## Appendix S6 - Properties of the Gross whole community synchrony index $\eta$ when two groups react in opposite ways

Here, we make  $\eta$  vary with the number of species, richness of the community, and the strength of the effect of the environment. Starting from the model developed by Gross et al. [1] in their Appendix D, we explored the effect of a shared environmental driver on a community formed by two groups reacting oppositely to this driver.

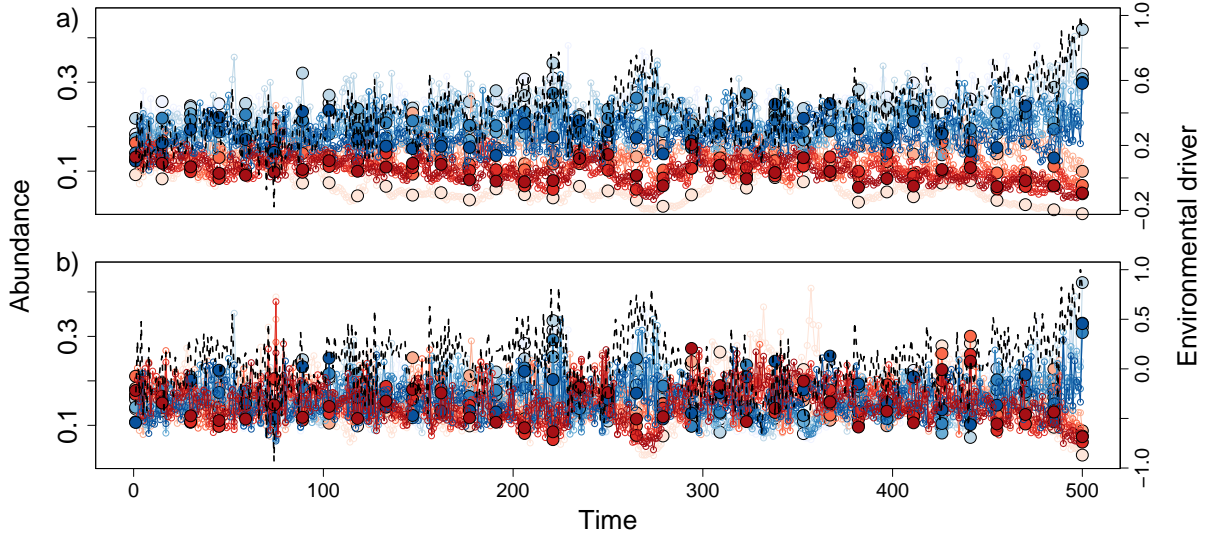


Figure S8: Time series for a community of 10 species, with a strong effect of the environment ( $b=0.75$ , see eq. 1) and a time series of 500 time steps. Open circles represent all points of the time series while large filled circles correspond to the sub-sampling of the time series (keeping only 35 points). Cold colors indicate species which react positively to the environmental signal and warm colors indicate species which have a negative reaction to the same signal. The environmental signal is shown in black, dashed lines, and indexed on the right axis. This signal either follows an increasing trend (a), or just an autocorrelated signal (b).

We assume that the environmental driver  $U(t)$  is an autocorrelated signal (see below for details).

The dynamics of species  $i$  then follows the equation 1:

$$x_i(t+1) = x_i(t) \exp \left( r_i \left( 1 - \frac{x_i(t) + \sum_{j \neq i}^n \alpha x_j(t)}{K} \right) + b_i U(t) + \epsilon_i(t) \right) \quad (1)$$

where the whole community is formed by  $N = 2n$  species, with 2 groups of  $n$  species who have exactly opposite reaction to the environmental driver, that is  $\forall i \in [1, n], \exists j \in [1, n], b_j = -b_i = b$ . The growth rate  $r_i$  follows a normal distribution with mean 1 and standard deviation 0.25. All interaction coefficients  $\alpha$  are set to 0.5 and  $K = \frac{1+\alpha(N-1)}{N}$ , to keep the model in other ways exactly similar to Gross et al. [1]. The noise  $\epsilon_i(t)$  is normally distributed, centered on 0 with a standard deviation of 0.1.

