Directional trends in species composition over time can lead to a widespread overemphasis of year-to-year asynchrony

Running title: Directional trends effects on synchrony

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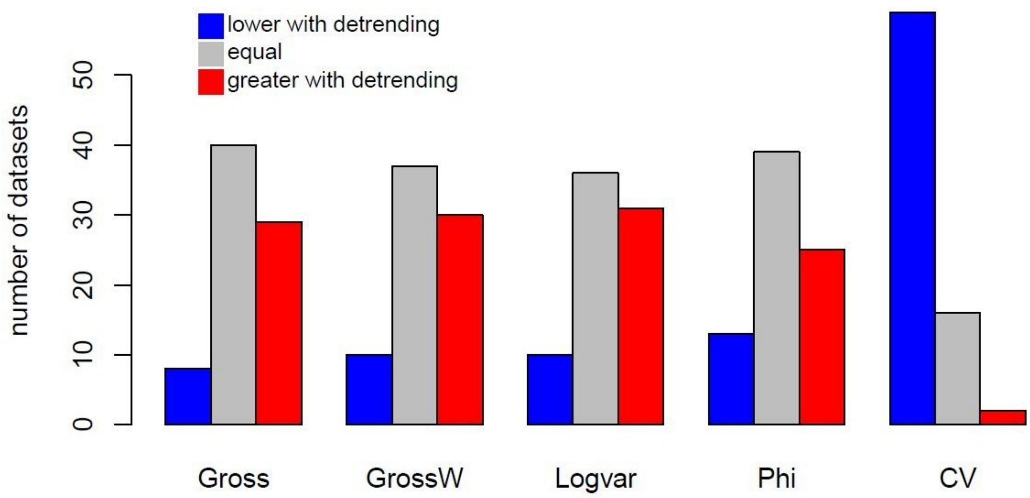
Web summary

Measures of community synchrony and stability aim at quantifying year-to-year fluctuations in species abundances. However, these indices reflect also long-term trends, potentially masking year-to-year signals. Using a large number of datasets with permanent vegetation plots we show a frequent greater synchrony and stability in year-to-year changes compared to when long-term trends are not taken into account.



Abstract

Questions

Compensatory dynamics are described as one of the main mechanisms that increase community stability, e.g. where decreases of some species on a year-to-year basis are offset by an increase in others. Deviations from perfect synchrony between species (asynchrony) have therefore been advocated as an important mechanism underlying iodiversity effects on stability. However, it is unclear to what extent existing measures of synchrony actually capture the signal of year-to-year species fluctuations in the presence of long-term directional trends in both species abundance and composition (species directional trends hereafter). Such directional trends may lead to a misinterpretation of indices commonly used to reflect year-to-year synchrony.

Methods

An approach based on three-term local quadrat variance (T3) which assess population variability in a three-year moving window, was used to overcome species directional trends effects. This 'detrending' approach was applied to common indices of synchrony across a Worldwide collection of 77 temporal plant community datasets comprising almost 7800 individual plots sampled for at least 6 years. Plots included were either maintained under constant 'control' conditions over time or were subjected to different management or disturbances treatments.

Results

Accounting for directional trends increased the detection of year-to-year synchronous patterns in all synchrony indices considered. Specifically, synchrony values increased significantly in ~40% of the datasets with the T3 detrending approach while in ~10% synchrony decreased. For the 38 studies with both control and manipulated conditions, the increase in synchrony values was stronger for longer-time series, particularly following experimental manipulation.

Conclusions

Species long-term directional trends can affect synchrony and stability measures potentially masking the ecological mechanism causing year-to-year fluctuations. As such, previous studies on community stability might have overemphasised the role of compensatory dynamic in real-world ecosystems, and particularly in manipulative conditions, when not considering the possible overriding effects of long-term directional trends.

Keywords: asynchrony, biodiversity, stability, synchrony, temporal dynamics, year-to-year fluctuation.

Introduction

Given the challenges posed by rapidly changing environments in the context of global change, it is crucial to understand how biological diversity is maintained over time (Cardinale et al. 2007; Tomimatsu et al. 2013; Tilman, Isbell, & Cowles 2014). There is a general consensus toward the role that synchrony (or lack of) in, e.g., year-to-year population fluctuations between co-existing species plays on species diversity and community stability (Hautier et al. 2014; Craven et al. 2018). On the one hand, a common response to environmental fluctuations (for example changes in temperature or precipitation from one year to another) of most species (synchrony) will tend to destabilize the community biomass or abundance. On the other hand, the opposite pattern (compensatory dynamics, i.e. increases or decreases in the relative abundance of some species that are offset by changes in the relative abundance of others; Hubbell 2001; Gonzalez & Loreau 2009) will lead to higher community stability. In this sense asynchrony, i.e. the extent of the deviation from lack of perfect synchrony between species, has been advocated as an important and widespread mechanism that contributes to stability (Loreau & de Mazancourt 2013).

While there is a lively debate on the importance of compensatory dynamics on the stability of communities (Houlahan et al. 2007; Blüthgen et al. 2016; Lepš et al. 2018) there are also important methodological aspects that can influence the detection of the underlying biological patterns. Recently, Lepš et al. (2019) demonstrated that the study of synchrony between species has traditionally disregarded the possible effects of long-term directional compositional trends in the analysed communities (i.e. a tendency of some species to increase or decrease over time, or to fluctuate cyclically, Wu et al. 2007). Species directional trends occur when the abundances of species respond not only to short-term environmental fluctuations, but also to the presence of monotonic or cyclical tendencies over the whole time series considered. Short term environmental fluctuations (Rabotnov 1974), for example on a year-to-year basis, are expected to affect species abundance but also to be largely reversible, so that species would not show long-term directional trends in their abundances. In contrast, long-term environmental changes, such as climate change, nutrient deposition and changes in land use (e.g. abandonment or intensification of agricultural land), generally cause long-term species directional trends (Stevens et al. 2011; Walter et al. 2018). Long-term directional trends can also be the result of the impact of undetermined drivers (Milchunas, Lauenroth, & Burkeal 1998). As repeatedly reported by many authors, long term trends in species abundance are probably omnipresent, and have been demonstrated even in, now, more than 160 years of the Park Grass Experiment (Silvertown et al. 2006).

To gain a better understanding of the underlying mechanisms regulating changes in species abundance, short-term fluctuations and long-term trends effects on synchrony should be disentangled. Unfortunately, this differentiation has been rare in studies assessing drivers of synchrony and stability (but see Vasseur & Gaedke 2007; Tredennick et al. 2017; and the review by Lepš et al. 2019). Indeed, using simulations and simple case studies Lepš et al. (2019) showed that species directional trends can mask year-to-year fluctuations among species. This has the potential to result in a biased estimation of asynchrony when using many widely used synchrony indices. Such directional trends could lead to either overestimation of year-to-year synchrony when the majority of species concomitantly increase or decrease over time, as well as overestimation of year-to-year asynchrony when some species increase and some others decrease over time.

Multiple indices have been developed to evaluate the level of synchrony among species in a community (Loreau & de Mazancourt 2008; Gross et al. 2014; Blüthgen et al. 2016; Lepš et al. 2018). Further methodologies have also been developed to assess directional trends, such as spectral or wavelet analyses, however, they are applicable only to very long or highly resolved time series (see Lepš et al. 2019 for an overview of these methods). None of the classically used synchrony indices disentangle, *a priori,* the actual year-to-year fluctuations from the directional trends. However, such indices can be 'detrended' using different methods (Wu et al. 2007; Lepš et al. 2019). One appealing a simple solution includes computing synchrony indices over moveable windows of three consecutive years (three-term local variance, 'T3', Hill 1973) instead of over the whole sampling period (Lepš et al. 2019). This 'detrending' approach, which we call T3 detrending approach, could allow testing the generality of the effect of directional trends on synchrony indices. If the focus of the research is on year-to-year fluctuations, then the minimum number of years to exclude trends and consider yearly fluctuations is 3 years, hence the three-term local variance. With bigger windows the computation of a common linear trend over the time window, and the focus on the deviation from this trend, does recall on the other method proposed by Lepš et al. (2019), using residuals of fitted linear models over a given time period. The first approach has the advantage that it can be computed with any existing index of synchrony and does not require the knowledge of the shape of possible linear trends in species abundance.

A widespread assessment of the effect of species directional trends on synchrony has been limited by the scarcity of available long-term data. Indeed, the study of temporal dynamics requires a substantial sampling effort to obtain meaningful data for temporal analyses. Although there are networks and independent groups with long-term ecological data around the world, no major efforts have been made to compile and standardize the existing data in order to achieve a worldwide perspective. Consequently, a global-scale analysis would improve our understanding of both directional trends and year-to-year species fluctuations among the different synchrony indices and across diverse habitats, as well as how they are related with different types of disturbances or stressors. To face this challenge, we compiled plant community data from 77 temporal datasets with at least six sampling years, including almost 7800 vegetation plots distributed across the world. First, we evaluated to what extent year-to-year synchrony could be masked by long-term trends, by using the T3 detrending approach for temporal series proposed by Lepš et al. (2019) on commonly used indices of synchrony. Second, we assessed whether synchrony patterns changed in plots in which initial conditions were maintained (‘control’) vs. plots in which new conditions were applied (‘manipulated’ plots, see methods), assuming that these new conditions would trigger compositional changes and therefore generate a trend. Third, we evaluated how detrended synchrony values are affected by the duration of the sampling. Finally, we asked if relationships that are commonly assessed in the literature regarding synchrony indices, i.e. the correlation between synchrony and species richness and the correlation between synchrony and community stability, changed markedly depending on whether the T3 detrending approach was applied. Additionally, beside the validation of the T3 approach introduced by Lepš et al. (2019), we further validated (using simulations) the functionality of the approach in the case of both monotonic and cyclical long-term trends and depending on the time series length (Appendix S1). We expect that: (1) directional trends in our datasets can overshadow either asynchrony or synchrony depending on the type of trend; (2) manipulative experiments can give rise to directional trends and therefore reinforce the need for detrended metrics to accurately evaluate and compare community dynamics; (3) longer time series would provide greater chances to detect species directional trends; and (4) the presence of directional trends may affect the strength of the relationship between synchrony indices and species richness or community stability.

Methods

We collected 77 worldwide datasets of aboveground dry biomass, cover percentage, or frequencies of natural or semi-natural plant communities. These datasets consist of 7788 permanent and semi-permanent plots sampled between 6 to 53 times over periods of 6 to 99 years. These datasets included plots with different treatments or manipulations. The plots were thus grouped into two categories: control vs. manipulated. In total 38 datasets presented both control and manipulated plots. Control includes those plots where the long-term conditions prior to the establishment of the sampling scheme were maintained throughout the sampling. For example, if the historical conditions in a given site include periodic mowing, this represents the 'control'. The 'manipulated' plots were exposed to different treatments that altered the long-term conditions in their respective sites. These treatments included introduction or exclusion of grazing, mowing, removal of dominant species, fire, fertilization and climate change treatments. These wide categories allowed us to perform broad comparisons between different land-use and management conditions that are expected to influence species trends. The list of datasets, their characteristics in habitat, vegetation type and their available data on location and main manipulations is provided in Appendix S2.

Synchrony measures

For each of the 7788 plots, we computed the most common indices of community-level synchrony from existing literature. The main indices fall into two families. The first one is based on correlations between species' abundances and includes two indices: the one proposed by Gross et al. (2014) and then this modified by Blüthgen et al. (2016), which weighs the contribution of species to community synchrony in terms of their abundance. We call these indices 'Gross' and 'GrossW', respectively. The second family of indices is based on variance ratios, i.e. the variance in species fluctuations is compared against the null model of independent fluctuations of individual populations, and includes two indices: log variance ratio ('Logvar', Lepš et al. 2018) and φ ('Phi', Loreau & de Mazancourt 2008).

The Gross and GrossW indices range from -1 to +1 and Logvar from *-Inf* to +ln(*nsp*), with *nsp* being the number of species in a community. High values indicate a common response of the species (synchrony), while any deviation from perfect synchrony indicates asynchrony; the lowest and negative values indicate that the increases or decreases in some species are compensated by opposite changes in others. For all, Gross, GrossW and Logvar, zero corresponds to a situation where the species fluctuate completely independently of each other. Finally, Phi ranges from 0 to 1, 1 being perfect synchrony and any deviation from this value means asynchrony.

For each plot we also computed the average number of species in the plots across years, as well as the coefficient of variation (*CV*) of species abundances (standard deviation of the total sum of abundances or biomass across years divided by the mean of abundances or biomass across years). CV of total community abundance is a common measure of community (in)stability, where high values of CV indicate low stability in the community.

All measures of synchrony (and the CV) can be computed using the three-term local variance (*T3; see* Lepš et al. 2019 for an explanation of how to apply this method to the synchrony measures), originally introduced by Hill (1973) in the context of spatial pattern analysis. T3 is then calculated as:

$$T3 = \frac{\sum_i^{n-2}(x_i - 2x_{i+1} + x_{i+2})^2}{6(n-2)}$$

where n is the number of years in the time-series, i is the year index, and x_i is the abundance recorded in year i. Consequently, T3 computes the variance by averaging variance estimates within a moving window of three consecutive years over the data. Any eventual increase in window size needs to be considered with respect to the limits imposed by total length of the series (Lepš 1990). In this context that the minimum length of the time series in our collection of datasets was 6 years, a movable window of 3 years seemed as a reasonable solution.

For the three-year window used in the calculations, the variance (which is needed in all existing index of synchrony) is estimated from the squared difference of the middle year and average of the years before and after. Therefore, if there is a perfect linear trend within these three years, the difference is zero. If there is no temporal trend in the time series analysed, then T3 is an estimate of classic variance (i.e. for long-time series without a trend the values of T3 and classical variance will converge; see below; Lepš et al. 2019). For each plot, each synchrony index (Gross, GrossW, Logvar and Phi) as well as the CV were calculated both with and without the T3 detrending method.

Data analysis

To assess to what extent the synchrony indices were affected by directional trends we followed different approaches. First, we correlated (across plots within each dataset) synchrony values with and without the T3 detrending approach. Specifically, for each dataset we retained a Rho coefficient from the Spearman correlation between indices calculated using the T3 detrending approach and their respective indices calculated without the T3 approach. Then, to test consistency across datasets another Spearman test was run on the average of each synchrony index per dataset to test if the ranking in synchrony between datasets was maintained.

Second, we determined in how many datasets the T3 detrending approach significantly increased, or decreased, the synchrony values. For this we ran a series of paired t-tests, with a correction of the resulting p-values using the Benjamini–Hochberg approach (Benjamini & Hochberg 1995) for false discovery rates (n = 77 tests for each index). To assess how the T3 detrending approach affected overall community stability, this test was also applied to the CV. For each of the assessed synchrony indices, we also retained for each dataset the t-statistic of the paired t-test, which indicates the strength and the direction of the effect (positive values implying T3 increased synchrony, negative ones when T3 decreased synchrony). Additionally, we evaluated how globally the synchrony values responded to the T3 detrending approach using Linear Mixed Models (LMM). In one approach, we computed for each plot two separate synchrony values (synchrony with and without the T3 detrending approach). The LMM contained one categorical variable (TraT3) as explanatory variable, specifying if the index was calculated with the T3 detrending approach or not. Plots nested in each dataset were considered as a random factor. Also, we computed for each plot the difference between the synchrony values with the T3 detrending approach and the values without it. Then, we evaluated how the effect of detrending (i.e. the difference between synchrony with and without T3) varied across habitat types and the biomes by fitting a LMM in which the dataset identity was considered as a random factor.

Third, we assessed whether synchrony values were affected by directional trends depending on the presence of an experimental manipulation changing abruptly the ecological conditions in a plot. To do this, we evaluated the effect of T3 using the t-statistic of the paired t-test within dataset (see above), separately in control and manipulated plots within datasets. This analysis was restricted to those 38 datasets (out of 77) in which both control and manipulated plots were present and with at least three plots in each category. The same approach was used to test the effect of the duration (number of years) of the sampling period. This was undertaken using a linear model to test the relationship between the t-statistic (resulting from the paired-test) and number of years sampled in each dataset. We also used a similar LMM as described above to jointly evaluate the effects of the duration of the sampling period and experimental manipulation on the difference between the synchrony values with and without the T3 detrending approach in these 38 datasets. In this model, we used the number of years of sampling, the experimental manipulation (manipulated vs. control plots) and their interaction as fixed factor, while each dataset was considered as a random factor. When a significant interaction was found, we split the database in control and manipulated plots and evaluated the effects of duration of the sampling period on both groups of plots.

Finally, to assess changes in strength of the commonly found ecological relationships involving synchrony with or without the use of the T3 detrending approach, we tested for each dataset using paired t-tests how strong were the (Pearson) correlations between synchrony and (i) species richness and (ii) community stability. For each of these two correlations, we considered the Pearson r and tested through a paired t-test if this r value (one for each dataset) was greater or smaller when using the T3 approach compared to when not using the T3 approach.

For simplicity, we mostly present the results of one index (GrossW) in the main text because it is widely applied in the literature. However, most of the results for the other indices considered are shown in Appendix (S3 and S4). Similarly, all results concerning simulations are also included as Supporting Information material (Appendix S1). All the analysis were run in R (R Development Core Team 2018).

Results

The ranking of synchrony values with and without the T3 detrending approach was relatively consistent, both within and across datasets (Fig. 1). The Spearman Rho values computed within each of the 77 datasets were mostly positive and significant (Fig. 1a, for GrossW as an example; similar patterns were obtained for the other indices, Appendix S3). For example, in 44 out of the 77 datasets, the Spearman Rho was above 0.5. This indicates a moderate correspondence in the ranking in synchronicity values across plots within datasets. Nevertheless, notable exceptions were present, for example in six datasets (~8% of the cases) Rho was below 0.1. However, in five out of these six datasets, either the number of manipulated plots was greater than the control plots, or the control plots were entirely absent. Overall, the Spearman ranking test done on the mean synchrony values indicated that greater synchrony without the T3 approach also provided greater synchrony with the T3 approach (Fig. 1b: Rho = 0.81 and $p < 0.001$). Most importantly, synchrony mean values were frequently greater where the T3 detrending approach was applied than without its use (paired t-test $p < 0.001$; Fig. 1b and Appendix S3).

We generally found a greater synchrony when accounting for long-terms trends with the T3 methods than without. A significant increase in synchrony values was found for over 1/3 of the datasets (~30 datasets of 77, i.e. in ~40% of datasets synchrony significantly increase, $p < 0.05$, after correcting p-values for multiple tests with the Benjamini & Hochberg correction for false discovery rate within each synchrony index, Fig. 2; all significant tests reported in this section account for this p-value correction). Conversely, in around 10 datasets (13%, depending on the indices) synchrony values decreased using the T3 approach. In total around 50% of the datasets showed a significant change in synchrony values when using or not using the T3 detrending approach. The pattern described for GrossW index was similar for all other synchrony indices. The number of datasets showing greater synchrony with the T3 approach was lower using Phi, which also showed a higher number of datasets showing lower synchrony with the T3 approach. In the majority of datasets (around 60) the CV computed using the T3 approach was significantly lower compared to the one computed without the T3 approach.

The LMM on the whole dataset showed a significant difference between the use of synchrony with and without the T3 detrending approach ($p < 0.001$) with an overall increase in synchrony with T3, meaning that the T3 detrending approach generally led to increased synchrony values among all the plots (other synchrony indices yielded similar results). This result (which is similar to the significant deviation from the 1:1 line in Fig. 1b mentioned above) further confirms that across the whole dataset long-term trends generally blur the importance of synchrony between species.

The results of the LMM evaluating the effects of habitat type and biomes on the T3 difference (i.e. on the difference between indices of synchrony with and without T3 within a plot) showed a significant effect of the habitat type ($\chi^2 = 47.21$; $p < 0.001$), but no effect of the biomes. Grassland and savanna had in average positive values, meaning that a difference between T3 synchrony and synchrony without T3 were greater in these two habitats.

As expected, detrending had greater impacts on measures of synchrony in experimental plots than controls. Specifically evaluating 'control' vs. 'manipulated' plots (using 38 datasets in which there were both types of plots), showed a greater number of cases in which the T3 approach produced significant changes in synchrony in the manipulated than in the control plots (Fig. 3 for the GrossW and Appendix S4 for the other synchrony indices): 21 significant datasets (60%) in the manipulated plots but only 10 (27%) in the control plots. Moreover, the effect of the sampling period length (number of years plots were sampled) was significantly related to the change in mean synchrony with the T3 approach only in the case of the manipulated plots (Fig. 3, using, as dependent variable, the t-values resulting by comparing synchrony with and without T3 approach using the paired t-tests within plot described above). Specifically, in the manipulated plots a longer sampling period improved the predictive ability of the effect of T3 approach on synchrony (increased detection of synchrony over long-term periods and increased detection of asynchrony in short-time periods). We confirmed these results using an LMM in which the difference of synchrony with and without T3 were computed for each plot. This analyses showed a significant interaction between sampling period length and experimental manipulation. Sampling period length significantly increased the difference between synchrony values with and without the T3 approach only in manipulated plots ($\chi^2 = 10.37$; $p = 0.001$, n = 3414).

Finally, we found that overall the relationships between synchrony and both species richness and community stability were similar (Appendix S5). Nevertheless there were slightly more frequent significant cases after detrending for Gross and GrossW (Appendix S5). For instance, the relationship between species richness and synchrony (i.e. when considering GrossW) was found significant in 15 and 11 datasets (out of 77) respectively when using or not using the T3 detrending approach (in both cases correcting for false discovery rates). However, this relationship, with LogVar, was found significant in 4 datasets less when using the T3. Further, with GrossW the expected positive relationship between synchrony and community CV was significant in 58 and 54 datasets while using or not using the T3 detrending, respectively (we did not detect significant negative relationship between CV and synchrony). The strength of these relationships, however, was not affected by the detrending approach. In neither the (i) species richness and synchrony correlations, nor the (ii) community CV and synchrony correlations, did we detect significant differences when using or not using the T3 detrending approach (in both cases $p > 0.2$). This implies that the use of the T3 detrending approach did not systematically produce greater or weaker correlations when analyzing these common relationships.

Discussion

In this study we show that the synchrony patterns usually attributed to compensatory dynamics could be actually caused by trends in species composition. Without accounting for these trends effectively, it is possible that compensatory effects could be generally overemphasized (in 30% of our datasets) or even underemphasized (in 10% of our datasets). Previous studies of synchrony and compensatory dynamics have often overlooked the possible effects of directional trends on the studied communities. Only few studies, such as Vasseur and Gaedke (2007), Loreau & de Mazancourt (2008) and Tredennick et al. (2017), have effectively filtered out species trends (using wavelet based methods or considering growth rates of species in time, instead of raw abundances). Long-term trends in abundances, either directional or cyclical, indeed have the potential to bias the interpretation of synchrony with the most commonly used indices. The T3 detrending approach can account for this bias (see simulation in Lepš et al. 2019 and in Appendix S1). The advantages of the T3 approach, compared to other approaches, are its lower data requirement and consideration of all species in a community, not just the most frequent ones (Lepš et al. 2019).