We compared results for time series of length 35 (the length of our data set when computing  $\eta$ ), 100 and 500. For all simulation experiments, the dynamics are first run for 500 time steps as a burn-in. To take into account different observational designs, we either take the first 35 or 100 time steps of the following 500-time steps series, or subsample the time series in order to get 35 or 100 time points (which removes some autocorrelation in the dynamics). We also considered several community richness (2, 30 and 60, to remain close to the number of species in the different groups we analysed), and several strengths of the response to the environmental signal ( $b = [0.1, 0.5, 0.75]$ ). For each combination of parameters, we computed 10 repetitions (i.e., replicates).

We considered different types of environmental driver (simply autocorrelated or with a linear trend), crossed with subsampling / no subsampling as described above. We considered in total three scenarios, and present below how an increasing strength of response to the environment changes expectations for all three:

- Scenario 1:  $U_t = u_t$  where  $u_t$  is an autocorrelated signal (standardized); no subsampling of the data

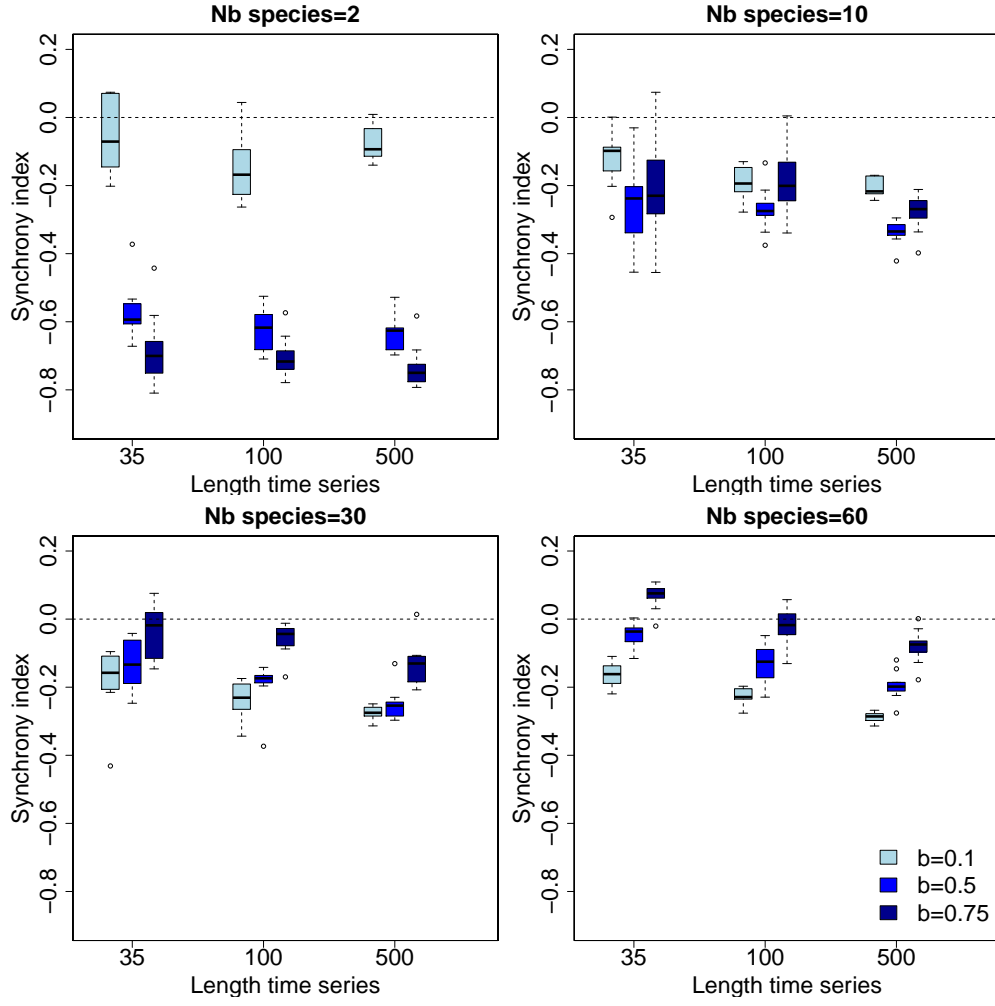


Figure S9: Evolution of Gross' synchrony index for different time series length and number of species in the community, in simulations where there is no trend in the environmental signal and the data is not subsampled, keeping the autocorrelation of the environment. The parameter  $b$  is the strength of the response to the the environmental signal.