In ~40% of the datasets, and in the overall model across all plots, synchrony using the T3 detrending approach was significantly greater than synchrony without using it (Fig. 2). The ~40% estimate is, furthermore, a conservative one as we account for Type I errors. Overall, the mean values of synchrony computed with the T3 detrending approach were higher than without it in the majority of cases, both within and across datasets (Fig. 1b, and LMM). This is an important finding because it suggests that our appreciation of the importance of asynchrony, and therefore compensatory dynamics, may have been possibly overestimated, leading to wrong conclusions about synchrony-asynchrony in communities. These findings highlight the necessity of evaluating the effects of possible directional trends on synchrony to accurately estimate the importance of ecological mechanisms regulating compensatory dynamics. The difference between the indices calculated using T3 detrending approach and without it were higher in grasslands and meadows, possibly because in the absence of slow-growing, less dynamic, woody species. In these communities temporal trends can thus be more easily detected compared to other types of vegetation. The increase in synchrony after detrending also suggests the presence of opposite trends of species abundances in time, such as when one species is decreasing steadily and another increasing. For example, trends could be the result of species responding differently to disturbance or to an increase in nutrient availability. Such opposite trends could be monotonic or following waves in time (Wu et al. 2007), e.g. resulting from periodic climate events such as "El Niño", or intrinsic cycling of particular functional groups such as legumes (Herben et al. 2017). These results are partially expected because our datasets comprised natural or semi-natural well-established plant communities but included experimental conditions in which changes in abundance or composition of species are common.

When considering datasets with both control and manipulated plots (~50% of the datasets) the effect of the T3 approach was more frequently significant in manipulated plots than in control plots (Fig. 3). These plots were more prone to be affected by a directional trend promoted by the specific manipulation imposed. This result agrees with our hypothesis that events like soil-nutrient alteration (e.g. by fertilization) and recovery from disturbance might promote directional trends. This result was expected as some of the experimental manipulations were designed to directly alter species composition, in order to test their effects on community synchrony. However, such prompted changes, often due to colonization-competition trade-offs in species composition, can mask year-to-year fluctuations, and hence these experiments should disentangle these biologically different effects on synchrony. For these reasons, we recommend that any index of synchrony should be computed with and without the T3 approach to properly evaluate the corresponding effects of long-term experimental treatments and year-to-year fluctuations. Our result reinforces the assumption that the effect of the T3 approach could be stronger in changing environments/communities and the combination of indices with and without the T3 approach can be important to distinguish the mechanisms causing differential long-term species responses to changes in environmental conditions from the differential species responses to short-term species fluctuations on synchrony/asynchrony relationships.

The effect of detrending on synchrony values was particularly pronounced in the case of succession. During succession the majority of species will increase their abundance, which will cause them to be ultimately positively correlated in time. However, these same species can compensate each other or vary independently on a year-by-year basis, even if they all generally increase in time, so the existing synchrony indices would tend to overestimate their actual year-to-year synchrony between species within such communities. In fact, among the seven datasets with a Rho below 0.1 (Fig. 1a), the majority were characterised by being exposed to intense disturbance regimes that triggered some type of successional process. For instance, plots of four datasets had been exposed to a fire before or during the experiment, and two evaluated the effect of herbivory exclusion (where the reduction in grazing intensity allowed the development of higher vegetation like shrubs and trees). Both treatments are good examples of environmental conditions promoting species directional trends (Pardo et al. 2015) and thus affect synchrony values.

Interestingly, the effect of the T3 approach on the synchrony measured in manipulated plots depended on the period length of the sampling scheme. Manipulated plots sampled over longer time periods revealed higher synchrony values when using the T3 detrending approach (Fig. 3). In other words, the longer is the sampling period the greatest chance that there is a difference between T3 synchrony and synchrony without T3 in manipulated plots. Longer time series likely increased the chances that some species will have opposite trends in response to manipulation, with some increasing over time and others decreasing. In a shorter time series, on the contrary, the time lag in species responses (particularly extinction debt, Helm, Hanski, & Partel 2006; Lepš 2014) could cause that some species increase quickly in response to manipulation, while others might respond more slowly. The T3 detrending approach, therefore, will affect those species with a similar temporal trend in response to short-term manipulations. Consequently, the duration of the sampling period stands out as a key factor in the evaluation of temporal dynamics. We showed that, in the case of manipulated communities, classical methods tended to overestimate year-to-year synchrony when the sampling period was shorter, and underestimate it when the sampling period was longer. This highlights the importance of T3 approach for a correct evaluation of year-to-year synchrony between species. However, further research is required to find the causes and consequences of these results.

Finally, we generally found that the T3 detrending approach did not cause strong changes in the correlation between synchrony and both species richness and community stability, two of the most iconic relationships in temporal dynamics studies (Hautier et al. 2014; Blüthgen et al. 2016). However, there were more cases of significant correlations with the T3 approach and strength of the correlations could vary considerably (i.e. $R < 0.6$) across datasets. In summary, this suggests that while the applications of the T3 detrending approach did not produce systematically greater or weaker correlations on commonly used tests in ecology, the strength of the relationships could differ. These results confirm that the use of T3 approach to detrend the synchrony indices is far from trivial. As such, the conclusions obtained previously from studies that did not apply the method are not necessarily incorrect. Therefore, applying the detrended and non-detrended methods in a complementary way might bring us closer to understanding the directional changes in community dynamics. For instance, divergent trends, e.g. due to differential response to global warming with some species increasing and other decreasing, might stabilize communities and could maintain ecosystem functions unaltered in response to global warming, even if there are no short-term compensatory mechanisms between species. Hence, it is important to consider both the synchrony with and without detrending approach for teasing apart different causes of stability, or instability, in response to global change drivers.

The evaluation of synchrony with the T3 detrending method provides a feasible measure to reveal year-to-year fluctuations of species by removing the effect of directional trends. In comparison to methods using species growth rates, the T3 approach can be important because it enables the evaluation of the indices with and without the approach and also accounts for species which are not dominant and/or less frequent (in the case of the growth rates, log-transformation is needed, which might not be advisable in the case of zero abundances in specific years). This method has the advantage of evaluating both monotonic and non-monotonic directional trends, and can thus be used to detect year-to-year fluctuations in the face of cyclical periods, such as alternation between drought-wet periods (e.g. Riginos et al. 2018).

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Author contributions: F.B., L.G. and J.L. conceived the project. All authors but E.V., F.B., T.G and L.G. collected the data used in this analysis. E.V. and T.G. assembled data. F.B. performed the analyses. E.V. and F.B. wrote the first draft of the manuscript and all the authors (especially L.G. and J. L.) contributed substantially to the revisions.

Data accessibility

The data that support the findings of this study are available at Figshare (Valencia et al. 2019).

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Figure 1. Effects of the T3 detrending approach on synchrony, using the GrossW index (Blüthgen et al. 2016) as an example. In panel (a), a ranking correlation between synchrony values with and without detrending was computed for each of the 77 datasets considered. The histogram reports the 77 Rho values of the Spearman ranking correlations. Panel (b) reports, for each of the 77 datasets, the mean (+/- standard error) of the synchrony values with and without the T3 detrending approach. Vertical and horizontal dashed lines indicate zero synchrony (i.e. absence of synchrony). The solid line represents the 1:1 line above which, for example T3 synchrony was greater than synchrony without T3.

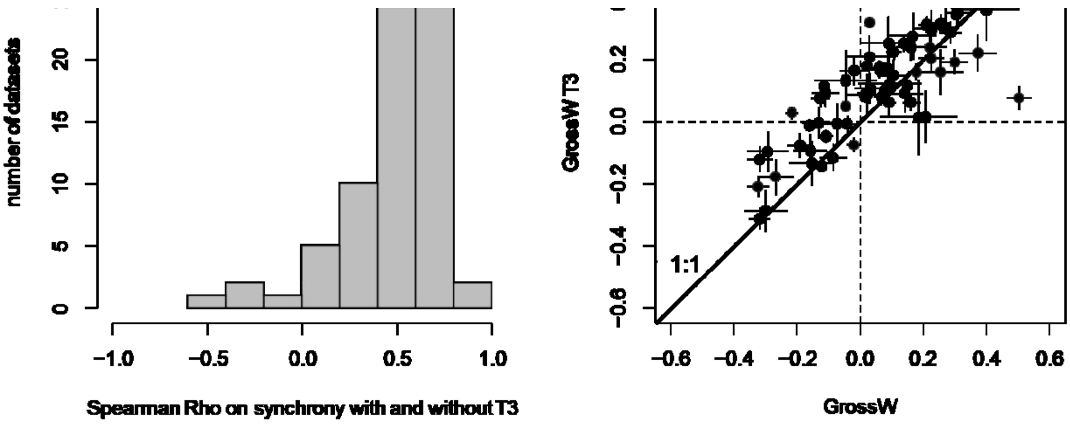


Figure 2. Summary of the directional effects of the T3 detrending approach on various synchrony indices and on CV. The bar plots indicate the numbers of datasets (n=77) in which the T3 approach significantly increased (red bars) or decreased (blue bars) synchrony values using a paired t-test after correction for false discovery rates. Grey bars indicate the number of datasets with non-significant paired t-tests.

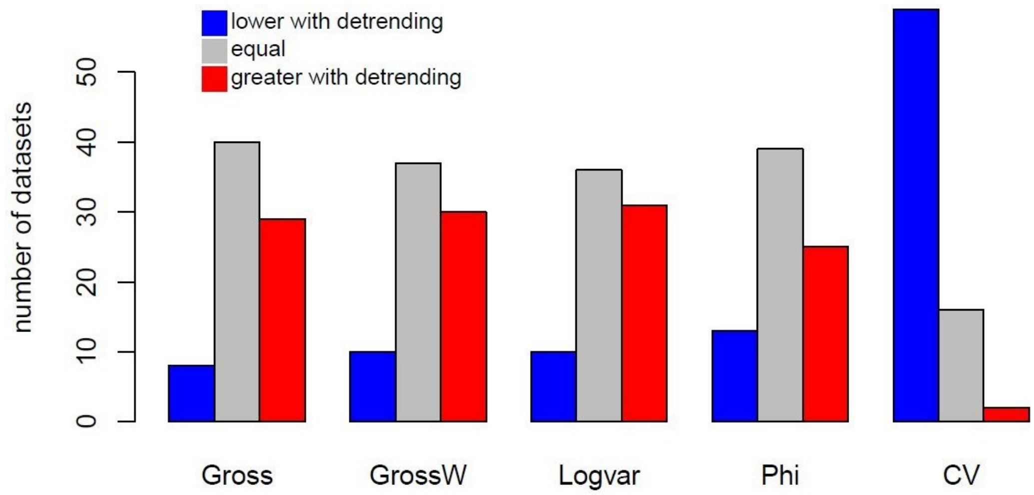
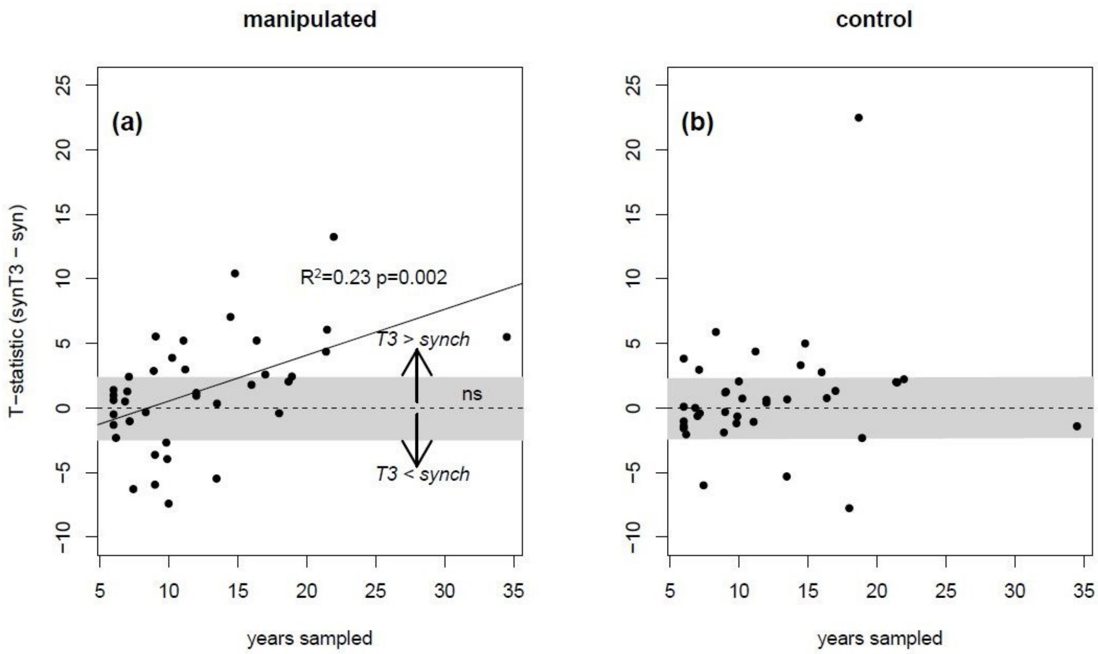


Figure 3. Effects of the T3 detrending approach in manipulated vs. control plots. The plots report results of t-tests on 38 datasets in which there were both manipulated and control plots. For each dataset we used a pairwise t-test to compare synchrony values (using the GrossW synchrony index, Blüthgen et al. 2016) with and without the T3 approach (a: manipulated plots, and b: control plots). Positive values of the t-statistic indicate that the T3 approach increased synchrony and negative ones indicate that the T3 decreased synchrony. Values outside the grey area in each plot indicate significant t-tests after correction for false discovery rates ('ns' indicates *p* > 0.05). For each panel an R^2 for the relationship between t-statistic and number of years sampled in each dataset is provided together with the p-value of the regression model (the corresponding regression line is shown when significant).



Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Simulating long term trends in artificial communities to validate effectiveness of the T3 approach

Appendix S2. Descriptions of each dataset, highlighting the treatments of the datasets with ‘control’ and ‘manipulated’ plots.

Appendix S3. Application of the analyses shown in Fig. 1 of the main text to the three remaining indices of synchrony.

Appendix S4. Application of the analyses shown in Fig. 3 of the main text to the three remaining indices of synchrony.

Appendix S5. Results of the correlation between synchrony indices with species richness or with the CV of total abundance.

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

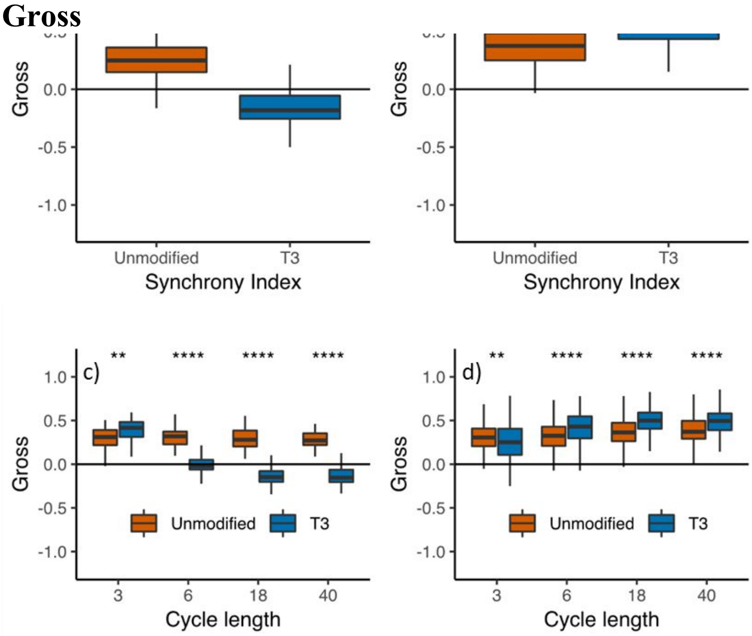
Appendix S1. *Simulating long term trends in artificial communities to validate effectiveness of the T3 approach*

We created artificial temporal community data with desired patterns of temporal fluctuations (prevailing synchrony or asynchrony) using the "syngenr" R function (Lepš et al. 2019). This function offers the possibility to build simulated communities, fixing some parameters, such as the years of the time series (100 years) and the number of species (8 species). Once the communities were established, communities fluctuating in time were created according to the following scenarios: prevailing synchrony or prevailing asynchrony. A synchronous pattern was simulated by having a common response for all species to a hypothetical environmental cue. Accordingly, an asynchronous pattern was created by having half of the species responding positively and the other half negatively to the environmental cue. Furthermore, we simulated directional (monotonic) and cyclical long term trends for these artificial communities. First, we simulated a case where most species had a common long-term positive trend (monotonic) leading to a steady increase of individual species over time. This would lead to detect synchrony with the synchrony indices (unmodified), even if the species are actually behaving asynchronous. Second, we simulated the opposite case, where species either increase or decrease in time, with the increase/decrease for each species defined by a combined bimodal distribution from two normal distributions with -1 and 1 as means, and random subset from half of the species more probably have a positive long-term trend and the other half of the species more probably a negative long-term trend. Finally, we simulated a case were the directional long-term had cyclical tendencies. The cyclical long term trends were evaluated with different cycle length: 3, 6, 18 and 40 years. These cycle lengths reflect some known potential long term cycles that drive communities across the world, such as the El Niño Oscillation or Pacific Decadal Oscillation, which have intervals of 3-6 years and 10-20 year, respectively. In summary, we simulated two scenarios of year-to-year species fluctuations (prevailing synchrony or prevailing asynchrony) and three types of long-term directional trends (i.e. monotonic with a common or contrasted trend, and cyclical trends), resulting in six possible combinations of trend–fluctuation scenarios. In all these simulated communities, we calculated the different synchrony indices (Gross, GrossW, Logvar and Phi), with or without the use of the T3 detrending approach, using the "calc_sync" R function (Lepš et al. 2019).

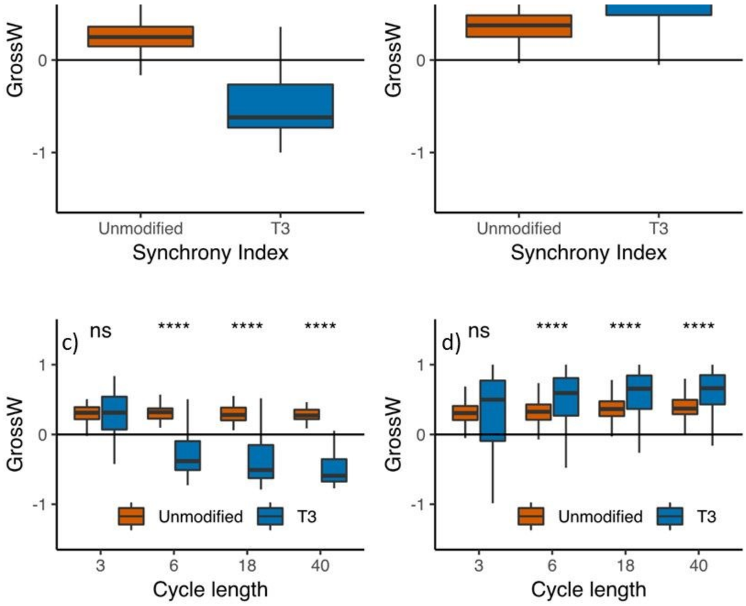
We assessed the effectiveness of the T3 detrending approach when long-term monotonic or cyclical trends are present in the data across the most common synchrony indices, using a paired t-test. Fluctuations simulated under scenarios of long-term trends in species abundances showed biased index estimates, i.e. the simulated synchrony or asynchrony patterns were overshadowed by the patterns caused by long-term trends. In the case of species having long-term directional or cyclical trends, asynchrony was masked by the synchrony (Figure Appendix S1a and S1c). Then, the synchrony indices without the T3 detrending approach were not able to detect asynchrony, even if the species were actually behaving asynchronously. These synchrony indices values were significantly higher than those with the T3 detrending approach. These biases were found across all indices but the application of the T3 detrending approach was correctly able to remove them, in all indices (Figure Appendix S1). In the opposite case, simulation of synchrony together with long-term monotonic or cyclical trends, the difference still prevailed among the synchrony with and without the T3 detrending approach, but with a less pronounced effect (Figure Appendix S1b and S1d).

Figure Appendix S1. Results of synchrony indices (Gross, GrossW Logvar, and Phi)('Logvar', Lepš et al. 2018)('Logvar', Lepš et al. 2018), with or without the use of the T3 detrending approach, in artificial temporal communities where long term trends were simulated. The panels report results for a common long-term directional trend (a) (i.e. creating synchrony; all species increasing in time), a contrasted long-term trend (b) (i.e. half species increasing, the other half decreasing, creating asynchrony) and a cyclical trend (c and d). Within each of these scenarios we considered two scenarios: year to year asynchrony (a and c) and synchrony (b and d). The cyclic trends also included different cycle length (3, 6, 18 and 40 years). The created communities had a total of 8 species. Asterisks above and between boxes depict significant differences among the synchrony indices with or without the T3 approach as assessed with a paired t-test. *: P < 0.05; **: P < 0.01; ***: P < 0.001; ****: P < 0.0001.

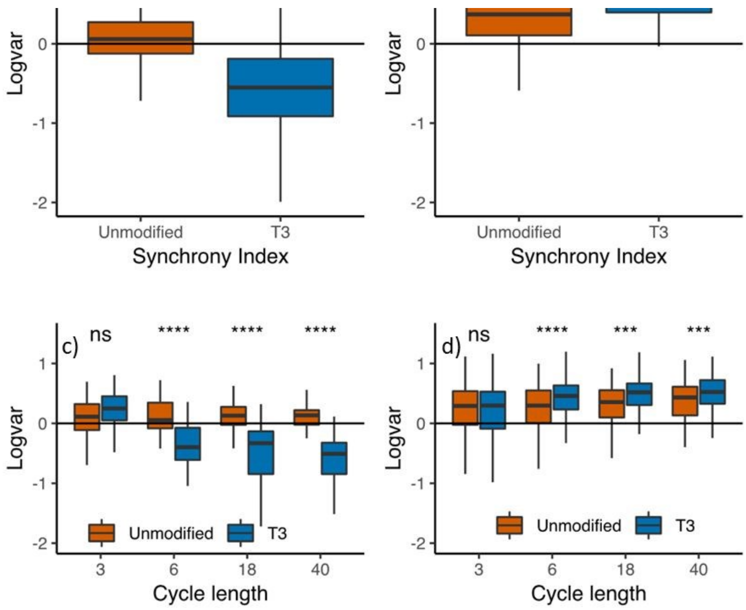
Gross



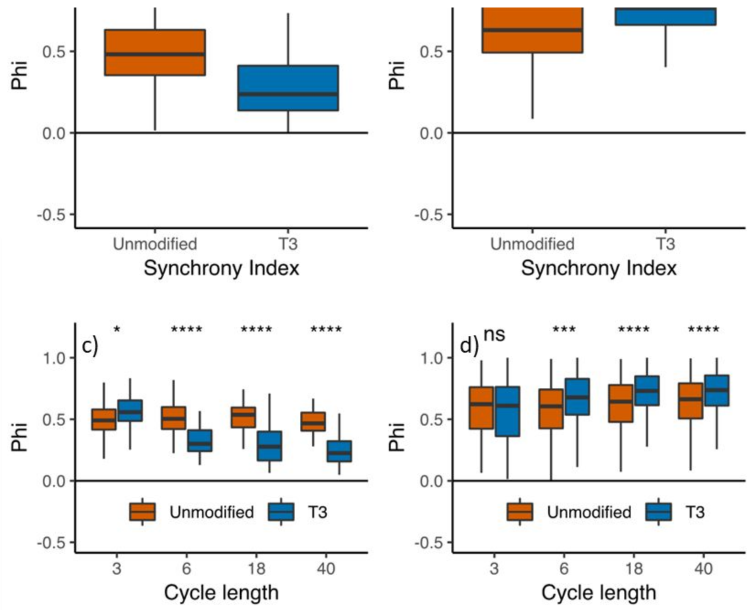
GrossW



Logvar



Phi


Phi
0.5
0.0
-0.5
Unmodified
T3
Synchrony Index
c)
*
****
1.0
Unmodified
T3
3
6
18
40
Cycle length
d)
ns
***

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

Appendix S2. Descriptions of each dataset, highlighting the treatments of the datasets with 'control' and 'manipulated' plots. LAT: latitude (WGS84 datum), and LON: longitude (WGS84 datum).

1. The dataset is issued from an experiment in a northern mixed prairie at a field station in Miles City, Montana, USA (LAT: 46.32, and LON: -105.80). This dataset consists of 42 plots, where each plot was sampled an average of 12.5 times. In each plot, individual plants were quantified and mapped annually. More information: http://esapubs.org/archive/ecol/E092/143/#data

2. The dataset is issued from an experiment located on a mixed grass prairie in Hays, Kansas, USA (LAT: 38.80, and LON: -99.30). This dataset consists of 51 plots, where each plot was sampled an average of 34.5 times. In each plot, individual plants were quantified and mapped. Thirty-six permanent quadrats were located inside livestock exclosures and 15 in grazed areas. More information: https://web.archive.org/web/20150128015820/http://esapubs.org:80/archive/ecol/E088/161/default.htm

3. The dataset is issued from an experiment located on a shortgrass steppe of North America in Nunn, Colorado, USA (LAT: 40.85, and LON: -104.71). This dataset consists of 24 plots, where each plot was sampled an average of 13.5 times. In each plot, individual plants were quantified and mapped. The quadrats were established in six grazed and ungrazed study sites on the Central Plains Experimental Range. There were four treatments combining past and present grazing status: ungrazed in the past and at present (ungrazed/ungrazed), grazed by livestock in the past and present (grazed/grazed), grazed in the past and ungrazed during the experiment (grazed/ungrazed), and ungrazed in the past and grazed during the experiment (ungrazed/grazed). More information: https://web.archive.org/web/20150502183659/http:/www.esapubs.org/archive/ecol/E094/128/

4. The dataset is issued from an experiment located on semi-desert grasslands at the Santa Rita Experimental Range, Arizona, USA (LAT: 31.83, and LON: -110.88). This dataset consists of 160 plots, where each plot was sampled an average of 11.2 times. In each plot, individual plants were quantified and mapped. Quadrats were located in exclosures (ungrazed) and in pastures grazed by livestock (grazed). More information: https://web.archive.org/web/20150502183207/http://esapubs.org:80/archive/ecol/E093/132/default.htm

5. The dataset is issued from an experiment located in sagebrush steppe in eastern Idaho, USA (LAT: 44.20, and LON: -112.20). This dataset consists of 23 plots, where each plot was sampled an average of 21.5 times. In each plot, individual plants were quantified and mapped. These permanent quadrats were located in both grazed (4 quadrats) and ungrazed units (18 quadrats), and one quadrat was grazed in the past and ungrazed during the experiment. More information: https://web.archive.org/web/20150128015825/http:/esapubs.org/archive/ecol/E091/243/default.htm.

6. The dataset is issued from an experiment on the Jornada Long-Term Ecological Research site in southern New Mexico, USA (LAT: 32.83, and LON: -107.33). This dataset consists of 222 plots, where each plot was sampled an average of 8.0 times. Previously grazing domestic livestock was excluded from the area where three permanent transects (2.7 km) were established. One of the transects received fertilization of 10 g/m^2 of nitrogen. One of the two control transects (not fertilized), was sampled at 40 stations, the other two transects had 91 stations each. At each station abundance of each species was estimated by point-intercept method along a 30 m transect perpendicular to each of the three permanent transects. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-jrn.2100119001.50.

7. The dataset is issued from an experiment on the Jornada Basin Long-Term Ecological Research Program (LTER) site in the Chihuahuan desert, New Mexico, USA (LAT: 32.93, and LON: -107.36). This dataset consists of 1001 plots, where each plot was sampled an average of 11.5 times. On the grassland site, three exclusion treatment levels were set in addition to the control treatment left open to all grazers. The first level excluded only domestic animals (cattle), the second excluded lagomorphs, and the third excluded rodents. In the shrubland site, only lagomorph- and rodent-exclusion treatments were set in addition to the control. In each treatment of each site, 4 grids of 36 permanent plots (1 m^2) were sampled (visual estimated cover). More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100086002.39.

8. The dataset is issued from an experiment in an open grassland of the South African Kalahari near Askham, South Africa (LAT: -26.76, and LON: 20.61). This dataset consists of 20 plots, where each plot was sampled an average of 10.7 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

9. The dataset is issued from an experiment located in the Succulent Karoo in Soebatsfontein, South Africa (LAT: -30.19, and LON: 17.54). This dataset consists of 24 plots, where each plot was sampled an average of 15.8 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

10. The dataset is issued from an experiment located in the Succulent Karoo, near Leliefontein, South Africa (LAT: 18.28, and LON: -30.40). This dataset consists of 42 plots, where each plot was sampled an average of 14.7 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

11. The dataset is issued from an experiment located in the Succulent Karoo, Knersvlakte near Vanrhynsdorp, South Africa (LAT: -31.28, and LON: 18.59). This dataset consists of 40 plots, where each plot was sampled an average of 16.0 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

12. The dataset is issued from an experiment on the Kiskun LTER located in Bugac and Orgovány sites of Kiskunság National Park, Hungary (LAT: 46.73, and LON: 19.54). This dataset consists of 380 plots, where each plot was sampled an average of 14.5 times. Half of the plots were fenced to control grazing pressure. In each plot, the cover values (%) were visually estimated annually. More information: Kertész et al. (2017).

13. The dataset is issued from an experiment on a grassland in Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.16). This dataset consists of 50 plots, where each plot was sampled an average of 7.0 times. The plots were divided in 10 treatments of fertilization and grazing exclusion (Control=no treatment, K=potassium, P=phosphate, N=nitrogen, PK=phosphate and potassium, NK=nitrogen and potassium, NP=nitrogen and phosphate, NPK=nitrogen, phosphate and potassium, Fence=Fence, NPK+Fence=nitrogen, phosphate and potassium + fence). In each plot, the cover values (%) were visually estimated annually. This dataset was provided from Cedar Creek LTER. More information: http://cedarcreek.umn.edu/research/data/dataset?acze247.

14. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.19). This dataset consists of 184 plots, where each plot was sampled an average of 6.2 times. Plots were distributed across 6 treatments with increasing burning frequency: i) no burning – control – (48 plots), ii) 1 per 10 years (16 plots), iii) 1 per 3 years (32 plots), iv) 1 per 2 years (32 plots), v) 2 per 3 years (8 plots) and vi) 4 per 5 years (48 plots). Plots are located on 12 management areas ranging in size from 2.4 to 30 ha. In each plot, the cover values (%) were visually estimated. More information: http://cedarcreek.umn.edu/research/data/dataset?herbe133.

15. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.19). This dataset consists of 60 plots, where each plot was sampled an average of 24.8 times. In each plot, the biomass of individual plants was recorded from 4 plots (0.3 m^2) per field until 2013. More information: http://cedarcreek.umn.edu/research/data/dataset?ple054.

16. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.40, and LON: -93.20). This dataset consists of 234 plots, where each plot was sampled an average of 22.0 times.

The experiment combines different levels of fertilization on 4 fields that were abandoned for different periods (14, 25, 48 years and never ploughed before the experiment started in 1982) and where mammal grazers were excluded. In each plot, individual plant biomass was recorded on 5 to 6 replicate plots of different fertilization treatments (from 0 to 40 g/m^2 of nitrogen) per field every year. More information: http://cedarcreek.umn.edu/research/data/dataset?ple001.

17. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.40, and LON: -93.20). This dataset consists of 237 plots, where each plot was sampled an average of 14.8 times. The experiment combines 9 levels of fertilization (from 0 to 40 g/m^2 of nitrogen) and prescribed burning on three fields that were abandoned since 14, 25 and 48 years, and where mammal grazers were excluded. All 3 fields had 6 replicate plots of the 9 fertility treatments from 1982. From 1992 half of the plots in field B were burned every spring, and half of the plots in field A and C stopped receiving the fertilization treatment. To maintain continuity of the treatments within plots the 1992-2011 period of those plots were entered in the database as separate plots of the same data set. Individual plant biomass was measured. More information: http://cedarcreek.umn.edu/research/data/dataset?ple002.

18. The dataset is issued from an experiment located in the Shortgrass Steppe LTER in the Central Plains Experimental Range, Colorado, USA (LAT: 40.85, and LON: -104.77). This dataset consists of 795 plots, where each plot was sampled an average of 13.5 times. Plots were distributed across four combinations of past/current management: grazed/grazed, ungrazed/ungrazed, grazed/ungrazed and ungrazed/grazed. In 1998, additional plots were added in a fifth treatment with fences excluding both large and small grazers (rodent exclusion). More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-sgs.527.1.

19. The dataset is issued from an experiment located in sandy semi-natural grasslands of the Elbe valley in Höhbeck, Germany (LAT: 53.05, and LON: 11.41). This dataset consists of 96 plots, where each plot was sampled an average of 6.0 times. The vegetation was surveyed once a year in 1 m^2 plots using the Londo scale (Londo 1976). More information: Schuhmacher & Dengler (2013).

20. The dataset is issued from an experiment located near Dufftown, Morayshire, United Kingdom (LAT: 57.73, and LON: -3.10). This dataset consists of 12 plots, where each plot was sampled an average of 6.0 times. Each species was measured in a transect, using the inclined-point quadrat method (Tinney et al. 1937) (32·5° to the horizontal). All contacts with 5 pins were recorded in 20 quadrat positions per plot. More information: Pakeman et al. (2003).

21. The dataset is issued from an experiment located in Andrew Experimental forest Program (AND-LTER), Oregon, USA (LAT: 44.35, and LON: -122.41). This dataset consists of 193 plots, where each plot was sampled an average of 21.4 times. Plots were established in i) undisturbed, ii) logged, iii) logged and lightly burned, and iv) logged and severely burned areas. In each plot, the cover values (%) were estimated. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-and.3217.11.

22. The dataset is issued from an experiment located on woodlands, grasslands, and shrublands in eastern Australia (LAT: -30.12, and LON: 147.17). This dataset consists of 47 plots, where each plot was sampled an average of 10.2 times. In each plot, the biomass of the vegetation was measured annually, from 1991 to 2002, in four 300 m long transects each containing 13 quadrats of 0.72 m x 0.72 m. Dataset owners: James Val and David Eldridge (Office of Environment & Heritage, University of New South Wales).

23. The dataset is issued from an experiment located on a pasture in Fasque, United Kingdom (LAT: 56.87, and LON: -2.60). This dataset consists of eight plots, where each plot was sampled an average of 8.0 times. Inclined-point quadrat method (32·5° to the horizontal) was used to record each species in a transect, with a minimum of 20 point contacts at 18 locations per plot (i.e. a minimum of 360 contacts per plot). More information: Marriott et al. (2002).

24. The dataset is issued from an experiment located on La Fage French National Institute for Agricultural Research (INRA) experimental station, close to Millau, France (LAT: 43.92, and LON: 3.10). This dataset consists of 16 plots, where each plot was sampled an average of 28.0 times. Individual plants were identified using the point intercept method on 5 m permanent lines (1 point/10 cm, i.e. 50 points/line). More information: Chollet et al. (2014) and Garnier et al. (2018).

25. The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 483 and 497- ITEX Dataset 5 - Teberda (Malaya Alpine-Snowbed and Geranium Hedysarum Meadow) and ITEX Dataset 19 - Teberda (Festuca Varia Grassland, Malaya Alpine Lichen-Heath). The dataset is issued from an experiment located in Teberda State Reserve, a part of the Karachaevo-Cherkessian Republic in the northwestern Caucasus, Russia (LAT: 43.45, and LON: 41.69). This dataset consists of 145 plots, where each plot was sampled an average of 24.3 times. In each plot, the cover of each plant species was recorded as number of shoots per m^2. More information: Onipchenko *et al.* (1998).

26. The dataset is issued from an experiment located a moorland in the Clocaenog Forest, United Kingdom (LAT: 53.06, and LON: -3.47). This dataset consists of 9 plots, where each plot was sampled an average of 12.0 times. The experiment was designed with three treatments: control, drought (~20% reduction in total annual rainfall) and warming (~64% reduction in heat loss during night and 14% reduction in total annual rainfall). Three quadrats per plot were chosen, and in each quadrat vegetation was quantified using a grid of 100 pins (pin-point methodology). Pin hits were then converted to biomass (g m^{-2}) using a biomass calibration-conversion. More information: https://catalogue.ceh.ac.uk/documents/5b39a644-d614-4f2b-8df6-202ed440b4ab. Doi: https://doi.org/10.5285/5b39a644-d614-4f2b-8df6-202ed440b4ab.

27. The dataset is issued from an experiment located on serpentine and non-serpentine meadows in California, USA (LAT: 38.85, and LON: -123.50). This dataset consists of 400 plots, where each plot was sampled an average of 10.0 times. In each plot, the species cover (%) was visually estimated annually. More information: Fernandez-Going et al. (2012) and Harrison (1999).

28. The dataset is issued from an experiment located on the Jornada Basin Experimental Range JRN-LTER in the Chihuahuan desert, New Mexico, USA (LAT:

32.62, and LON: -106.67). This dataset consists of 68 plots, where each plot was sampled an average of 27.8 times. Density of individuals per species and per plot was recorded. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.210351002.75.

29. The dataset is issued from an experiment located on a grassland in Krkonose Mountains, Czech Republic (LAT: 50.69, and LON: 15.71). This dataset consists of four plots, where each plot was sampled an average of 16.8 times. Standing biomass was sampled annually. More information: Herben et al. (1997).

30. The dataset is issued from an experiment located on a grassland in Krkonose Mountains, Czech Republic (LAT: 50.69, and LON: 15.79). This dataset consists of four plots, where each plot was sampled an average of 29.8 times. Standing biomass was sampled annually. More information: Herben et al. (2017).

31. The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 243 - Virginia Coast Reserve Long-Term Ecological Research. The dataset is issued from an experiment located in the coastal sand dunes of Hog island, Virginia, USA (LAT: 37.67, and LON: -75.67). This dataset consists of 28 plots, where each plot was sampled an average of 18.9 times. Half of the plots received nitrogen fertilization each year in the form of urea nitrogen (30% uncoated (46-0-0) and 70% (40-0-0) coated for slow release). The fertilizer was applied evenly in a dry form (15 g/m^2 of nitrogen). In each plot, species cover (%) was visually estimated in five 0.25 m^2 plots. More information: Day et al. (2016).

32. The dataset is issued from an experiment located on a grassland near Napal, Spain (LAT: 42.72, and LON: -1.22). This dataset consists of 12 plots, where each plot was sampled an average of 12.0 times. The experimental area was fenced and shrubs were removed. Six plots were fertilized (sewage sludge to the soil surface with 5000 g/m^2) and six plots were used as controls. All vascular plant species were measured annually using frequencies. To do so, each plot was divided into 100 subplots, and the presence/absence of each species was recorded. More information: Gazol et al. (2016).

33. The data were sourced from BioTIME (Dornelas et al. 2018), Study_ID 491 - ITEX Dataset 13 - Toolik (Dry, Moist). The dataset is issued from an experiment located on tundra vegetation near Toolik, Alaska, USA (LAT: 68.62, and LON: -149.61). This dataset consists of eight plots, where each plot was sampled an average of 6.0 times. The plots are divided between dry tundra with control and warming treatments and moist tundra with only control treatment. Biomass estimates were obtained using a fixed 75 cm^2 point frame, with 100 measurements spaced 7 cm apart.

34. The data was sourced from BioTIME (Dornelas et al. 2018), Study_ID 492 - ITEX Dataset 14 - Toolik (LTER Heath, LTER Moist acidic tussock, LTER non-acidic tussock, LTER wet sedge, SAG wet sedge2, Tussock 1981 plots). The dataset is issued from an experiment located in Toolik, Alaska, USA (LAT: 68.63, and LON: -149.58). This dataset consists of four plots, where each plot was sampled an average of 6.0 times. In each plot, species biomass was assessed by clipping of four or five 0.25 m x 0.25 m plots, and sorting to species level.

35. The dataset is issued from an experiment located on a grassland in Bayreuth, Germany (LAT: 49.92, and LON: 11.59). This dataset consists of 15 plots, where each plot was sampled an average of 7.7 times. Three treatments were applied: 1) control (ambient condition), 2) winter warming (October–March), and 3) summer warming (April–September). In each plot, species cover (%) was visually estimated annually. More information: Grant et al. (2017).

36. The dataset is issued from an experiment located on a grassland in the Czech Republic (LAT: 48.87, and LON: 16.64). This dataset consists of seven plots, where each plot was sampled an average of 8.0 times. In each plot (1 m^2), the species cover (%) was visually estimated annually from 1993 to 2001. Dataset owner: Jiří Danihelka (Department of Botany and Zoology, Masaryk University and Department of Vegetation Ecology, Institute of Botany, The Czech Academy of Sciences).

37. The dataset is issued from an experiment located on a grassland in Laqueuille, France (LAT: 45.64, and LON: 2.73). This dataset consists of 10 plots, where each plot was sampled an average of 13.0 times. Half of the plots were located in an intensively managed grassland (10-15 animals ha^{-1} yr^{-1} and 20 g/m^2 of nitrogen), and the other half were located in a neighbouring grassland under extensive management (5-8 animals ha^{-1} yr^{-1} and no fertilization). In each plot, presence/absence of each species was recorded in 40 pin-points regularly spaced (pin-point methodology. Dataset owner: Katja Klumpp (INRA, Grassland Ecosystem Research Unit).

38. The dataset is issued from an experiment located on Shortgrass Steppe (SGS-LTER) in the Central Plains Experimental Range Nunn, Colorado, USA (LAT: 40.85, and LON: -104.71). This dataset consists of 48 plots, where each plot was sampled an average of 9.0 times. The experiment evaluated four treatments: control inside exclosure, control outside exclosures, *Bouteloua gracilis* removal inside exclosure and *Bouteloua gracilis* removal outside exclosure. Species density was measured in a quadrat (1 m^2) using vegetation point intercept method (40 points of contact was recorded for each quadrat). More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.703.1.

39. The dataset is issued from an experiment located on a wet meadow in Ohrazeni, Czech Republic (LAT: 48.95, and LON: 14.59). This dataset consists of 12 plots, where each plot was sampled an average of 16.0 times. The experiment evaluated four treatments: control, mowing (annually in the second half of June), fertilization (65 g/m^2 of commercial NPK fertilizer) and dominant removal (*Molinia caerulea* plants were manually removed annually). In each plot, the biomass of each species was measured annually. More information: Lepš (2014).

40. The dataset is issued from an experiment (Long Term Experiment SOERE-ACBB) located on a grassland in Theix, France (LAT: 45.72, and LON: 3.02). This dataset consists of eight plots, where each plot was sampled an average of 8.0 times. The experiment evaluated, on one hand, the effect of the intensity of grazing with two treatments with cattle rotational grazing at high (Ca+) or low (Ca-) level of herbage utilisation; these two treatments did not receive any mineral fertilisation. On the other hand, it also evaluated the effect of nutrient availability, comparing two treatments conducted under fixed cutting regime (three cuts/per year), one with fertilization (NPK fertilizer) and the other without fertilization. The presence/absence of each plant species was measured using 40 pin-points regularly spaced along fixed transects. Complementarily, at each pin-point, 6 points are distributed to species according to visual estimation of their volume. Dataset owner: Frédérique Louault (INRA-UREP). More information: Louault et al. (2017).

41. The dataset is issued from an experiment belonging to the Sevilleta LTER and located on Chihuahuan desert in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.27, and LON: -106.68). This dataset consists of six plots, where each plot was sampled an average of 14.3 times. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.200.174699.

42. The dataset is issued from an experiment located on hyper-oceanic coastal grasslands in United Kingdom (LAT: 57.27, and LON: -7.40). This dataset consists of 48 plots, where each plot was sampled an average of 6.8 times. The experiment evaluated six treatments: 1) vertebrate grazing exclusion, 2) burial box with no sand added, 3) buried to 10 cm, 4) buried to 20 cm, 5) windbreak - shelter from prevailing SW winds, 6) no treatment. The cover values (%) of all individual plant species were estimated annually from 2004 to 2010. Data owners: Robin Pakeman (James Hutton Institute. Aberdeen) and Jack J. Lennon (School of Biological Sciences, Queen's University Belfast).

43. The dataset is issued from an experiment located on a grassland in Cleish and Kirkton, United Kingdom (LAT: 56.29, and LON: -4.07). This dataset consists of 16 plots, where each plot was sampled an average of 6.0 times. The experiment evaluated ungrazed and sheep-grazed plots to maintain three different levels of sward height. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Hulme et al. (1999).

44. The dataset is issued from an experiment located on a grassland in Bell Hill and Cleish, United Kingdom (LAT: 55.80, and LON: -2.84). This dataset consists of eight plots, where each plot was sampled an average of 7.0 times. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Grant et al. (1996a).

45. The dataset is issued from an experiment located on a grassland in Cleish and Sourhope, United Kingdom (LAT: 55.81, and LON: -2.86). This dataset consists of seven plots, where each plot was sampled an average of 6.0 times. There were different treatments where cattle or sheep density was adjusted twice a week to maintain the vegetation height between tussocks. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Grant et al. (1996) and Common et al. (1998).

46. The dataset is issued from an experiment located on a moorland previously on the Burnhead heft at the Redesdale Experimental Farm in Northumberland, United Kingdom (LAT: 55.37, and LON: -2.45). This dataset consists of 12 plots, where each plot was sampled an average of 6.0 times. The 12 plots were divided in three areas with different grazing treatments: ungrazed, sheep-grazed (three levels: 0.4, 0.8 and 1.2 ha^{-1} yr^{-1}). In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Pakeman & Nolan (2009).