- Scenario 2:  $U_t = u_t$ ; data subsampling

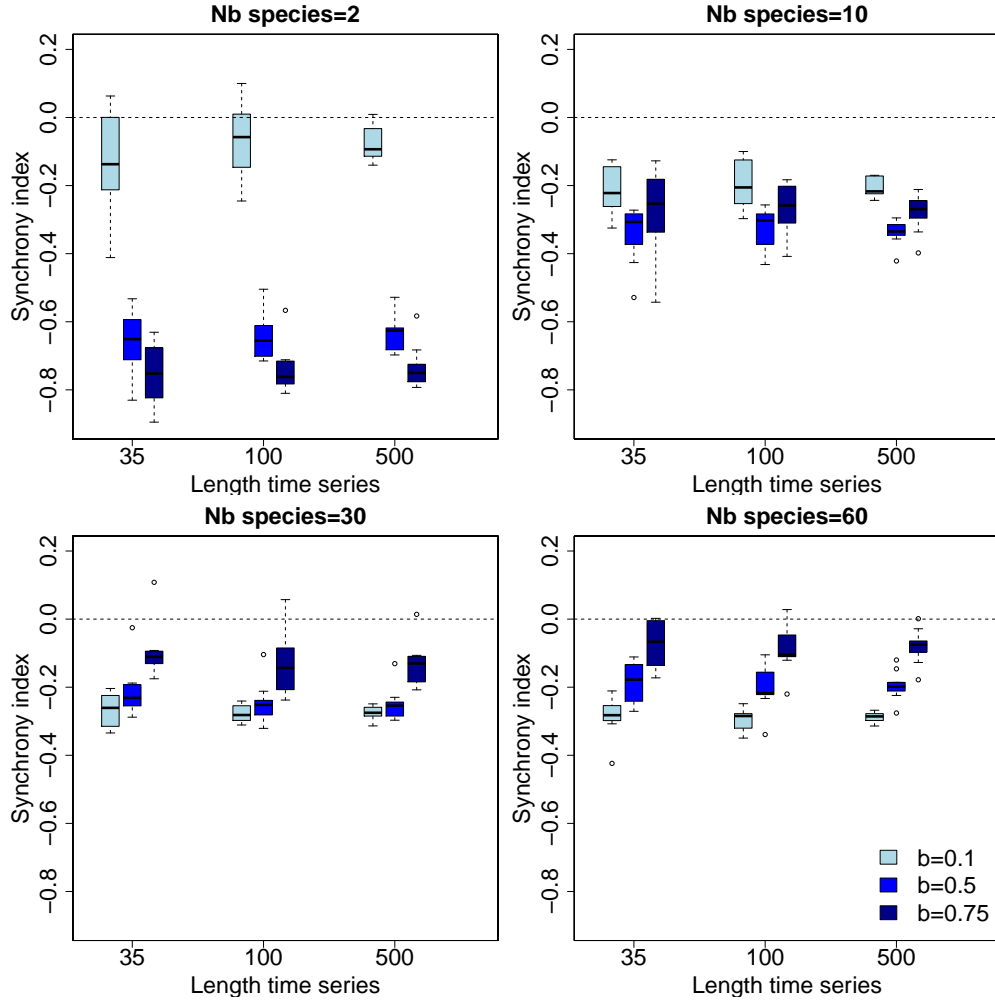


Figure S10: Gross' synchrony index for different time series length and number of species in the community, in simulations where there is no trend in the environmental signal and the data is subsampled (keeping 35 or 100 time steps), removing in effect the autocorrelation of the environment. The parameter  $b$  is the strength of the response to the environmental signal.

- Scenario 3:  $U_t = U_{\min} + (U_{\max} - U_{\min})(u_t + x_t)/2$  where  $x_t \in [0, 1]$  follows an increasing trend; data subsampling

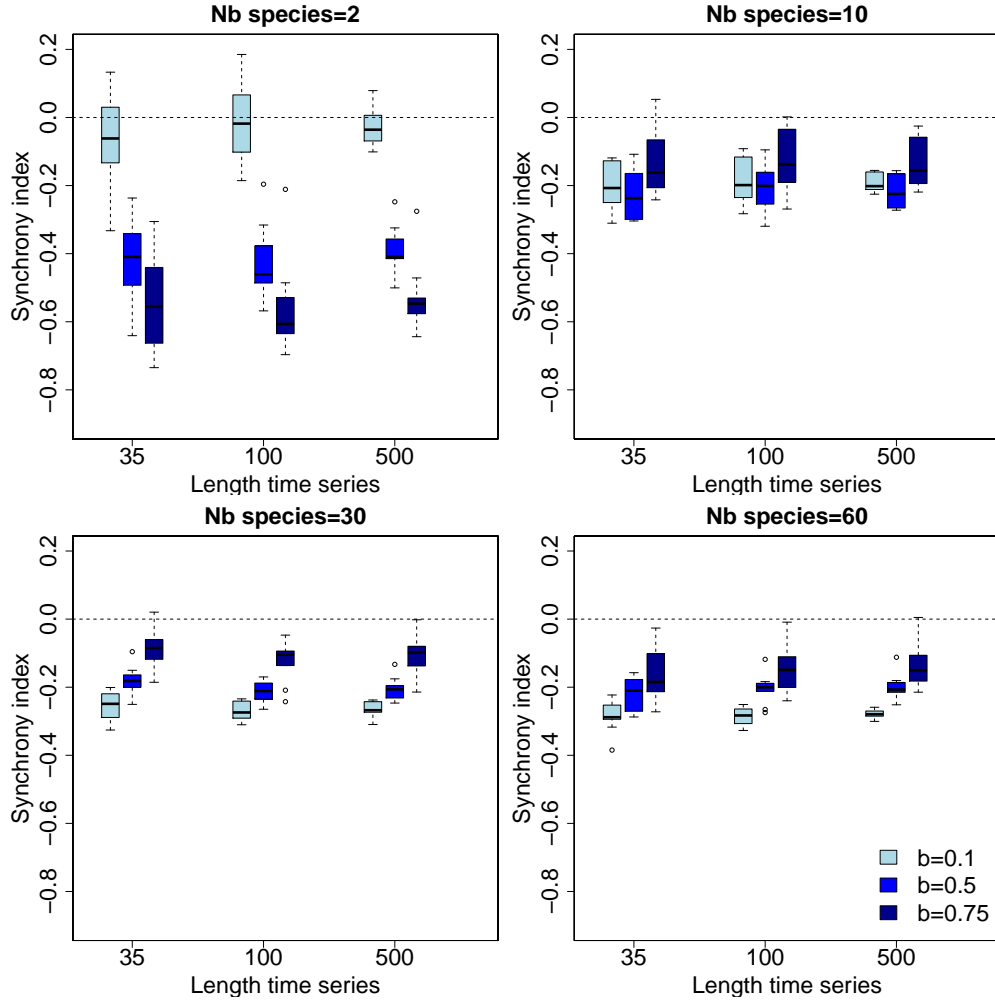


Figure S11: Gross' synchrony index for different time series length and number of species in the community, in simulations where there is an increasing trend in the environmental signal and the data is subsampled (for 35 or 100 time steps), removing part of the autocorrelation of the environment in the dynamics of the species. The parameter  $b$  is the strength of the response to the environmental signal.