47. The dataset is issued from an experiment located on a heather moorland at Dundonnell near Ullapool and at Claonaig, near Tarbert Loch Fyne, Argyll and Bute, United Kingdom (LAT: 57.35, and LON: -5.55). This dataset consists of 17 plots, where each plot was sampled an average of 6.0 times. The experiment had different sheep grazing and exclusion treatments: 1) low at 0.4 sheep ha^{-1} yr^{-1}, 2) moderate at 0.8 sheep ha^{-1} yr^{-1}, 3) high at 1.2 sheep ha^{-1} yr^{-1}, 4) fenced against both cattle and sheep, and 5) fenced against cattle, also 6) sheep and cattle recorded from the open hill. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations was used to measure each species. More information: Pakeman & Nolan (2009).

48. The dataset is issued from an experiment located on a grassland in the Ordesa-Monte Perdido National Park, Spain (LAT: 42.67, and LON: -0.06). This dataset consists of four plots, where each plot was sampled an average of 19.0 times. The point intercept method at 20 locations was used to measure each species.

In each plot, the point intercept method was used annually to measure vegetation along two perpendicular transects (a total of 400 sample points). More information: Pardo et al. (2015).

49. The dataset is issued from an experiment located in Soto de Viñuelas, Spain (LAT: 40.60, and LON: -3.63). This dataset consists of 68 plots, where each plot was sampled an average of 11.5 times. In each plot, all plant species was recorded using presence/absence data in five quadrats of 400 cm^2 each from 1980 to 1995. Dataset owner: Begoña Peco (Ecology Department Autonomous, University of Madrid).

50. The dataset is issued from an experiment located on a shrubland in Garraf, Spain (LAT: 41.30, and LON: 1.82). This dataset consists of nine plots, where each plot was sampled an average of 17.0 times. Three experiment evaluated three treatments: 1) control, 2) warming (metallic curtain covering the plots during the night), and 3) drought (transparent curtain covering the plots during rainfall). Number of contacts per plot was used to quantify each species. Dataset owners: Josep Penuelas, Marc Estiarte and Romà Ogaya (Global Ecology Unit CREAF-CSIC-UAB).

51. The dataset is issued from an experiment belong to the Jornada LTER (JRN-LTER) and located in Chihuahuan desert, Jornada Basin Experimental Range, New Mexico, USA (LAT: 32.00, and LON: -106.00). This dataset consists of 734 plots, where each plot was sampled an average of 24.0 times. In each plot, the biomass of each species was calculated from field measurement of individual species cover and height. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100011001.49.

52. The dataset is issued from an experiment located on a moorland on the Burnhead heft at the Redesdale Experimental Farm in Northumberland, United Kingdom (LAT: 55.37, and LON: -2.45). This dataset consists of 10 plots, where each plot was sampled an average of 6.0 times. The experiment had different grazing treatments: summer grazing, winter grazing or year-round grazing (0.7 sheep ha^{-1} yr^{-1}), year-round grazing (1.4 sheep ha^{-1} yr^{-1}), and no grazing. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Hulme et al. (2002) and Pakeman & Nolan (2009).

53. The dataset is issued from an experiment located on moorlands in Derbyshire, United Kingdom (LAT: 54.69, and LON: -2.41). This dataset consists of 216 plots, where each plot was sampled an average of 10.0 times. The experiment evaluated 36 treatments: no treatment; cut once per year; cut twice per year; herbicide sprayed; herbicide sprayed in first year, cut in second; and cut in first year, sprayed in second. Within each of these main plot treatments there were two sub-plot grazing treatments - sheep grazing and no sheep grazing. Finally, there were three restoration treatments applied at the sub-sub-plot level: untreated, *Calluna* moorland litter applied as litter, and *Calluna* vegetation applied as cut brash. All these 36 treatments had 6 replicates. In each plot, the species composition was recorded using point-quadrats (1 m-long frame with 10 pin positions at 10 cm intervals, pin diameter = 2 mm). Dataset owner: Rob Marrs (University of Liverpool).

54. The dataset is issued from an experiment belonging to the Environmental Change Network (ECN) and located in the United Kingdom (LAT: 53.95, and LON: -3.23). This dataset consists of 198 plots, where each plot was sampled an average of 11.1 times. In each plot (ten quadrats of 0.16 m^2), the inclined-point quadrat method was used to evaluate the vegetation annually. More information: Rennie et al. (2016) and https://catalogue.ceh.ac.uk/documents/b98efec8-6de0-4e0c-85dc-fe4cdf01f086 and https://catalogue.ceh.ac.uk/documents/d349babc-329a-4d6e-9eca-92e630e1be3f.

55. The dataset is issued from an experiment belonging to the Andrews Forest LTER (AND-LTER) and located in a forest in the Oregon Cascade Range, USA (LAT: 44.22, and LON: -122.25). This dataset consists of 5 plots, where each plot was sampled an average of 10.0 times. The vegetation cover (%) was visually estimated 10 times in a quadrat of 4 m^2 for trees (vegetation > 60 cm tall) and 9 quadrats (0.1 m^2) for herb and low shrub (< 60 cm tall). More information: Rothacher (Rothacher 2013) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-and.3190.7.

56. The dataset is issued from an experiment belonging to the Park Grass permanent grassland and located in Rothamsted, United Kingdom (LAT: 51.81, and LON: -

0.37). This dataset consists of 74 plots, where each plot was sampled an average of 9.9 times. The purpose of the experiment was to evaluate different fertility and lime treatments. Herbage was taken from six randomly located quadrats measuring 0.5 m x 0.25 m within each plot, resulting in a total sampling area of 0.75 m^2 within each plot. In each plot, the biomass of each species was measured annually in quadrats (sampling area: 0.75 m^2). More information: Crawley et al. (2005) and http://www.era.rothamsted.ac.uk/Park.

57. The dataset is issued from an experiment located on a savannah in central Spain (LAT: 40.38, and LON: -4.20). This dataset consists of 210 plots, where each plot was sampled an average of 6.0 times. The experiment evaluated two types of pastures (higher-productivity pastures and low-productivity pastures) and three treatments (ungrazed, grazed by small herbivores, and grazed by large and small herbivores). In each plot, the species cover (%) was visually estimated. More information: Rueda et al. (2013).

58. The dataset is issued from an experiment located in Central Germany (LAT: 51.55, and LON: 10.07). This dataset consists of 14 plots, where each plot was sampled an average of 14.9 times. In each plot, species vegetation cover (%) was visually estimated. More information: Schmidt (2007).

59. The dataset is issued from an experiment located on a former arable field in the Experimental Botanical Garden of the University of Göttingen, Germany (LAT: 51.56, and LON: 9.96). This dataset consists of six plots, where each plot was sampled an average of 38.0 times. In each plot, species vegetation cover (%) was visually estimated. More information: Schmidt (Schmidt 2006) and Bernhardt-Römermann et al. (2011).

60. The dataset is issued from an experiment located in the Swiss National Park (IUCN Ia reserve, LAT: 46.68, and LON: 10.22). This dataset consists of 41 plots, where each plot was sampled an average of 12.2 times. In each plot, plant species cover (%) was visually estimated. More information: Braun-Blanquet et al. (1931), Schütz et al. (2000).

61. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.31, and LON: -106.49). This dataset consists of 95 plots, where each plot was sampled an average of 9.8 times. The experiment was designed to evaluate the effect of prescribed burning (two areas were left unburned as control treatments, and the other plots were burned in different dates) and grazing exclusion (fenced and unfenced). In each plot, the individuals present in 36 quadrats (0.1 m^2) were recorded. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.148.131885.

62. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.33, and LON: -106.74). This dataset consists of 81 plots, where each plot was sampled an average of 9.2 times. The experiment had three treatments: 1) control plots (natural rainfall regime) 2) drought was induced by rainfall shelters, and 3) watering was applied by redirecting the water from the nearby rainfall shelters. In each plot, the plant cover (%) was estimated every spring. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.147.167839.

63. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located on a grassland in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.33, and LON: -106.63). This dataset consists of 216 plots, where each plot was sampled an average of 7.7 times. The experiment evaluated the impact of prairie dog reintroduction (grazed and ungrazed areas) on vegetation. In each plot, the plant cover (%) was estimated annually. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-sev.212.4.

64. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located on a woodland in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.37, and LON: -106.54). This dataset consists of 100 plots, where each plot was sampled an average of 13.0 times. In each plot, the plant cover (%) was visually estimated annually. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.278.245672.

65. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.37, and LON: -106.58). This dataset consists of 100 plots, where each plot was sampled an average of 16.4 times. The experiment evaluated three treatments: 1) control plots (untouched vegetation), 2) removal of all three dominant species (*Larrea tridentata*, *Bouteloua eriopoda*, *Bouteloua gracilis*), and 3) removal of one dominant species. In each plot, the plant cover (%) was visually estimated annually. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.168.192543.

66. The dataset is issued from an experiment belonging to the Shortgrass Steppe LTER (SGS-LTER) and located on grasslands and shrublands in Central Plains Experimental Range, Colorado, USA (LAT: 40.85, and LON: -104.77). This dataset consists of 18 plots, where each plot was sampled an average of 8.2 times. In each plot, the plant cover was recorded on three permanent transects (1 m^2: sum of plots along the transect). More information: Stapp (Stapp 2013) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.140.17.

67. The dataset is issued from an experiment located in a beech forest near Göttingen, Central Germany (LAT: 51.57, and LON: 10.32). This dataset consists of seven plots, where each plot was sampled an average of 18.0 times. Four plots had a fertilization treatment (NP addition) and three were the control plots. In each plot, the species cover (%) was visually estimated. More information: Schmidt (2009).

68. The dataset is issued from an experiment located on a meadow near Zvíkov, Czech Republic (LAT: 48.99, and LON: 14.61). This dataset consists of 40 plots, where each plot was sampled an average of 10.3 times. The experiment evaluated four treatments: 1) control (intact vegetation), 2) mycorrhizal grasses and forbs left, non-mycorrhizal species weeded out, 3) mycorrhizal forbs remaining, everything else weeded out, and 4) mycorrhizal grasses remaining, everything else weeded out. In each plot, the species cover (%) was visually estimated annually. More information: Šmilauer & Šmilauerová (2013).

69. The dataset is issued from an experiment located on a floodplain grassland in Anloo and Taarlo, The Netherlands (LAT: 53.05, and LON: 6.66). This dataset consists of 80 plots, where each plot was sampled an average of 28.9 times. In each plot, the species cover (%) was estimated almost every year from 1973 to 2008. Dataset owners: Christian Smit and Jan P. Bakker (Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences).

70. The dataset is issued from an experiment located on a meadow in the north-eastern Tibetan Plateau in Qinghai Province, China (LAT: 37.62, and LON: 101.20). This dataset consists of 30 plots, where each plot was sampled an average of 9.0 times. The experiment was designed to evaluate 10 nitrogen treatments (no N added and 9 combinations of three N forms and three N rates). In each plot, the species cover (%) was visually estimated annually. More information: Song et al. (2012).

71. The dataset is issued from an experiment located on salt marshes of the Schleswig-Holstein Wadden Sea National Park in Hamburger Hallig and Westerhever, Germany (LAT: 54.49, and LON: 8.75). This dataset consists of 212 plots, where each plot was sampled an average of 18.7 times. There were two treatments in Westerhever: natural condition and intensive grazing, and only natural conditions in Hamburger Hallig. In each plot, the species cover was measured annually using the Londo scale (percentage of vegetation cover) from 1997 to 2015 in Hamburger Hallig and from 1995 to 2012 in Westerhever. Dataset owner: Martin Stock (Wadden Sea National Park of Schleswig-Holstein).

72. The dataset is issued from an experiment located on a wooded savanna in Laikipia, Kenya (LAT: 0.28, and LON: 36.87). This dataset consists of 18 plots, where each plot was sampled an average of 14.7 times. The treatments were six combinations (3 replicates) of cattle, wildlife, and mega-herbivore grazing. These either allowed (1) the entry of all large mammalian herbivores, (2) all large mammalian herbivores except mega-herbivores (elephants *Loxodonta africana* and giraffe *Giraffa camelopardis*) to enter, or (3) excluded all large herbivores. In each plot, vegetation was assessed annually by counting the number of pins hit by each species over a ten-point pin frame at each station. More information: Veblen et al. (2016).

73. The dataset is issued from an experiment located on a coastal heathland in Lurekalven, Norway (LAT: 60.70, and LON: 5.08). This dataset consists of 42 plots, where each plot was sampled an average of 6.0 times. In each plot, all vascular plants, bryophytes and lichens were recorded annually using frequencies (1 m x 1 m metal frame divided into 16 subplots). More information: Vandvik et al. (2005).

74. The dataset is issued from an experiment located in Bonanza Creek LTER, Alaska, USA (LAT: 65.00, and LON: -148.00). This dataset consists of 59 plots, where each plot was sampled an average of 12.0 times. In each plot, the species cover (%) was visually estimated. More information: Viereck et al. (2010) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-bnz.174.19.

75. The dataset is issued from an experiment located on desert steppes in Gobi Gurvan Saykhan National Park, Mongolia (LAT: 43.61, and LON: 104.13). This dataset consists of 18 plots, where each plot was sampled an average of 7.1 times. The experiment evaluated two treatments: 1) exclusion of large ungulates, and 2) no exclusion of large ungulates. In each plot, the species cover (%) was visually estimated annually. More information: Wesche et al. (2010).

76. The 9dataset is issued from an experiment located on a floodplain grassland on formerly arable land (LAT: 51.78, and LON: -1.31). From 1989 the site was divided into nine plots of c. 0.4 ha over which three contrasting grazing management practices (control, cattle and sheep) were randomly superimposed. These nine plots were monitored in June of each year from 1991-2009. More information: Woodcock et al. (2011).

77. The dataset is issued from an experiment located on a grassland in southeast Estonia (LAT: 58.11, and LON: 27.07). This dataset consists of 55 plots, where each plot was sampled an average of 8.9 times. The treatments were: fertilizer, sucrose and control. In each plot, the species cover (%) was visually estimated annually. More information: Liira et al. (2012).

Figure Table S2. Characteristics of the study sites.

ID	Country	Biome	Habitats	Duration	CP	MP
1	USA	TGD	Grassland	12.5	NO	YES
2	USA	WS	Grassland	34.5	YES	YES
3	USA	TGD	Grassland	13.5	YES	YES
4	USA	SD	Grassland	11.2	YES	YES
5	USA	TGD	Savanna	21.5	YES	YES
6	USA	TGD	Grassland	8.0	YES	YES
7	USA	TGD	Grassland and Shrubland	11.5	YES	YES
8	South Africa	SD	Grassland	10.7	YES	NO
9	South Africa	SD	Savanna	15.8	YES	NO
10	South Africa	TGD	Savanna	14.7	YES	NO
11	South Africa	SD	Savanna	16.0	YES	NO
12	Hungary	WS	Savanna	14.5	YES	YES
13	USA	TF	Grassland	7.0	YES	YES
14	USA	TF	Savanna	6.2	YES	YES
15	USA	TF	Grassland	24.8	YES	NO
16	USA	TF	Grassland	22.0	YES	YES
17	USA	TF	Grassland	14.8	YES	YES
18	USA	TGD	Grassland	13.5	YES	YES
19	Germany	WS	Grassland	6.0	YES	NO
20	United Kingdom	WS	Shrubland	6.0	NO	YES
21	USA	TRF	Forest	21.4	YES	YES
22	Australia	SD and WS	Savanna	10.2	YES	NO
23	United Kingdom	WS	Grassland	8.0	YES	YES
24	France	WS	Grassland	28.0	NO	YES
25	Russia	BF	Grassland	24.3	YES	NO
26	United Kingdom	TF	Shrubland	12.0	YES	YES
27	USA	TF	Grassland	10.0	YES	NO
28	USA	TGD	Grassland	27.8	YES	NO
29	Czech Republic	TF	Grassland	16.8	YES	NO
30	Czech Republic	TF	Grassland	29.8	YES	NO
31	USA	WS	Grassland	18.9	YES	YES
32	Spain	WS	Grassland	12.0	YES	YES
33	USA	Tu	Grassland	6.0	YES	YES
34	USA	Tu	Grassland	6.0	YES	NO
35	Germany	WS	Grassland	7.7	YES	YES
36	Czech Republic	WS	Grassland	8.0	YES	NO
37	France	TF	Grassland	13.0	NO	YES
38	USA	TGD	Grassland	9.0	YES	YES
39	Czech Republic	WS	Grassland	16.0	YES	YES
40	France	WS	Grassland	8.0	YES	YES
41	USA	TGD	Grassland, Shrubland and Savanna	14.3	YES	NO
42	United Kingdom	TF	Grassland	6.8	YES	YES
43	United Kingdom	TF and TRF	Grassland	6.0	YES	YES

44	United Kingdom	TF	Grassland	7.0	YES	YES
45	United Kingdom	TF	Grassland	6.0	YES	YES
46	United Kingdom	TF	Shrubland	6.0	NO	YES
47	United Kingdom	TF	Savanna	6.0	YES	YES
48	Spain	BF	Grassland	19.0	YES	YES
49	Spain	TGD	Grassland	11.5	YES	NO
50	Spain	WS	Shrubland	17.0	YES	YES
51	USA	TGD	Grassland, Shrubland and Savanna	24.0	YES	NO
52	United Kingdom	TF	Savanna	6.0	NO	YES
53	United Kingdom	TF	Shrubland	10.0	YES	YES
54	United Kingdom	TF and WS	Grassland, Savanna and Forest	11.1	YES	NO
55	USA	TF	Forest	10.0	YES	NO
56	United Kingdom	WS	Grassland	9.9	YES	YES
57	Spain	TGD	Savanna	6.0	YES	YES
58	Germany	WS	Grassland	14.9	YES	NO
59	Germany	WS	Grassland	38.0	NO	YES
60	Switzerland	BF	Grassland and Forest	12.2	NO	YES
61	USA	TGD	Savanna	9.8	YES	YES
62	USA	TGD	Grassland, Shrubland and Savanna	9.2	YES	YES
63	USA	TGD	Grassland	7.7	YES	YES
64	USA	TGD	Forest	13.0	YES	NO
65	USA	TGD	Grassland and Savanna	16.4	YES	YES
66	USA	TGD	Grassland and Shrubland	8.2	YES	NO
67	Germany	WS	Forest	18.0	YES	YES
68	Czech Republic	WS	Grassland	10.3	YES	YES
69	Netherlands	WS	Grassland	28.9	NO	YES
70	China	WS	Grassland	9.0	YES	YES
71	Germany	WS	Salt marsh	18.7	YES	YES
72	Kenya	WS	Savanna	14.7	NO	YES
73	Norway	TRF	Grassland	6.0	NO	YES
74	USA	BF	Grassland and Savanna	12.0	YES	NO
75	Mongolia	TGD	Grassland	7.1	YES	YES
76	United Kingdom	WS	Grassland	18.0	NO	YES
77	Estonia	WS	Grassland	8.9	YES	YES

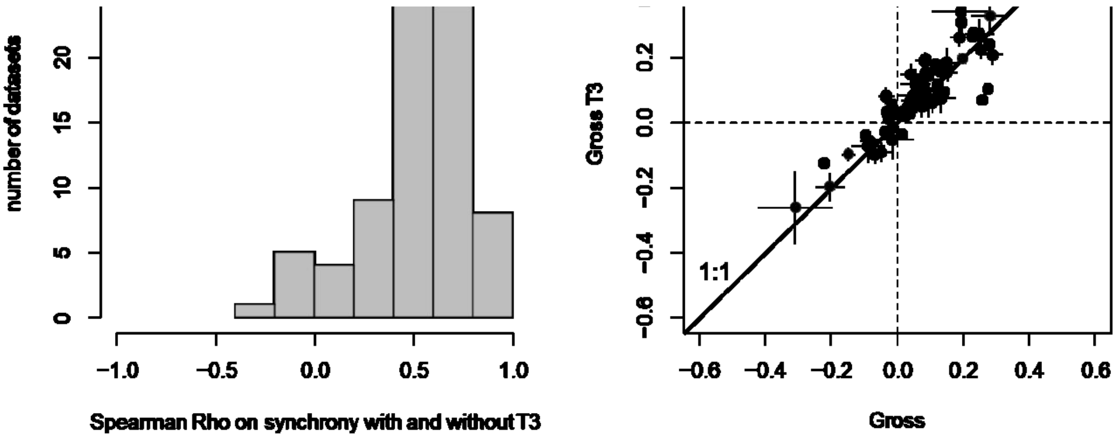
ID: Identification of the data set, biomes (TGD: temperate grassland desert, SD: subtropical desert, WS: woodland shrubland, TF: temperate forest, BF: boreal forest, Tu: Tundra, and TRF: temperate rain forest), Duration: Average number of years of the dataset, CP: presence of plots where the long-term conditions prior to the establishment of the sampling scheme were maintained throughout the sampling, MP: presence of plots exposed to different treatments that altered the long-term conditions.

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

Appendix S3. Application of the analyses shown in Fig. 1 of the main text to the three remaining indices of synchrony.

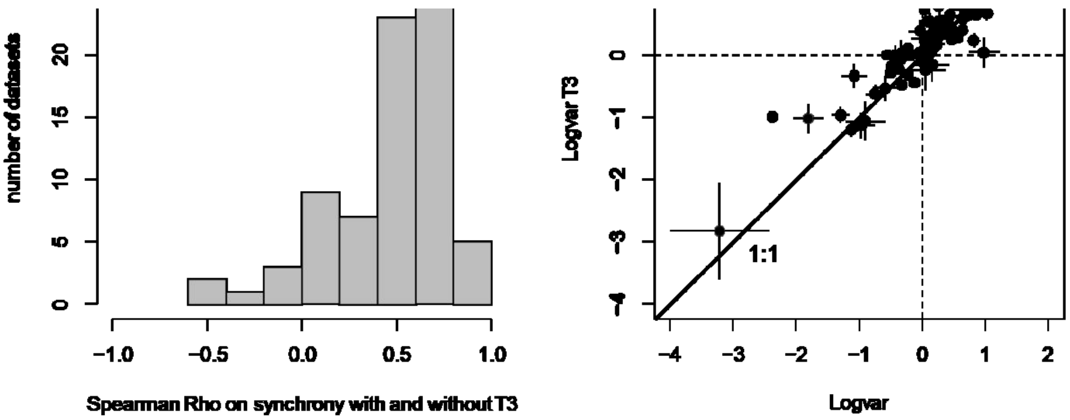
Gross

Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach ($p < 0.001$, paired t-test)



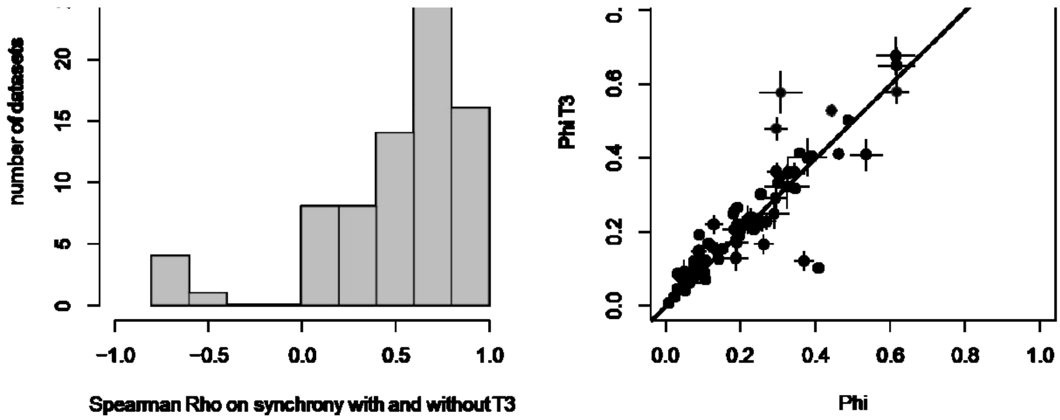
Logvar

Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach ($p < 0.06$, paired t-test)



Phi

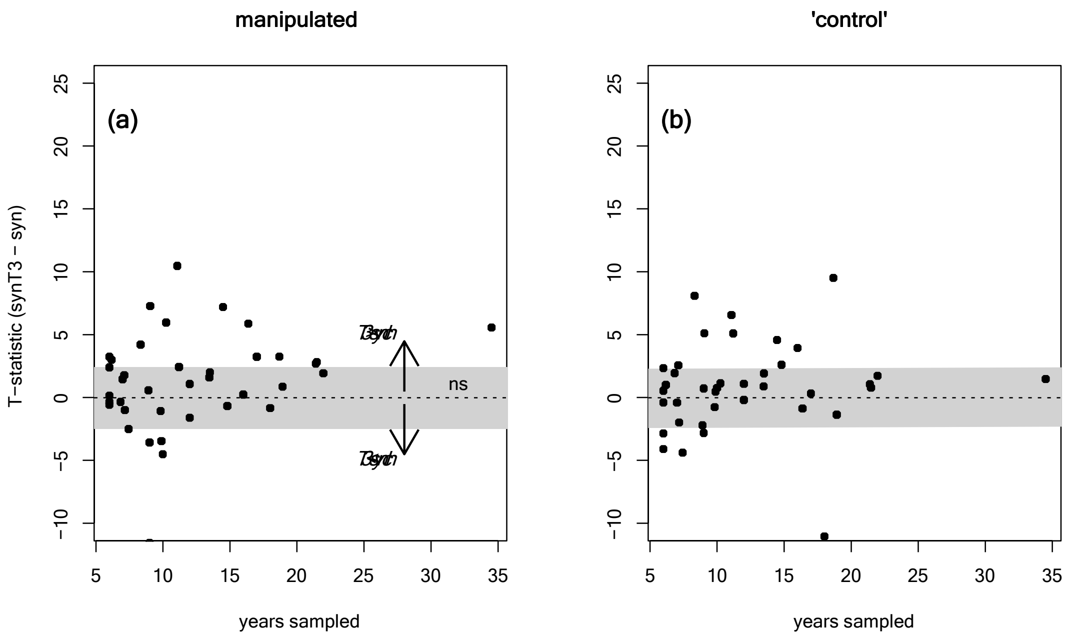
Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach (*p* < 0.22, paired t-test)



Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

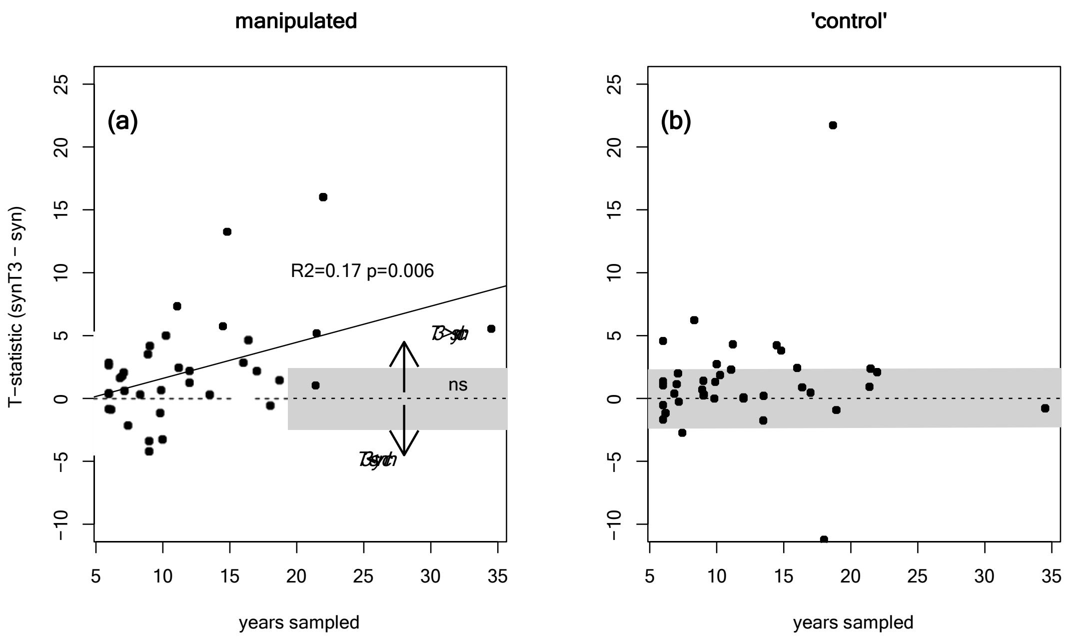
Appendix S4. Application of the analyses shown in Fig. 3 of the main text to the three remaining indices of synchrony. For each index, also, a table of number of datasets with either positive or negative significant t-statitstic values is reported for both manipulated and control plots (positive means that the T3 approach increased synchrony; negative means that the T3 approach decreased synchrony). The grey area in each panel reports and approximate are where t-statistic values were not significant (‘*ns*’).

Gross



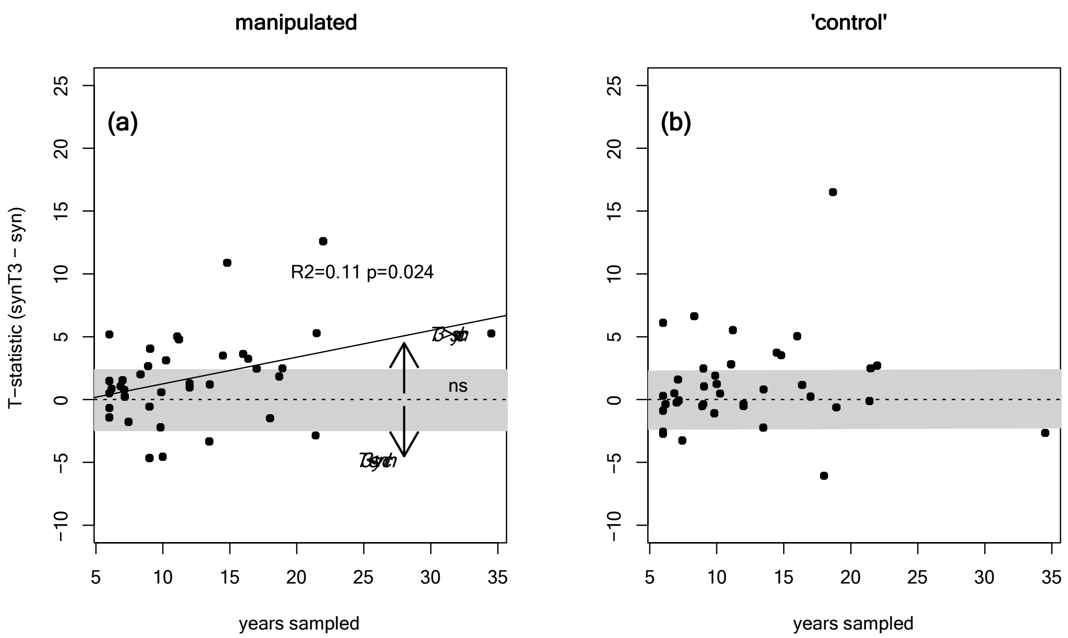
Manipulated		Control	
-	+	-	+
5	13	2	9

Logvar



Manipulated		Control	
-	+	-	+
4	13	2	7

Phi



Manipulated		Control	
-	+	-	+
5	14	3	8

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

Appendix S5. Results of the correlation between synchrony indices with species richness or with the *CV* of total abundance. Each table reports the number of datasets with a significant correlations between either Synchrony ~ richness or CV~richness (after correction for false discovery rates, see main text). The number of positive correlations is provided in parenthesis.

Gross

	Richness ~ synchrony	CV~synchrony
Without T3	11 (+7)	42 (+42)
With T3	13 (+8)	48 (+42)

Logvar

	Richness ~ synchrony	CV~synchrony
Without T3	21 (17)	52 (+52)
With T3	16 (13)	59 (+59)

Phi

	Richness ~ synchrony	CV~ synchrony
Without T3	31 (1)	66 (+66)
With T3	30 (1)	65 (65)

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Directional trends in species composition over time can lead to a widespread overemphasis of year-to-year asynchrony

Running title: Directional trends effects on synchrony

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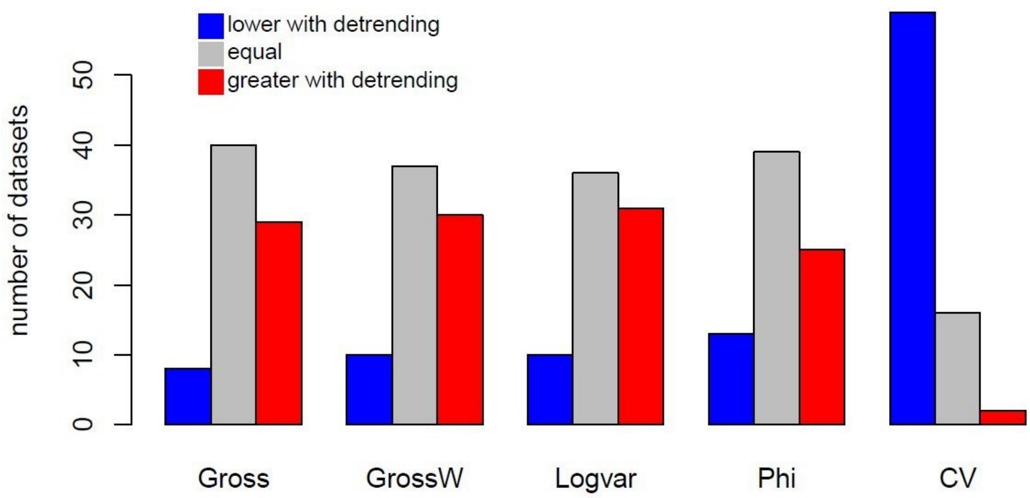
Web summary

Measures of community synchrony and stability aim at quantifying year-to-year ~~changes~~ fluctuations in species abundances. However, these indices reflect also long-term trends, potentially masking year-to-year signals. Using a large number ofdatasets with permanent vegetation plots we show a frequent greater synchrony and stability in year-to-year changes compared to when long-term trends are not taken into account.



Abstract

Questions

Compensatory dynamics are described as one of the main mechanisms that increase community stability, e.g. where decreases of some species on a year-to-year basis are offset by an increase in others. Deviations from perfect synchrony between species (asynchrony) have therefore been advocated as an important mechanism underlying biodiversity effects on stability. However, it is unclear to what extent existing measures of synchrony actually capture the signal of year-to-year species fluctuations in the presence of long-term directional trends in both species abundance and composition (species directional trends hereafter). Such directional trends may lead to a misinterpretation of indices commonly used to reflect year-to-year synchrony.

Methods

An approach based on three-term local quadrat variance (T3) which assess population variability in a three-year moving window, was used to overcome species directional trends effects. This 'detrending' approach was applied to common indices of synchrony across a Worldwide collection of 77 temporal plant community datasets comprising almost 7800 individual plots sampled for at least 6 years. Plots included were either maintained under constant 'control' conditions over time or were subjected to different management or disturbances treatments.

Results

Accounting for directional trends increased the detection of year-to-year synchronous patterns in all synchrony indices considered. Specifically, synchrony values increased significantly in ~40% of the datasets with the T3 detrending approach while in ~10% synchrony decreased. For the 368 studies with both control and manipulated conditions,

the increase in synchrony values was stronger for longer-time series, particularly following experimental manipulation.

Conclusions

Species long-term directional trends can affect synchrony and stability measures potentially masking the ecological mechanism causing year-to-year fluctuations. As such, previous studies on community stability might have overemphasised the role of compensatory dynamic in real-world ecosystems, and particularly in manipulative conditions, when not considering the possible overriding effects of long-term directional trends.

Keywords: asynchrony, biodiversity, stability, synchrony, temporal dynamics, year-to-year fluctuation.

Introduction

Given the challenges posed by rapidly changing environments in the context of global change, it is crucial to understand how biological diversity is maintained over time (Cardinale et al. 2007; Tomimatsu et al. 2013; Tilman, Isbell, & Cowles 2014). There is a general consensus toward the role that synchrony (or lack of) in, e.g., year-to-year population fluctuations between co-existing species plays on species diversity and community stability (Hautier et al. 2014; Craven et al. 2018). On the one hand, a common response to environmental fluctuations (for example changes in temperature or precipitation from one year to another) of most species (synchrony) will tend to destabilize the community biomass or abundance. On the other hand, the opposite pattern (compensatory dynamics, i.e. increases or decreases in the relative abundance of some species that are offset by changes in the relative abundance of others; Hubbell 2001; Gonzalez & Loreau 2009) will lead to higher community stability. In this sense asynchrony, i.e. the extent of the deviation from lack of perfect synchrony between species, has been advocated as an important and widespread mechanism that contributes to stability (Loreau & de Mazancourt 2013).

While there is a lively debate on the importance of compensatory dynamics on the stability of communities (Houlahan et al. 2007; Blüthgen et al. 2016; Lepš et al. 2018) there are also important methodological aspects that can influence the detection of the underlying biological patterns. Recently, Lepš et al. (2019) demonstrated that the study of synchrony between species has traditionally disregarded the possible effects of long-term directional compositional trends in the analysed communities (i.e. a tendency of some species to increase or decrease over time, or to fluctuate cyclically, Wu et al. 2007). Species directional trends occur when the abundances of species respond not only to short-term environmental fluctuations, but also to the presence of monotonic or cyclical tendencies over the whole time series considered. Short term environmental fluctuations (Rabotnov 1974), for example on a year-to-year basis, are expected to affect species abundance, but also to be largely reversible, so that species would not show long-term directional trends in their abundances. In contrast, long-term environmental changes, such as climate change, nutrient deposition and changes in land use (e.g. abandonment or intensification of agricultural land), generally cause long-term species directional trends (Stevens et al. 2011; Walter et al. 2018). Long-term directional trends can also be the result of the impact of undetermined drivers (Milchunas, Lauenroth, & Burkeal 1998). As repeatedly reported by many authors, long term trends in species abundance are probably omnipresent, and have been demonstrated even in, now, more than 160 years of the Park Grass Experiment (Silvertown et al. 2006).

To gain a better understanding of the underlying mechanisms regulating changes in species abundance, short-term fluctuations and long-term trends effects on synchrony should be disentangled. Unfortunately, this differentiation has been rare in studies assessing drivers of synchrony and stability (but see Vasseur & Gaedke 2007; Tredennick et al. 2017; and the review by Lepš et al. 2019). Indeed, using simulations and simple case studies Lepš et al. (2019) showed that species directional trends can mask year-to-year fluctuations among species. This has the potential to result in a biased estimation of asynchrony when using many widely used synchrony indices. Such directional trends could lead to either overestimation of year-to-year synchrony when the majority of species concomitantly increase or decrease over time, as well as overestimation of year-to-year asynchrony when some species increase and some others decrease over time.

Multiple indices have been developed to evaluate the level of synchrony among species in a community (Loreau & de Mazancourt 2008; Gross et al. 2014; Blüthgen et al. 2016; Lepš et al. 2018). Further methodologies have also been developed to assess directional trends, such as spectral or wavelet analyses, however, they are applicable only to very long or highly resolved time series (see Lepš et al. 2019 for an overview of these methods). None of the classically used synchrony indices disentangle, *a priori,* the actual year-to-year fluctuations from the directional trends. However, such indices can be 'detrended' using different methods (Wu et al. 2007; Lepš et al. 2019).~~,~~ One appealing a simple solution includes~~ing~~ computing synchrony indices over moveable windows of three consecutive years (three-term local variance, 'T3', Hill 1973) instead of over the whole sampling period (Lepš et al. 2019). This 'detrending' approach, which we call T3 detrending approach, could allow testing the generality of the effect of directional trends on synchrony indices. If the focus of the research is on year-to-year fluctuations, then the minimum number of years to exclude trends and consider yearly fluctuations is 3 years, hence the three-term local variance. With bigger windows the computation of a common linear trend over the time window, and the focus on the deviation from this trend, does recall on the other method proposed by Lepš et al. (2019), using residuals of fitted linear models over a given time period. The first approach has the advantage that it can be computed with any existing index of synchrony and does not require the knowledge of the shape of possible linear trends in species abundance.

A widespread assessment of the effect of species directional trends on synchrony has been limited by the scarcity of available long-term data. Indeed, the study of temporal dynamics requires a substantial sampling effort to obtain meaningful data for temporal analyses. Although there are networks and independent groups with long-term ecological data around the world, no major efforts have been made to compile and standardize the existing data in order to achieve a worldwide perspective. Consequently, a global-scale analysis would improve our understanding of both directional trends and year-to-year species fluctuations among the different synchrony indices and across diverse habitats, as well as how they are related with different types of disturbances or stressors. To face this challenge, we compiled plant community data from 77 temporal datasets with at least six sampling years, including almost 7800 vegetation plots distributed across the world. First, we evaluated to what extent year-to-year synchrony could be masked by long-term trends, by using the T3 detrending approach for temporal series proposed by Lepš et al. (2019) on commonly used indices of synchrony. Second, we assessed whether synchrony patterns changed in plots in which initial conditions were maintained ('control') vs. plots in which new conditions were applied ('manipulated' plots, see methods), assuming that these new conditions would trigger compositional changes and therefore generate a trend. Third, we evaluated how detrended synchrony values are affected by the duration of the sampling. Finally, we asked if relationships that are commonly assessed in the literature regarding synchrony indices, i.e. the correlation between synchrony and species richness and the correlation between synchrony and community stability, changed markedly depending on whether the T3 detrending approach was applied. Additionally, beside the validation of the T3 approach introduced by Lepš et al. (2019), we further validated (using simulations) the functionality of the approach in the case of both monotonic and cyclical long-term trends and depending on the time series length (Appendix S1). We expect that: (1) directional trends in our datasets can overshadow either asynchrony or synchrony depending on the type of trend; (2) manipulative experiments can give rise to directional trends and therefore reinforce the need for detrended metrics to accurately evaluate and compare community dynamics; (3) longer time series would provide greater chances to detect species directional trends; and (4) the presence of directional trends may affect the strength of the relationship between synchrony indices and species richness or community stability.

Methods

We collected 77 worldwide datasets of aboveground dry biomass, cover percentage, or frequencies of natural or semi-natural plant communities. These datasets consist of 7788 permanent and semi-permanent plots sampled between 6 to 53 times over periods of 6 to 99 years. These datasets included plots with different treatments or manipulations. The plots were thus grouped into two categories: control vs. manipulated. In total 38~~6~~ datasets presented both control and manipulated plots. Control includes those plots where the long-term conditions prior to the establishment of the sampling scheme were maintained throughout the sampling. For example, if the historical conditions in a given site include periodic mowing, this represents the 'control'. The 'manipulated' plots were exposed to different treatments that altered the long-term conditions in their respective sites. These treatments included introduction or exclusion of grazing, mowing, removal of dominant species, fire, fertilization and climate change treatments. These wide categories allowed us to perform broad comparisons between different land-use and management conditions that are expected to influence species trends. The list of ~~all~~ datasets, their characteristics in habitat, vegetation type and their available data on location and main manipulations is provided in Appendix S2.

Synchrony measures

For each of the 7788 plots, we computed the most common indices of community-level synchrony from existing literature. The main indices fall into two families. The first one is based on correlations between species' abundances and includes two indices: the one proposed by Gross et al. (2014) and then this modified by Blüthgen et al. (2016), which weighs the contribution of species to community synchrony in terms of their abundance. We call these indices 'Gross' and 'GrossW', respectively. The second family of indices is based on variance ratios, i.e. the variance in species fluctuations is compared against the null model of independent fluctuations of individual populations, and includes two indices: log variance ratio ('Logvar', Lepš et al. 2018) and φ ('Phi', Loreau & de Mazancourt 2008).

The Gross and GrossW indices range from -1 to +1 and Logvar from -*Inf* to +ln(*nsp*), with *nsp* being the number of species in a community. High values indicate a common response of the species (synchrony), while any deviation from perfect synchrony indicates asynchrony; the lowest and negative values indicate that the increases or decreases in some species are compensated by opposite changes in others. For all, Gross, GrossW and Logvar, zero corresponds to a situation where the species fluctuate completely independently of each other. Finally, Phi ranges from 0 to 1, 1 being perfect synchrony and any deviation from this value means asynchrony.

For each plot we also computed the average number of species in the plots across years, as well as the coefficient of variation (*CV*) of species abundances (standard deviation of the total sum of abundances or biomass across years divided by the mean of abundances or biomass across years). CV of total community abundance is a common measure of community (in)stability, where high values of CV indicate low stability in the community.

All measures of synchrony (and the CV) can be computed using the three-term local variance ~~(*T3*)~~(*T3; see* Lepš et al. 2019 for an explanation of how to apply this method to the synchrony measures), originally introduced by Hill (1973) in the context of spatial pattern analysis. T3 is then calculated as:

$$T3 = \frac{\sum_{i}^{n-2}(x_i - 2x_{i+1} + x_{i+2})^2}{6(n-2)}$$

where n is the number of years in the time-series, i is the year index, and x_i is the abundance recorded in year i. Consequently, T3 computes the variance by averaging variance estimates within a moving window of three consecutive years over the data. Any eventual increase in window size needs to be considered with respect to the limits imposed by total length of the series (Lepš 1990). In this context that the minimum length of the time series in our collection of datasets was 6 years, a movable window of 3 years seemed as a reasonable solution.

For ~~Within~~ the three-year window used in the calculations, the variance (which is needed in all existing index of synchrony) is estimated from the squared difference of the middle year and average of the years before and after.~~;~~ T~~t~~herefore, if there is a perfect linear trend within these three years, the difference is zero. If there is no temporal trend in the time series analysed, then T3 is an estimate of classic variance (i.e. for long-time series without a trend the values of T3 and classical variance will converge; see below; Lepš et al. 2019). For each plot, each synchrony index (Gross, GrossW, Logvar and Phi) as well as the CV were calculated both with and without the T3 detrending method.