We first confirm that unless there is a very high temporal autocorrelation in the driver (as in Fig. S9), if we consider two groups which have opposite reactions to the same driver, the Gross index is not sensitive to the length of the time series or to the number of species in the community, in the sense that it will not indicate false synchrony. The only contradiction to this observation appears when the driver has only a small effect on the community, and the Gross index is actually a simple correlation (i.e., the community is made of 2 species). The main finding of these analyses, aside from the robustness of the  $\eta$  index, is that for large communities (over 10 species), synchrony is always higher when the response to the driver is stronger. Coming back to the interpretation of our results in the Teich reserve case, this means that the more bird

population growth rates respond to changes in the water levels, the less we can expect compensation at the whole community level, even though compensation may be manifest at the functional group level (here, the group of species responding similarly to the environmental variable). Compensation between groups in the case of a small effect of the environment can also be difficult to detect if there are only two functional groups (between-guilds compensation).

## Appendix S7 - Effect of “missing” values on wavelet analyses

We investigate here if exactly-zero abundances can distort the compensation patterns evidenced by the wavelet coherence. We chose a simulation with 10 species and 10% missing values for all species (close to a worst-case scenario) . The results show that while the statistical significance of the values can change (i.e., the data is more compatible with the null hypothesis of time series uncorrelated between species, assuming the null is true), the occurrence of compensation (blue values in Fig.S12) does not. The wavelet coherence index is therefore robust to the presence of zeroes in the time series.

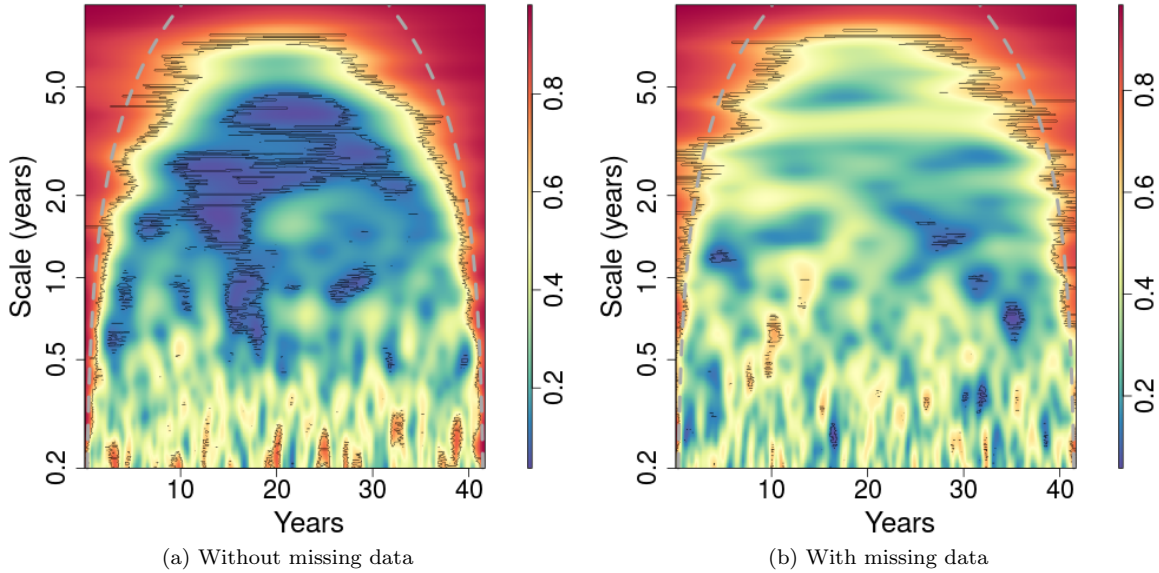


Figure S12: Wavelet coherence for a 10-species community with compensatory dynamics, without (a) and with (b) missing data



## References

- [1] Gross, K., Cardinale, B. J., Fox, J. W., Gonzalez, A., Loreau, M., Wayne Polley, H., Reich, P. B. & van Ruijven, J., 2013 Species richness and the temporal stability of biomass production: a new analysis of recent biodiversity experiments. *The American Naturalist* **183**, 1–12.