Data analysis

To assess to what extent the synchrony indices were affected by directional trends we followed different approaches.~~we~~ F~~f~~irst, we correlated (across plots within each dataset) synchrony values with and without the T3 detrending approach. Specifically, for each dataset we retained a Rho coefficient from the Spearman correlation between indices calculated using the T3 detrending approach and their respective indices calculated without the T3 approach. Then, to test consistency across datasets another Spearman test was run on the average of each synchrony index per dataset to test if the ranking in synchrony between datasets was maintained.

Second, we determined in how many datasets the T3 detrending approach significantly increased, or decreased, the synchrony values. For this we ran a series of paired t-tests, with a correction of the resulting p-values using the Benjamini–Hochberg approach (Benjamini & Hochberg 1995) for false discovery rates (n = 77 tests for each index). To assess how the T3 detrending approach affected overall community stability, this test was also applied to the CV. For each of the assessed synchrony indices, we also retained for each dataset the t-statistic of the paired t-test, which indicates the strength and the direction of the effect (positive values implying T3 increased synchrony, negative ones when T3 decreased synchrony). Additionally, we evaluated how globally the synchrony values responded to the T3 detrending approach using Linear Mixed Models (LMM). ~~To do so~~In one approach, we computed for each plot two separate synchrony values (synchrony with and without the T3 detrending approach). The LMM contained one categorical variable (TraT3) as explanatory variable, specifying if the index was calculated with the T3 detrending approach or not. Plots nested in each dataset were considered as a random factor. Also, we computed for each plot the difference between the synchrony values with the T3 detrending approach and the values without it. Then, we evaluated how the effect of detrending (i.e. the difference between synchrony with and without T3) varied across habitat types and the biomes by fitting a LMM in which the dataset identity was considered as a random factor.

Third, we assessed whether synchrony values were affected by directional trends depending on the presence of an experimental manipulation changing abruptly the ecological conditions in a plot. To do this, we evaluated the effect of T3 using the t-statistic of the paired t-test within dataset (see above), separately in control and manipulated plots within datasets. This analysis was restricted to those ~~36~~ 38 datasets (out of 77) in which both control and manipulated plots were present and with at least three plots in each category. The same approach was used to test the effect of the duration (number of years) of the sampling period. This was undertaken using a linear model to test the relationship between the t-statistic (resulting from the paired-test) and number of years sampled in each dataset. We also used a similar LMM as described above to jointly evaluate the effects of the duration of the sampling period and experimental manipulation on the difference between the synchrony values with and without the T3 detrending approach in these 38 datasets. In this model, we used the number of years of sampling, the experimental manipulation (manipulated vs. control plots) and their interaction as fixed factor, while each dataset was considered as a random factor. When a significant interaction was found, we split the database in control and manipulated plots and evaluated the effects of duration of the sampling period on both groups of plots.

Finally, to assess changes in strength of the commonly found ecological relationships involving synchrony with or without the use of the T3 detrending approach, we tested for each dataset using paired t-tests how strong were the (Pearson) correlations between synchrony and (i) species richness and (ii) community stability. For each of these two correlations, we considered the Pearson r and tested through a paired t-test if this r value (one for each dataset) was greater or smaller when using the T3 approach compared to when not using the T3 approach.

For simplicity, we mostly present the results of one index (GrossW) in the main text because it is widely applied in the literature. However, most of the results for the other indices considered are shown in Appendix (S3 and S4). Similarly, all results concerning simulations are also included as Supporting Information material (Appendix S1). All the analysis were run in R (R Development Core Team 2018).

Results

The ranking of synchrony values with and without the T3 detrending approach was relatively consistent, both within and across datasets (Fig. 1). The Spearman Rho values computed within each of the 77 datasets were mostly positive and significant (Fig. 1a, for GrossW as an example; similar patterns were obtained for the other indices, Appendix S3). For example, in 44 out of the 77 datasets, the Spearman Rho was above 0.5. This indicates a moderate correspondence in the ranking in synchronicity values across plots within datasets. Nevertheless, notable exceptions were present, for example in six datasets (~8% of the cases) Rho was below 0.1. However, in five out of these six datasets, either the number of manipulated plots was greater than the control plots, or the control plots were entirely absent. Overall, the Spearman ranking test done on the mean synchrony values indicated that greater synchrony without the T3 approach also provided greater synchrony with the T3 approach (Fig. 1b: Rho = 0.81 and $p < 0.001$). Most importantly, synchrony mean values were frequently greater where the T3 detrending approach was applied than without its use (paired t-test $p < 0.001$; Fig. 1b and Appendix S3).

We generally found a greater synchrony when accounting for long-terms trends with the T3 methods than without. A significant increase in synchrony values was found for over 1/3 of the datasets (~30 datasets of 77, i.e. in ~40% of datasets synchrony significantly increase, $p < 0.05$, after correcting p-values for multiple tests with the Benjamini & Hochberg correction for false discovery rate within each synchrony index, Fig. 2; all significant tests reported in this section account for this p-value correction). Conversely, in around 10 datasets (13%, depending on the indices) synchrony values decreased using the T3 approach. In total around 50% of the datasets showed a significant change in synchrony values when using or not using the T3 detrending approach. The pattern described for GrossW index was similar for all other synchrony indices. The number of datasets showing greater synchrony with the T3 approach was lower using Phi, which also showed a higher number of datasets showing lower synchrony with the T3 approach. In the majority of datasets (around 60) the CV computed using the T3 approach was significantly lower compared to the one computed without the T3 approach.

The LMM on the whole dataset showed a significant difference between the use of synchrony with and without the T3 detrending approach ($p < 0.001$) with an overall increase in synchrony with T3, meaning that the T3 detrending approach generally led to increased synchrony values among all the plots (other synchrony indices yielded similar results). This result (which is similar to the significant deviation from the 1:1 line in Fig. 1b mentioned above) further confirms that across the whole dataset long-term trends generally blur the importance of synchrony between species.

The results of the LMM evaluating the effects of habitat type and biomes on the T3 difference (i.e. on the difference between indices of synchrony with and without T3 within a plot) showed a significant effect of the habitat type ($\chi^2 = 47.21$; $p < 0.001$), but no effect of the biomes. Grassland and savanna had in average positive values, meaning that a difference between T3 synchrony and synchrony without T3 were greater in these two habitats.

As expected, detrending had greater impacts on measures of synchrony in experimental plots than controls. Specifically evaluating 'control' vs. 'manipulated' plots (using 36 38 datasets in which there were both types of plots), showed a greater number of cases in which the T3 approach produced significant changes in synchrony in the manipulated than in the control plots (Fig. 3 for the GrossW and Appendix S4 for the other synchrony indices): 21 significant datasets (60%) in the manipulated plots but only 10 (27%) in the control plots. Moreover, the effect of the sampling period length (number of years plots were sampled) was significantly related to the change in mean synchrony with the T3 approach only in the case of the manipulated plots (Fig. 3, using, as dependent variable, the t-values resulting by comparing synchrony with and without T3 approach using the paired t-tests within plot described above). Specifically, in the manipulated plots a longer sampling period improved the predictive ability of the effect of T3 approach on synchrony (increased detection of synchrony over long-term periods and increased detection of asynchrony in short-time periods). We confirmed these results using an LMM in which the difference of synchrony with and without T3 were computed for each plot. This analyses showed a significant interaction between sampling period length and experimental manipulation. Sampling period length significantly increased the difference between synchrony values with and without the T3 approach only in manipulated plots ($\chi^2 = 10.37$; $p = 0.001$, n = 3414).

Finally, we found that overall the relationships between synchrony and both species richness and community stability were similar (Appendix S5). Nevertheless there were slightly more frequent significant cases after detrending for Gross and GrossW (Appendix S5). For instance, the relationship between species richness and synchrony (i.e. when considering GrossW) was found significant in 15 and 11 datasets (out of 77) respectively when using or not using the T3 detrending approach (in both cases correcting for false discovery rates). However, this relationship, with LogVar, was found significant in 4 datasets less when using the T3. Further, with GrossW the expected positive relationship between synchrony and community CV was significant in 58 and 54 datasets while using or not using the T3 detrending, respectively (we did not detect significant negative relationship between CV and synchrony). The strength of these relationships, however, was not affected by the detrending approach. In neither the (i) species richness and synchrony correlations, nor the (ii) community CV and synchrony correlations, did we detect significant differences when using or not using the T3 detrending approach (in both cases $p > 0.2$). This implies that the use of the T3 detrending approach did not systematically produce greater or weaker correlations when analyzing these common relationships.

Discussion

In this study we show that the synchrony patterns usually attributed to compensatory dynamics could be actually caused by trends in species composition. Without accounting for these trends effectively, it is possible that compensatory effects could be generally overemphasized (in 30% of our datasets) or even underemphasized (in 10% of our datasets). Previous studies of synchrony and compensatory dynamics have often overlooked the possible effects of directional trends on the studied communities. Only few studies, such as Vasseur and Gaedke (2007), Loreau & de Mazancourt (2008) and Tredennick et al. (2017), have effectively filtered out species trends (using wavelet based methods or considering growth rates of species in time, instead of raw abundances). Long-term trends in abundances, either directional or cyclical, indeed have the potential to bias the interpretation of synchrony with the most commonly used indices. The T3 detrending approach can account for this bias (see simulation in Lepš et al. 2019 and in Appendix S1). The advantages of the T3 approach, compared to other approaches, are its lower data requirement and consideration of all species in a community, not just the most frequent ones (Lepš et al. 2019). ~~Using the T3 approach across a large global dataset, shows that species' directional trends in time can often result in overemphasising year-to-year asynchrony, especially in rather long time series, and when analysing manipulative experiments.~~

In ~40% of the datasets, and in the overall model across all plots, synchrony using the T3 detrending approach was significantly greater than synchrony without using it (Fig. 2). The ~40% estimate is, furthermore, a conservative one as we account for Type I errors. Overall, the mean values of synchrony computed with the T3 detrending approach were higher than without it in the majority of cases, both within and across datasets (Fig. 1b, and LMM). This is an important finding because it suggests that our appreciation of the importance of asynchrony, and therefore compensatory dynamics, may have been possibly overestimated, leading to wrong conclusions about synchrony-asynchrony in communities. These findings highlight the necessity of evaluating the effects of possible directional trends on synchrony to accurately estimate the importance of ecological mechanisms regulating compensatory dynamics. The difference between the indices calculated using T3 detrending approach and without it were higher in grasslands and meadows, possibly because in the absence of slow-growing, less dynamic, woody species. In these communities temporal trends can thus be more easily detected compared to other types of vegetation. The increase in synchrony after detrending also suggests the presence of opposite trends of species abundances in time, such as when one species is decreasing steadily and another increasing. For example, trends could be the result of species responding differently to disturbance or to an increase in nutrient availability. Such opposite trends could be monotonic or following waves in time (Wu et al. 2007), e.g. resulting from periodic climate events such as “El Niño”, or intrinsic cycling of particular functional groups such as legumes (Herben et al. 2017). These results are partially expected because our datasets comprised natural or semi-natural well-established plant communities but included experimental conditions in which changes in abundance or composition of species are common.

When considering datasets with both control and manipulated plots (~50% of the datasets) the effect of the T3 approach was more frequently significant in manipulated plots than in control plots (Fig. 3). These plots were more prone to be affected by a directional trend promoted by the specific manipulation imposed. This result agrees with our hypothesis that events like soil-nutrient alteration (e.g. by fertilization) and recovery from disturbance might promote directional trends. This result was expected as some of the experimental manipulations were designed to directly alter species composition, in order to test their effects on community synchrony. However, such prompted changes, often due to colonization-competition trade-offs in species composition, can mask year-to-year fluctuations, and hence these experiments should disentangle these biologically different effects on synchrony. For these reasons, we recommend that any index of synchrony should be computed with and without the T3 approach to properly evaluate the corresponding effects of long-term experimental treatments and year-to-year fluctuations. Our result reinforces the assumption that the effect of the T3 approach could be stronger in changing environments/communities and the combination of indices with and without the T3 approach can be important to distinguish the mechanisms causing differential long-term species responses to changes in environmental conditions from the differential species responses to short-term species fluctuations on synchrony/asynchrony relationships.

The effect of detrending on synchrony values was particularly pronounced in the case of succession. During succession the majority of species will increase their abundance, which will cause them to be ultimately positively correlated in time. However, these same species can compensate each other or vary independently on a year-by-year basis, even if they all generally increase in time, so the existing synchrony indices would tend to overestimate their actual year-to-year synchrony between species within such communities. In fact, among the seven datasets with a Rho below 0.1 (Fig. 1a), the majority were characterised by being exposed to intense disturbance regimes that triggered some type of successional process. For instance, plots of four datasets had been exposed to a fire before or during the experiment, and two evaluated the effect of herbivory exclusion (where the reduction in grazing intensity allowed the development of higher vegetation like shrubs and trees). Both treatments are good examples of environmental conditions promoting species directional trends (Pardo et al. 2015) and thus affect synchrony values.

Interestingly, the effect of the T3 approach on the synchrony measured in manipulated plots depended on the period length of the sampling scheme. Manipulated plots sampled over longer time periods revealed higher synchrony values when using the T3 detrending approach (Fig. 3). In other words, the longer is the sampling period the greatest chance that there is a difference between T3 synchrony and synchrony without T3 in manipulated plots. Longer time series likely increased the chances that some species will have opposite trends in response to manipulation, with some increasing over time and others decreasing. In a shorter time series, on the contrary, the time lag in species responses (particularly extinction debt, Helm, Hanski, & Partel 2006; Lepš 2014) could cause that some species increase quickly in response to manipulation, while others might respond more slowly. The T3 detrending approach, therefore, will affect those species with a similar temporal trend in response to short-term manipulations. Consequently, the duration of the sampling period stands out as a key factor in the evaluation of temporal dynamics. We showed that, in the case of manipulated communities, classical methods tended to overestimate year-to-year synchrony when the sampling period was shorter, and underestimate it when the sampling period was longer. This highlights the importance of T3 approach for a correct evaluation of year-to-year synchrony between species. However, further research is required to find the causes and consequences of these results.

Finally, we generally found that the T3 detrending approach did not cause strong changes in the correlation between synchrony and both species richness and community stability, two of the most iconic relationships in temporal dynamics studies (Hautier et al. 2014; Blüthgen et al. 2016). However, there were more cases of significant correlations with the T3 approach and strength of the correlations could vary considerably (i.e. $R < 0.6$) across datasets. In summary, this suggests that while the applications of the T3 detrending approach did not produce systematically greater or weaker correlations on commonly used tests in ecology, the strength of the relationships could differ. These results confirm that the use of T3 approach to detrend the synchrony indices is far from trivial. As such, the conclusions obtained previously from studies that did not apply the method are not necessarily incorrect. Therefore, applying the detrended and non-detrended methods in a complementary way might bring us closer to understanding the directional changes in community dynamics. For instance, divergent trends, e.g. due to differential response to global warming with some species increasing and other decreasing, might stabilize communities and could maintain ecosystem functions unaltered in response to global warming, even if there are no short-term compensatory mechanisms between species. Hence, it is important to consider both the synchrony with and without detrending approach for teasing apart different causes of stability, or instability, in response to global change drivers.

The evaluation of synchrony with the T3 detrending method provides a feasible measure to reveal year-to-year fluctuations of species by removing the effect of directional trends. In comparison to methods using species growth rates, the T3 approach can be important because it enables the evaluation of the indices with and without the approach and also accounts for species which are not dominant and/or less frequent (in the case of the growth rates, log-transformation is needed, which might not be advisable in the case of zero abundances in specific years). This method has the advantage of evaluating both monotonic and non-monotonic directional trends, and can thus be used to detect year-to-year fluctuations in the face of cyclical periods, such as alternation between drought-wet periods (e.g. Riginos et al. 2018).

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Author contributions: F.B., L.G. and J.L. conceived the project. All authors but E.V., F.B., T.G and L.G. collected the data used in this analysis. E.V. and T.G. assembled data. F.B. performed the analyses. E.V. and F.B. wrote the first draft of the manuscript and all the authors (especially L.G. and J. L.) contributed substantially to the revisions.

Data accessibility

The data that support the findings of this study are available at Figshare (Valencia et al. 2019).

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Figure 1. Effects of the T3 detrending approach on synchrony, using the GrossW index (Blüthgen et al. 2016) as an example. In panel (a), a ranking correlation between synchrony values with and without detrending was computed for each of the 77 datasets considered. The histogram reports the 77 Rho values of the Spearman ranking correlations. Panel (b) reports, for each of the 77 datasets, the mean (+/- standarderror) of the synchrony values with and without the T3 detrending approach. Vertical and horizontal dashed lines indicate zero synchrony (i.e. absence of synchrony). The solid line represents the 1:1 line above which, for example T3 synchrony was greater than synchrony without T3.

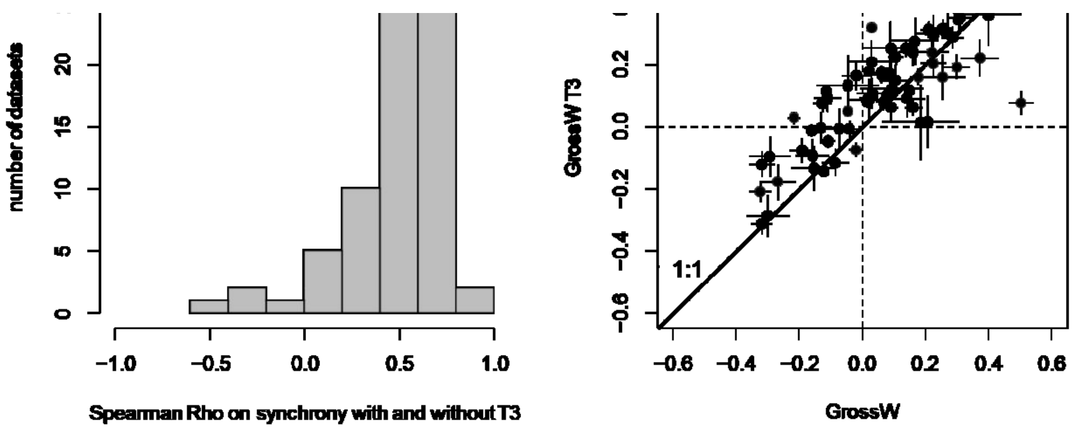


Figure 2. Summary of the directional effects of the T3 detrending approach on various synchrony indices and on CV. The bar plots indicate the numbers of datasets (n=77) in which the T3 approach significantly increased (red bars) or decreased (blue bars) synchrony values using a paired t-test after correction for false discovery rates. Grey bars indicate the number of datasets with non-significant paired t-tests.

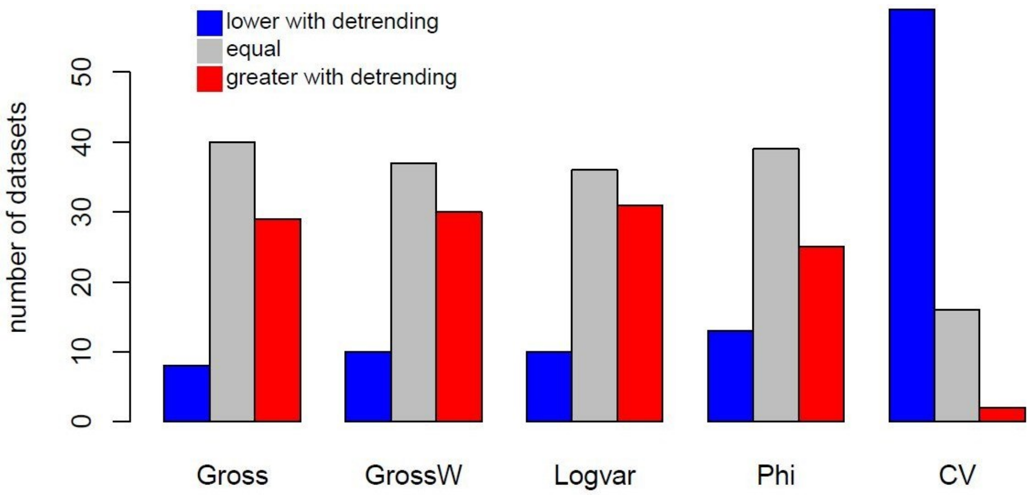
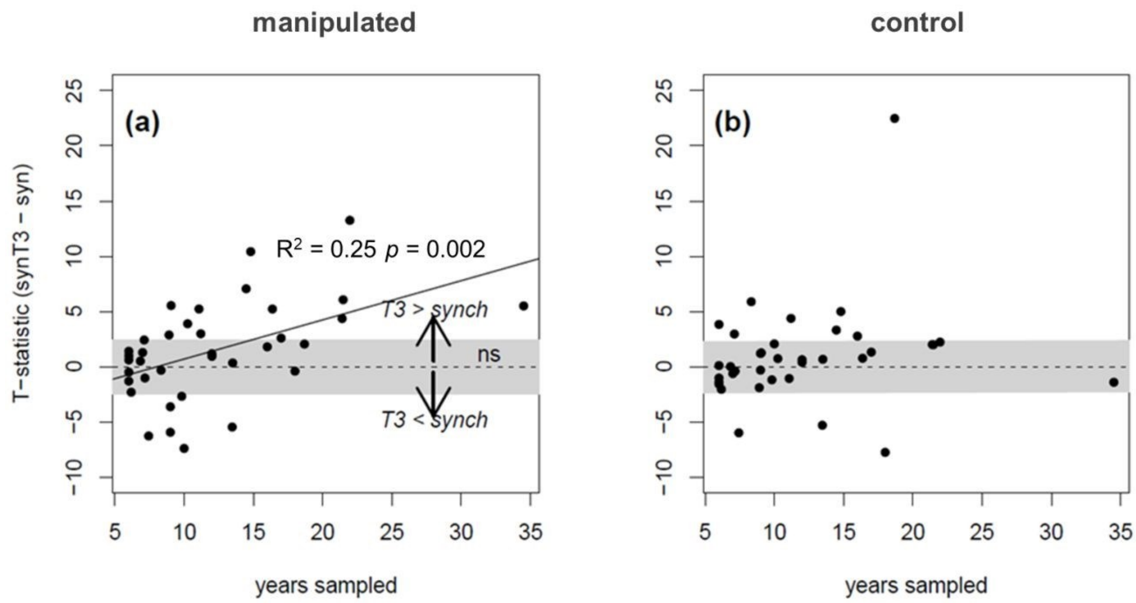
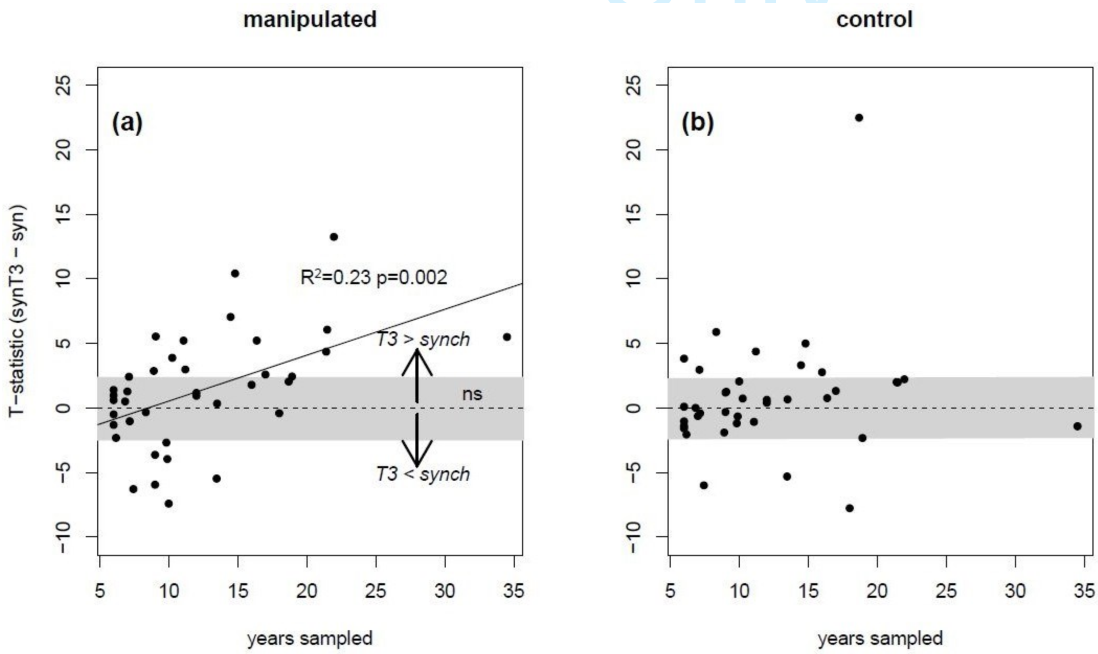


Figure 3. Effects of the T3 detrending approach in manipulated vs. control plots. The plots report results of t-tests on 36 38 datasets in which there were both manipulated and 'control' plots. For each dataset we used a pairwise t-test to compare synchrony values (using the GrossW synchrony index, Blüthgen et al. 2016) with and without the T3 approach (a: manipulated plots, and b: control plots). Positive values of the t-statistic indicate that the T3 approach increased synchrony and negative ones indicate that the T3 decreased synchrony. Values outside the grey area in each plot indicate significant t-tests after correction for false discovery rates ('ns' indicates $p > 0.05$). For each panel an R^2 for the relationship between t-statistic and number of years sampled in each dataset is provided together with the p-value of the regression model (the corresponding regression line is shown when significant).





Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Simulating long term trends in artificial communities to validate effectiveness of the T3 approach

Appendix S2. Descriptions of each dataset, highlighting the treatments of the datasets with ‘control’ and ‘manipulated’ plots.

Appendix S3. Application of the analyses shown in Fig. 1 of the main text to the three remaining indices of synchrony.

Appendix S4. Application of the analyses shown in Fig. 3 of the main text to the three remaining indices of synchrony.

Appendix S5. Results of the correlation between synchrony indices with species richness or with the CV of total abundance.

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

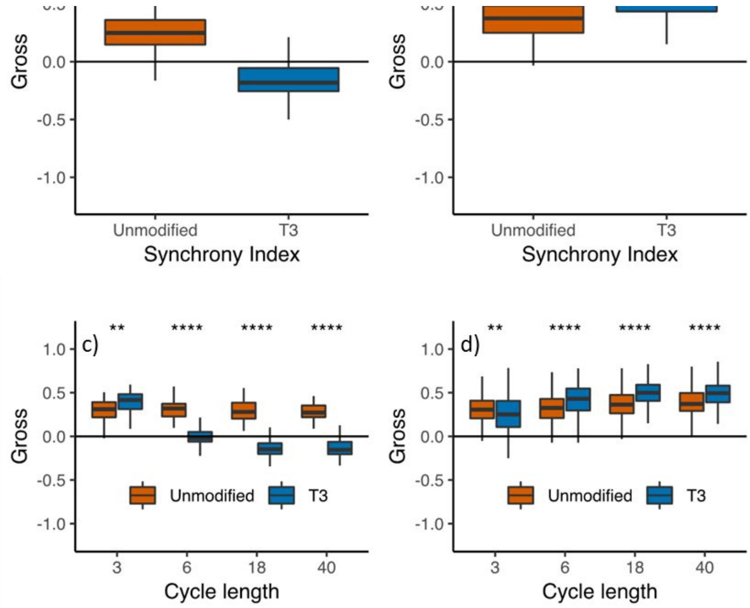
Appendix S1. *Simulating long term trends in artificial communities to validate effectiveness of the T3 approach*

We created artificial temporal community data with desired patterns of temporal fluctuations (prevailing synchrony or asynchrony) using the “syngenr” R function (Lepš et al. 2019). This function offers the possibility to build simulated communities, fixing some parameters, such as the years of the time series (100 years) and the number of species (8 species). Once the communities were established, communities fluctuating in time were created according to the following scenarios: prevailing synchrony or prevailing asynchrony. A synchronous pattern was simulated by having a common response for all species to a hypothetical environmental cue. Accordingly, an asynchronous pattern was created by having half of the species responding positively and the other half negatively to the environmental cue. Furthermore, we simulated directional (monotonic) and cyclical long term trends for these artificial communities. First, we simulated a case where most species had a common long-term positive trend (monotonic) leading to a steady increase of individual species over time. This would lead to detect synchrony with the synchrony indices (unmodified), even if the species are actually behaving asynchronous. Second, we simulated the opposite case, where species either increase or decrease in time, with the increase/decrease for each species defined by a combined bimodal distribution from two normal distributions with -1 and 1 as means, and random subset from half of the species more probably have a positive long-term trend and the other half of the species more probably a negative long-term trend. Finally, we simulated a case were the directional long-term had cyclical tendencies. The cyclical long term trends were evaluated with different cycle length: 3, 6, 18 and 40 years. These cycle lengths reflect some known potential long term cycles that drive communities across the world, such as the El Niño Oscillation or Pacific Decadal Oscillation, which have intervals of 3-6 years and 10-20 year, respectively. In summary, we simulated two scenarios of year-to-year species fluctuations (prevailing synchrony or prevailing asynchrony) and three types of long-term directional trends (i.e. monotonic with a common or contrasted trend, and cyclical trends), resulting in six possible combinations of trend–fluctuation scenarios. In all these simulated communities, we calculated the different synchrony indices (Gross, GrossW, Logvar and Phi), with or without the use of the T3 detrending approach, using the "calc_sync" R function (Lepš et al. 2019).

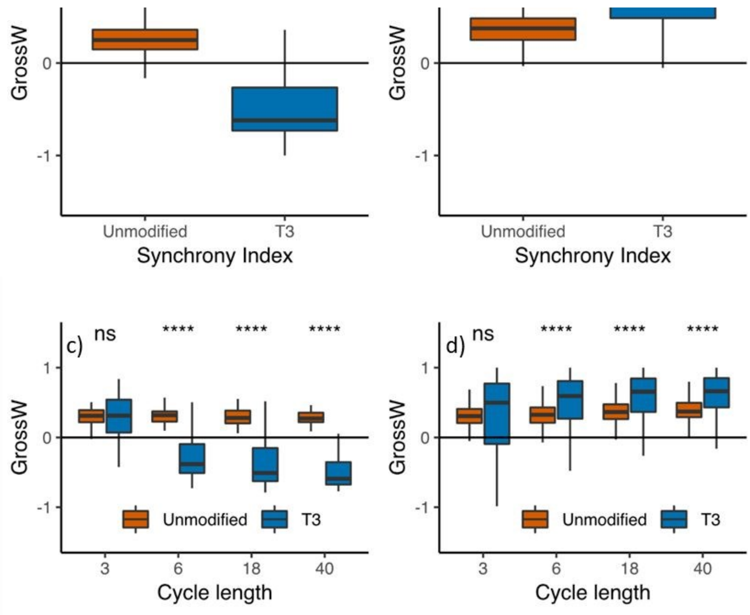
We assessed the effectiveness of the T3 detrending approach when long-term monotonic or cyclical trends are present in the data across the most common synchrony indices, using a paired t-test. Fluctuations simulated under scenarios of long-term trends in species abundances showed biased index estimates, i.e. the simulated synchrony or asynchrony patterns were overshadowed by the patterns caused by long-term trends. In the case of species having long-term directional or cyclical trends, asynchrony was masked by the synchrony (Figure Appendix S1a and S1c). Then, the synchrony indices without the T3 detrending approach were not able to detect asynchrony, even if the species were actually behaving asynchronously. These synchrony indices values were significantly higher than those with the T3 detrending approach. These biases were found across all indices but the application of the T3 detrending approach was correctly able to remove them, in all indices (Figure Appendix S1). In the opposite case, simulation of synchrony together with long-term monotonic or cyclical trends, the difference still prevailed among the synchrony with and without the T3 detrending approach, but with a less pronounced effect (Figure Appendix S1b and S1d).

Figure Appendix S1. Results of synchrony indices (Gross, GrossW Logvar, and Phi)(‘Logvar’, Lepš et al. 2018)(‘Logvar’, Lepš et al. 2018), with or without the use of the T3 detrending approach, in artificial temporal communities where long term trends were simulated. The panels report results for a common long-term directional trend (a) (i.e. creating synchrony; all species increasing in time), a contrasted long-term trend (b) (i.e. half species increasing, the other half decreasing, creating asynchrony) and a cyclical trend (c and d). Within each of these scenarios we considered two scenarios: year to year asynchrony (a and c) and synchrony (b and d). The cyclic trends also included different cycle length (3, 6, 18 and 40 years). The created communities had a total of 8 species. Asterisks above and between boxes depict significant differences among the synchrony indices with or without the T3 approach as assessed with a paired t-test. *: P < 0.05; **: P < 0.01; ***: P < 0.001; ****: P < 0.0001.

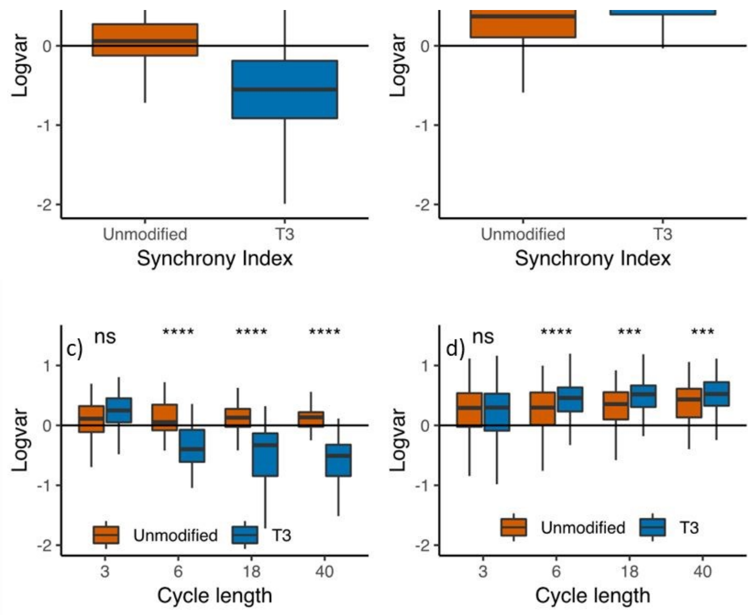
Gross



GrossW

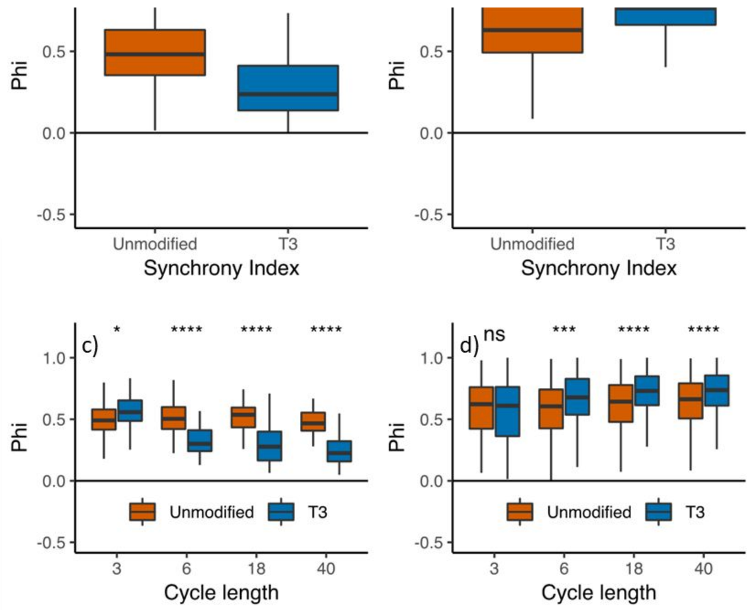


Logvar



82 **Phi**

83



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Supporting Information to the paper
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Appendix S2. Descriptions of each dataset, highlighting the treatments of the datasets with ‘control’ and ‘manipulated’ plots. LAT: latitude (WGS84 datum), and LON: longitude (WGS84 datum).

1. The dataset is issued from an experiment in a northern mixed prairie at a field station in Miles City, Montana, USA (LAT: 46.32, and LON: -105.80). This dataset consists of 42 plots, where each plot was sampled an average of 12.5 times. In each plot, individual plants were quantified and mapped annually. More information: http://esapubs.org/archive/ecol/E092/143/#data

2. The dataset is issued from an experiment located on a mixed grass prairie in Hays, Kansas, USA (LAT: 38.80, and LON: -99.30). This dataset consists of 51 plots, where each plot was sampled an average of 34.5 times. In each plot, individual plants were quantified and mapped. Thirty-six permanent quadrats were located inside livestock exclosures and 15 in grazed areas. More information: https://web.archive.org/web/20150128015820/http://esapubs.org:80/archive/ecol/E088/161/default.htm

3. The dataset is issued from an experiment located on a shortgrass steppe of North America in Nunn, Colorado, USA (LAT: 40.85, and LON: -104.71). This dataset consists of 24 plots, where each plot was sampled an average of 13.5 times. In each plot, individual plants were quantified and mapped. The quadrats were established in six grazed and ungrazed study sites on the Central Plains Experimental Range. There were four treatments combining past and present grazing status: ungrazed in the past and at present (ungrazed/ungrazed), grazed by livestock in the past and present (grazed/grazed), grazed in the past and ungrazed during the experiment (grazed/ungrazed), and ungrazed in the past and grazed during the experiment (ungrazed/grazed). More information: https://web.archive.org/web/20150502183659/http:/www.esapubs.org/archive/ecol/E094/128/

4. The dataset is issued from an experiment located on semi-desert grasslands at the Santa Rita Experimental Range, Arizona, USA (LAT: 31.83, and LON: -110.88). This dataset consists of 160 plots, where each plot was sampled an average of 11.2 times. In each plot, individual plants were quantified and mapped. Quadrats were located in exclosures (ungrazed) and in pastures grazed by livestock (grazed). More information: https://web.archive.org/web/20150502183207/http://esapubs.org:80/archive/ecol/E093/132/default.htm

5. The dataset is issued from an experiment located in sagebrush steppe in eastern Idaho, USA (LAT: 44.20, and LON: -112.20). This dataset consists of 23 plots, where each plot was sampled an average of 21.5 times. In each plot, individual plants were quantified and mapped. These permanent quadrats were located in both grazed (4 quadrats) and ungrazed units (18 quadrats), and one quadrat was grazed in the past and ungrazed during the experiment. More information: https://web.archive.org/web/20150128015825/http:/esapubs.org/archive/ecol/E091/243/default.htm.

6. The dataset is issued from an experiment on the Jornada Long-Term Ecological Research site in southern New Mexico, USA (LAT: 32.83, and LON: -107.33). This dataset consists of 222 plots, where each plot was sampled an average of 8.0 times. Previously grazing domestic livestock was excluded from the area where three permanent transects (2.7 km) were established. One of the transects received fertilization of 10 g/m^2 of nitrogen. One of the two control transects (not fertilized), was sampled at 40 stations, the other two transects had 91 stations each. At each station abundance of each species was estimated by point-intercept method along a 30 m transect perpendicular to each of the three permanent transects. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-jrn.2100119001.50.

7. The dataset is issued from an experiment on the Jornada Basin Long-Term Ecological Research Program (LTER) site in the Chihuahuan desert, New Mexico, USA (LAT: 32.93, and LON: -107.36). This dataset consists of 1001 plots, where each plot was sampled an average of 11.5 times. On the grassland site, three exclusion treatment levels were set in addition to the control treatment left open to all grazers. The first level excluded only domestic animals (cattle), the second excluded lagomorphs, and the third excluded rodents. In the shrubland site, only lagomorph- and rodent-exclusion treatments were set in addition to the control. In each treatment of each site, 4 grids of 36 permanent plots (1 m^2) were sampled (visual estimated cover). More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100086002.39.

8. The dataset is issued from an experiment in an open grassland of the South African Kalahari near Askham, South Africa (LAT: -26.76, and LON: 20.61). This dataset consists of 20 plots, where each plot was sampled an average of 10.7 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

9. The dataset is issued from an experiment located in the Succulent Karoo in Soebatsfontein, South Africa (LAT: -30.19, and LON: 17.54). This dataset consists of 24 plots, where each plot was sampled an average of 15.8 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

10. The dataset is issued from an experiment located in the Succulent Karoo, near Leliefontein, South Africa (LAT: 18.28, and LON: -30.40). This dataset consists of 42 plots, where each plot was sampled an average of 14.7 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

11. The dataset is issued from an experiment located in the Succulent Karoo, Knersvlakte near Vanrhynsdorp, South Africa (LAT: -31.28, and LON: 18.59). This dataset consists of 40 plots, where each plot was sampled an average of 16.0 times. The cover values (%) of all individual plant species were estimated annually. More information: Jürgens et al. (2010).

12. The dataset is issued from an experiment on the Kiskun LTER located in Bugac and Orgovány sites of Kiskunság National Park, Hungary (LAT: 46.73, and LON: 19.54). This dataset consists of 380 plots, where each plot was sampled an average of 14.5 times. Half of the plots were fenced to control grazing pressure. In each plot, the cover values (%) were visually estimated annually. More information: Kertész et al. (2017).

13. The dataset is issued from an experiment on a grassland in Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.16). This dataset consists of 50 plots, where each plot was sampled an average of 7.0 times. The plots were divided in 10 treatments of fertilization and grazing exclusion (Control=no treatment, K=potassium, P=phosphate, N=nitrogen, PK=phosphate and potassium, NK=nitrogen and potassium, NP=nitrogen and phosphate, NPK=nitrogen, phosphate and potassium, Fence=Fence, NPK+Fence=nitrogen, phosphate and potassium + fence). In each plot, the cover values (%) were visually estimated annually. This dataset was provided from Cedar Creek LTER. More information: http://cedarcreek.umn.edu/research/data/dataset?acze247.

14. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.19). This dataset consists of 184 plots, where each plot was sampled an average of 6.2 times. Plots were distributed across 6 treatments with increasing burning frequency: i) no burning – control – (48 plots), ii) 1 per 10 years (16 plots), iii) 1 per 3 years (32 plots), iv) 1 per 2 years (32 plots), v) 2 per 3 years (8 plots) and vi) 4 per 5 years (48 plots). Plots are located on 12 management areas ranging in size from 2.4 to 30 ha. In each plot, the cover values (%) were visually estimated. More information: http://cedarcreek.umn.edu/research/data/dataset?herbe133.

15. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.19). This dataset consists of 60 plots, where each plot was sampled an average of 24.8 times. In each plot, the biomass of individual plants was recorded from 4 plots (0.3 m^2) per field until 2013. More information: http://cedarcreek.umn.edu/research/data/dataset?ple054.

16. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.40, and LON: -93.20). This dataset consists of 234 plots, where each plot was sampled an average of 22.0 times.

The experiment combines different levels of fertilization on 4 fields that were abandoned for different periods (14, 25, 48 years and never ploughed before the experiment started in 1982) and where mammal grazers were excluded. In each plot, individual plant biomass was recorded on 5 to 6 replicate plots of different fertilization treatments (from 0 to 40 g/m^2 of nitrogen) per field every year. More information: http://cedarcreek.umn.edu/research/data/dataset?ple001.

17. The dataset is issued from an experiment located in the Cedar Creek LTER Ecosystem Science Reserve, Minnesota, USA (LAT: 45.40, and LON: -93.20). This dataset consists of 237 plots, where each plot was sampled an average of 14.8 times. The experiment combines 9 levels of fertilization (from 0 to 40 g/m^2 of nitrogen) and prescribed burning on three fields that were abandoned since 14, 25 and 48 years, and where mammal grazers were excluded. All 3 fields had 6 replicate plots of the 9 fertility treatments from 1982. From 1992 half of the plots in field B were burned every spring, and half of the plots in field A and C stopped receiving the fertilization treatment. To maintain continuity of the treatments within plots the 1992-2011 period of those plots were entered in the database as separate plots of the same data set. Individual plant biomass was measured. More information: http://cedarcreek.umn.edu/research/data/dataset?ple002.

18. The dataset is issued from an experiment located in the Shortgrass Steppe LTER in the Central Plains Experimental Range, Colorado, USA (LAT: 40.85, and LON: -104.77). This dataset consists of 795 plots, where each plot was sampled an average of 13.5 times. Plots were distributed across four combinations of past/current management: grazed/grazed, ungrazed/ungrazed, grazed/ungrazed and ungrazed/grazed. In 1998, additional plots were added in a fifth treatment with fences excluding both large and small grazers (rodent exclusion). More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-sgs.527.1.

19. The dataset is issued from an experiment located in sandy semi-natural grasslands of the Elbe valley in Höhbeck, Germany (LAT: 53.05, and LON: 11.41). This dataset consists of 96 plots, where each plot was sampled an average of 6.0 times. The vegetation was surveyed once a year in 1 m^2 plots using the Londo scale (Londo 1976). More information: Schuhmacher & Dengler (2013).

20. The dataset is issued from an experiment located near Dufftown, Morayshire, United Kingdom (LAT: 57.73, and LON: -3.10). This dataset consists of 12 plots, where each plot was sampled an average of 6.0 times. Each species was measured in a transect, using the inclined-point quadrat method (Tinney et al. 1937) (32·5° to the horizontal). All contacts with 5 pins were recorded in 20 quadrat positions per plot. More information: Pakeman et al. (2003).

21. The dataset is issued from an experiment located in Andrew Experimental forest Program (AND-LTER), Oregon, USA (LAT: 44.35, and LON: -122.41). This dataset consists of 193 plots, where each plot was sampled an average of 21.4 times. Plots were established in i) undisturbed, ii) logged, iii) logged and lightly burned, and iv) logged and severely burned areas. In each plot, the cover values (%) were estimated. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-and.3217.11.

22. The dataset is issued from an experiment located on woodlands, grasslands, and shrublands in eastern Australia (LAT: -30.12, and LON: 147.17). This dataset consists of 47 plots, where each plot was sampled an average of 10.2 times. In each plot, the biomass of the vegetation was measured annually, from 1991 to 2002, in four 300 m long transects each containing 13 quadrats of 0.72 m x 0.72 m. Dataset owners: James Val and David Eldridge (Office of Environment & Heritage, University of New South Wales).

23. The dataset is issued from an experiment located on a pasture in Fasque, United Kingdom (LAT: 56.87, and LON: -2.60). This dataset consists of eight plots, where each plot was sampled an average of 8.0 times. Inclined-point quadrat method (32·5° to the horizontal) was used to record each species in a transect, with a minimum of 20 point contacts at 18 locations per plot (i.e. a minimum of 360 contacts per plot). More information: Marriott et al. (2002).

24. The dataset is issued from an experiment located on La Fage French National Institute for Agricultural Research (INRA) experimental station, close to Millau, France (LAT: 43.92, and LON: 3.10). This dataset consists of 16 plots, where each plot was sampled an average of 28.0 times. Individual plants were identified using the point intercept method on 5 m permanent lines (1 point/10 cm, i.e. 50 points/line). More information: Chollet et al. (2014) and Garnier et al. (2018).

25. The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 483 and 497- ITEX Dataset 5 - Teberda (Malaya Alpine-Snowbed and Geranium Hedysarum Meadow) and ITEX Dataset 19 - Teberda (Festuca Varia Grassland, Malaya Alpine Lichen-Heath). The dataset is issued from an experiment located in Teberda State Reserve, a part of the Karachaevo-Cherkessian Republic in the northwestern Caucasus, Russia (LAT: 43.45, and LON: 41.69). This dataset consists of 145 plots, where each plot was sampled an average of 24.3 times. In each plot, the cover of each plant species was recorded as number of shoots per m^2. More information: Onipchenko *et al.* (1998).

26. The dataset is issued from an experiment located a moorland in the Clocaenog Forest, United Kingdom (LAT: 53.06, and LON: -3.47). This dataset consists of 9 plots, where each plot was sampled an average of 12.0 times. The experiment was designed with three treatments: control, drought (~20% reduction in total annual rainfall) and warming (~64% reduction in heat loss during night and 14% reduction in total annual rainfall). Three quadrats per plot were chosen, and in each quadrat vegetation was quantified using a grid of 100 pins (pin-point methodology). Pin hits were then converted to biomass (g m^{-2}) using a biomass calibration-conversion. More information: https://catalogue.ceh.ac.uk/documents/5b39a644-d614-4f2b-8df6-202ed440b4ab. Doi: https://doi.org/10.5285/5b39a644-d614-4f2b-8df6-202ed440b4ab.

27. The dataset is issued from an experiment located on serpentine and non-serpentine meadows in California, USA (LAT: 38.85, and LON: -123.50). This dataset consists of 400 plots, where each plot was sampled an average of 10.0 times. In each plot, the species cover (%) was visually estimated annually. More information: Fernandez-Going et al. (2012) and Harrison (1999).

28. The dataset is issued from an experiment located on the Jornada Basin Experimental Range JRN-LTER in the Chihuahuan desert, New Mexico, USA (LAT:

32.62, and LON: -106.67). This dataset consists of 68 plots, where each plot was sampled an average of 27.8 times. Density of individuals per species and per plot was recorded. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.210351002.75.

29. The dataset is issued from an experiment located on a grassland in Krkonose Mountains, Czech Republic (LAT: 50.69, and LON: 15.71). This dataset consists of four plots, where each plot was sampled an average of 16.8 times. Standing biomass was sampled annually. More information: Herben et al. (1997).

30. The dataset is issued from an experiment located on a grassland in Krkonose Mountains, Czech Republic (LAT: 50.69, and LON: 15.79). This dataset consists of four plots, where each plot was sampled an average of 29.8 times. Standing biomass was sampled annually. More information: Herben et al. (2017).

31. The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 243 - Virginia Coast Reserve Long-Term Ecological Research. The dataset is issued from an experiment located in the coastal sand dunes of Hog island, Virginia, USA (LAT: 37.67, and LON: -75.67). This dataset consists of 28 plots, where each plot was sampled an average of 18.9 times. Half of the plots received nitrogen fertilization each year in the form of urea nitrogen (30% uncoated (46-0-0) and 70% (40-0-0) coated for slow release). The fertilizer was applied evenly in a dry form (15 g/m^2 of nitrogen). In each plot, species cover (%) was visually estimated in five 0.25 m^2 plots. More information: Day et al. (2016).

32. The dataset is issued from an experiment located on a grassland near Napal, Spain (LAT: 42.72, and LON: -1.22). This dataset consists of 12 plots, where each plot was sampled an average of 12.0 times. The experimental area was fenced and shrubs were removed. Six plots were fertilized (sewage sludge to the soil surface with 5000 g/m^2) and six plots were used as controls. All vascular plant species were measured annually using frequencies. To do so, each plot was divided into 100 subplots, and the presence/absence of each species was recorded. More information: Gazol et al. (2016).

33. The data were sourced from BioTIME (Dornelas et al. 2018), Study_ID 491 - ITEX Dataset 13 - Toolik (Dry, Moist). The dataset is issued from an experiment located on tundra vegetation near Toolik, Alaska, USA (LAT: 68.62, and LON: -149.61). This dataset consists of eight plots, where each plot was sampled an average of 6.0 times. The plots are divided between dry tundra with control and warming treatments and moist tundra with only control treatment. Biomass estimates were obtained using a fixed 75 cm^2 point frame, with 100 measurements spaced 7 cm apart.

34. The data was sourced from BioTIME (Dornelas et al. 2018), Study_ID 492 - ITEX Dataset 14 - Toolik (LTER Heath, LTER Moist acidic tussock, LTER non-acidic tussock, LTER wet sedge, SAG wet sedge2, Tussock 1981 plots). The dataset is issued from an experiment located in Toolik, Alaska, USA (LAT: 68.63, and LON: -149.58). This dataset consists of four plots, where each plot was sampled an average of 6.0 times. In each plot, species biomass was assessed by clipping of four or five 0.25 m x 0.25 m plots, and sorting to species level.

35. The dataset is issued from an experiment located on a grassland in Bayreuth, Germany (LAT: 49.92, and LON: 11.59). This dataset consists of 15 plots, where each plot was sampled an average of 7.7 times. Three treatments were applied: 1) control (ambient condition), 2) winter warming (October–March), and 3) summer warming (April–September). In each plot, species cover (%) was visually estimated annually. More information: Grant et al. (2017).

36. The dataset is issued from an experiment located on a grassland in the Czech Republic (LAT: 48.87, and LON: 16.64). This dataset consists of seven plots, where each plot was sampled an average of 8.0 times. In each plot (1 m^2), the species cover (%) was visually estimated annually from 1993 to 2001. Dataset owner: Jiří Danihelka (Department of Botany and Zoology, Masaryk University and Department of Vegetation Ecology, Institute of Botany, The Czech Academy of Sciences).

37. The dataset is issued from an experiment located on a grassland in Laqueuille, France (LAT: 45.64, and LON: 2.73). This dataset consists of 10 plots, where each plot was sampled an average of 13.0 times. Half of the plots were located in an intensively managed grassland (10-15 animals ha^{-1} yr^{-1} and 20 g/m^2 of nitrogen), and the other half were located in a neighbouring grassland under extensive management (5-8 animals ha^{-1} yr^{-1} and no fertilization). In each plot, presence/absence of each species was recorded in 40 pin-points regularly spaced (pin-point methodology. Dataset owner: Katja Klumpp (INRA, Grassland Ecosystem Research Unit).

38. The dataset is issued from an experiment located on Shortgrass Steppe (SGS-LTER) in the Central Plains Experimental Range Nunn, Colorado, USA (LAT: 40.85, and LON: -104.71). This dataset consists of 48 plots, where each plot was sampled an average of 9.0 times. The experiment evaluated four treatments: control inside exclosure, control outside exclosures, *Bouteloua gracilis* removal inside exclosure and *Bouteloua gracilis* removal outside exclosure. Species density was measured in a quadrat (1 m^2) using vegetation point intercept method (40 points of contact was recorded for each quadrat). More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.703.1.

39. The dataset is issued from an experiment located on a wet meadow in Ohrazeni, Czech Republic (LAT: 48.95, and LON: 14.59). This dataset consists of 12 plots, where each plot was sampled an average of 16.0 times. The experiment evaluated four treatments: control, mowing (annually in the second half of June), fertilization (65 g/m^2 of commercial NPK fertilizer) and dominant removal (*Molinia caerulea* plants were manually removed annually). In each plot, the biomass of each species was measured annually. More information: Lepš (2014).

40. The dataset is issued from an experiment (Long Term Experiment SOERE-ACBB) located on a grassland in Theix, France (LAT: 45.72, and LON: 3.02). This dataset consists of eight plots, where each plot was sampled an average of 8.0 times. The experiment evaluated, on one hand, the effect of the intensity of grazing with two treatments with cattle rotational grazing at high (Ca+) or low (Ca-) level of herbage utilisation; these two treatments did not receive any mineral fertilisation. On the other hand, it also evaluated the effect of nutrient availability, comparing two treatments conducted under fixed cutting regime (three cuts/per year), one with fertilization (NPK fertilizer) and the other without fertilization. The presence/absence of each plant species was measured using 40 pin-points regularly spaced along fixed transects. Complementarily, at each pin-point, 6 points are distributed to species according to visual estimation of their volume. Dataset owner: Frédérique Louault (INRA-UREP). More information: Louault et al. (2017).

41. The dataset is issued from an experiment belonging to the Sevilleta LTER and located on Chihuahuan desert in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.27, and LON: -106.68). This dataset consists of six plots, where each plot was sampled an average of 14.3 times. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.200.174699.

42. The dataset is issued from an experiment located on hyper-oceanic coastal grasslands in United Kingdom (LAT: 57.27, and LON: -7.40). This dataset consists of 48 plots, where each plot was sampled an average of 6.8 times. The experiment evaluated six treatments: 1) vertebrate grazing exclusion, 2) burial box with no sand added, 3) buried to 10 cm, 4) buried to 20 cm, 5) windbreak - shelter from prevailing SW winds, 6) no treatment. The cover values (%) of all individual plant species were estimated annually from 2004 to 2010. Data owners: Robin Pakeman (James Hutton Institute. Aberdeen) and Jack J. Lennon (School of Biological Sciences, Queen's University Belfast).

43. The dataset is issued from an experiment located on a grassland in Cleish and Kirkton, United Kingdom (LAT: 56.29, and LON: -4.07). This dataset consists of 16 plots, where each plot was sampled an average of 6.0 times. The experiment evaluated ungrazed and sheep-grazed plots to maintain three different levels of sward height. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Hulme et al. (1999).

44. The dataset is issued from an experiment located on a grassland in Bell Hill and Cleish, United Kingdom (LAT: 55.80, and LON: -2.84). This dataset consists of eight plots, where each plot was sampled an average of 7.0 times. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Grant et al. (1996a).

45. The dataset is issued from an experiment located on a grassland in Cleish and Sourhope, United Kingdom (LAT: 55.81, and LON: -2.86). This dataset consists of seven plots, where each plot was sampled an average of 6.0 times. There were different treatments where cattle or sheep density was adjusted twice a week to maintain the vegetation height between tussocks. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Grant et al. (1996) and Common et al. (1998).

46. The dataset is issued from an experiment located on a moorland previously on the Burnhead heft at the Redesdale Experimental Farm in Northumberland, United Kingdom (LAT: 55.37, and LON: -2.45). This dataset consists of 12 plots, where each plot was sampled an average of 6.0 times. The 12 plots were divided in three areas with different grazing treatments: ungrazed, sheep-grazed (three levels: 0.4, 0.8 and 1.2 ha^{-1} yr^{-1}). In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Pakeman & Nolan (2009).

47. The dataset is issued from an experiment located on a heather moorland at Dundonnell near Ullapool and at Claonaig, near Tarbert Loch Fyne, Argyll and Bute, United Kingdom (LAT: 57.35, and LON: -5.55). This dataset consists of 17 plots, where each plot was sampled an average of 6.0 times. The experiment had different sheep grazing and exclusion treatments: 1) low at 0.4 sheep ha^{-1} yr^{-1}, 2) moderate at 0.8 sheep ha^{-1} yr^{-1}, 3) high at 1.2 sheep ha^{-1} yr^{-1}, 4) fenced against both cattle and sheep, and 5) fenced against cattle, also 6) sheep and cattle recorded from the open hill. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations was used to measure each species. More information: Pakeman & Nolan (2009).

48. The dataset is issued from an experiment located on a grassland in the Ordesa-Monte Perdido National Park, Spain (LAT: 42.67, and LON: -0.06). This dataset consists of four plots, where each plot was sampled an average of 19.0 times. The point intercept method at 20 locations was used to measure each species.

In each plot, the point intercept method was used annually to measure vegetation along two perpendicular transects (a total of 400 sample points). More information: Pardo et al. (2015).

49. The dataset is issued from an experiment located in Soto de Viñuelas, Spain (LAT: 40.60, and LON: -3.63). This dataset consists of 68 plots, where each plot was sampled an average of 11.5 times. In each plot, all plant species was recorded using presence/absence data in five quadrats of 400 cm^2 each from 1980 to 1995. Dataset owner: Begoña Peco (Ecology Department Autonomous, University of Madrid).

50. The dataset is issued from an experiment located on a shrubland in Garraf, Spain (LAT: 41.30, and LON: 1.82). This dataset consists of nine plots, where each plot was sampled an average of 17.0 times. Three experiment evaluated three treatments: 1) control, 2) warming (metallic curtain covering the plots during the night), and 3) drought (transparent curtain covering the plots during rainfall). Number of contacts per plot was used to quantify each species. Dataset owners: Josep Penuelas, Marc Estiarte and Romà Ogaya (Global Ecology Unit CREAF-CSIC-UAB).

51. The dataset is issued from an experiment belong to the Jornada LTER (JRN-LTER) and located in Chihuahuan desert, Jornada Basin Experimental Range, New Mexico, USA (LAT: 32.00, and LON: -106.00). This dataset consists of 734 plots, where each plot was sampled an average of 24.0 times. In each plot, the biomass of each species was calculated from field measurement of individual species cover and height. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100011001.49.

52. The dataset is issued from an experiment located on a moorland on the Burnhead heft at the Redesdale Experimental Farm in Northumberland, United Kingdom (LAT: 55.37, and LON: -2.45). This dataset consists of 10 plots, where each plot was sampled an average of 6.0 times. The experiment had different grazing treatments: summer grazing, winter grazing or year-round grazing (0.7 sheep ha^{-1} yr^{-1}), year-round grazing (1.4 sheep ha^{-1} yr^{-1}), and no grazing. In each plot, the inclined-point quadrat method (32·5° to the horizontal) at 20 locations (with a minimum of 25 contacts per location) was used to measure each species. More information: Hulme et al. (2002) and Pakeman & Nolan (2009).

53. The dataset is issued from an experiment located on moorlands in Derbyshire, United Kingdom (LAT: 54.69, and LON: -2.41). This dataset consists of 216 plots, where each plot was sampled an average of 10.0 times. The experiment evaluated 36 treatments: no treatment; cut once per year; cut twice per year; herbicide sprayed; herbicide sprayed in first year, cut in second; and cut in first year, sprayed in second. Within each of these main plot treatments there were two sub-plot grazing treatments - sheep grazing and no sheep grazing. Finally, there were three restoration treatments applied at the sub-sub-plot level: untreated, *Calluna* moorland litter applied as litter, and *Calluna* vegetation applied as cut brash. All these 36 treatments had 6 replicates. In each plot, the species composition was recorded using point-quadrats (1 m-long frame with 10 pin positions at 10 cm intervals, pin diameter = 2 mm). Dataset owner: Rob Marrs (University of Liverpool).

54. The dataset is issued from an experiment belonging to the Environmental Change Network (ECN) and located in the United Kingdom (LAT: 53.95, and LON: -3.23). This dataset consists of 198 plots, where each plot was sampled an average of 11.1 times. In each plot (ten quadrats of 0.16 m^2), the inclined-point quadrat method was used to evaluate the vegetation annually. More information: Rennie et al. (2016) and https://catalogue.ceh.ac.uk/documents/b98efec8-6de0-4e0c-85dc-fe4cdf01f086 and https://catalogue.ceh.ac.uk/documents/d349babc-329a-4d6e-9eca-92e630e1be3f.

55. The dataset is issued from an experiment belonging to the Andrews Forest LTER (AND-LTER) and located in a forest in the Oregon Cascade Range, USA (LAT: 44.22, and LON: -122.25). This dataset consists of 5 plots, where each plot was sampled an average of 10.0 times. The vegetation cover (%) was visually estimated 10 times in a quadrat of 4 m^2 for trees (vegetation > 60 cm tall) and 9 quadrats (0.1 m^2) for herb and low shrub (< 60 cm tall). More information: Rothacher (Rothacher 2013) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-and.3190.7.

56. The dataset is issued from an experiment belonging to the Park Grass permanent grassland and located in Rothamsted, United Kingdom (LAT: 51.81, and LON: -

0.37). This dataset consists of 74 plots, where each plot was sampled an average of 9.9 times. The purpose of the experiment was to evaluate different fertility and lime treatments. Herbage was taken from six randomly located quadrats measuring 0.5 m x 0.25 m within each plot, resulting in a total sampling area of 0.75 m^2 within each plot. In each plot, the biomass of each species was measured annually in quadrats (sampling area: 0.75 m^2). More information: Crawley et al. (2005) and http://www.era.rothamsted.ac.uk/Park.

57. The dataset is issued from an experiment located on a savannah in central Spain (LAT: 40.38, and LON: -4.20). This dataset consists of 210 plots, where each plot was sampled an average of 6.0 times. The experiment evaluated two types of pastures (higher-productivity pastures and low-productivity pastures) and three treatments (ungrazed, grazed by small herbivores, and grazed by large and small herbivores). In each plot, the species cover (%) was visually estimated. More information: Rueda et al. (2013).

58. The dataset is issued from an experiment located in Central Germany (LAT: 51.55, and LON: 10.07). This dataset consists of 14 plots, where each plot was sampled an average of 14.9 times. In each plot, species vegetation cover (%) was visually estimated. More information: Schmidt (2007).

59. The dataset is issued from an experiment located on a former arable field in the Experimental Botanical Garden of the University of Göttingen, Germany (LAT: 51.56, and LON: 9.96). This dataset consists of six plots, where each plot was sampled an average of 38.0 times. In each plot, species vegetation cover (%) was visually estimated. More information: Schmidt (Schmidt 2006) and Bernhardt-Römermann et al. (2011).

60. The dataset is issued from an experiment located in the Swiss National Park (IUCN Ia reserve, LAT: 46.68, and LON: 10.22). This dataset consists of 41 plots, where each plot was sampled an average of 12.2 times. In each plot, plant species cover (%) was visually estimated. More information: Braun-Blanquet et al. (1931), Schütz et al. (2000).

61. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.31, and LON: -106.49). This dataset consists of 95 plots, where each plot was sampled an average of 9.8 times. The experiment was designed to evaluate the effect of prescribed burning (two areas were left unburned as control treatments, and the other plots were burned in different dates) and grazing exclusion (fenced and unfenced). In each plot, the individuals present in 36 quadrats (0.1 m^2) were recorded. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.148.131885.

62. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.33, and LON: -106.74). This dataset consists of 81 plots, where each plot was sampled an average of 9.2 times. The experiment had three treatments: 1) control plots (natural rainfall regime) 2) drought was induced by rainfall shelters, and 3) watering was applied by redirecting the water from the nearby rainfall shelters. In each plot, the plant cover (%) was estimated every spring. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.147.167839.

63. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located on a grassland in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.33, and LON: -106.63). This dataset consists of 216 plots, where each plot was sampled an average of 7.7 times. The experiment evaluated the impact of prairie dog reintroduction (grazed and ungrazed areas) on vegetation. In each plot, the plant cover (%) was estimated annually. More information: https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-sev.212.4.

64. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located on a woodland in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.37, and LON: -106.54). This dataset consists of 100 plots, where each plot was sampled an average of 13.0 times. In each plot, the plant cover (%) was visually estimated annually. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.278.245672.

65. The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT: 34.37, and LON: -106.58). This dataset consists of 100 plots, where each plot was sampled an average of 16.4 times. The experiment evaluated three treatments: 1) control plots (untouched vegetation), 2) removal of all three dominant species (*Larrea tridentata*, *Bouteloua eriopoda*, *Bouteloua gracilis*), and 3) removal of one dominant species. In each plot, the plant cover (%) was visually estimated annually. More information: https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.168.192543.

66. The dataset is issued from an experiment belonging to the Shortgrass Steppe LTER (SGS-LTER) and located on grasslands and shrublands in Central Plains Experimental Range, Colorado, USA (LAT: 40.85, and LON: -104.77). This dataset consists of 18 plots, where each plot was sampled an average of 8.2 times. In each plot, the plant cover was recorded on three permanent transects (1 m^2: sum of plots along the transect). More information: Stapp (Stapp 2013) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.140.17.

67. The dataset is issued from an experiment located in a beech forest near Göttingen, Central Germany (LAT: 51.57, and LON: 10.32). This dataset consists of seven plots, where each plot was sampled an average of 18.0 times. Four plots had a fertilization treatment (NP addition) and three were the control plots. In each plot, the species cover (%) was visually estimated. More information: Schmidt (2009).

68. The dataset is issued from an experiment located on a meadow near Zvíkov, Czech Republic (LAT: 48.99, and LON: 14.61). This dataset consists of 40 plots, where each plot was sampled an average of 10.3 times. The experiment evaluated four treatments: 1) control (intact vegetation), 2) mycorrhizal grasses and forbs left, non-mycorrhizal species weeded out, 3) mycorrhizal forbs remaining, everything else weeded out, and 4) mycorrhizal grasses remaining, everything else weeded out. In each plot, the species cover (%) was visually estimated annually. More information: Šmilauer & Šmilauerová (2013).

69. The dataset is issued from an experiment located on a floodplain grassland in Anloo and Taarlo, The Netherlands (LAT: 53.05, and LON: 6.66). This dataset consists of 80 plots, where each plot was sampled an average of 28.9 times. In each plot, the species cover (%) was estimated almost every year from 1973 to 2008. Dataset owners: Christian Smit and Jan P. Bakker (Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences).

70. The dataset is issued from an experiment located on a meadow in the north-eastern Tibetan Plateau in Qinghai Province, China (LAT: 37.62, and LON: 101.20). This dataset consists of 30 plots, where each plot was sampled an average of 9.0 times. The experiment was designed to evaluate 10 nitrogen treatments (no N added and 9 combinations of three N forms and three N rates). In each plot, the species cover (%) was visually estimated annually. More information: Song et al. (2012).

71. The dataset is issued from an experiment located on salt marshes of the Schleswig-Holstein Wadden Sea National Park in Hamburger Hallig and Westerhever, Germany (LAT: 54.49, and LON: 8.75). This dataset consists of 212 plots, where each plot was sampled an average of 18.7 times. There were two treatments in Westerhever: natural condition and intensive grazing, and only natural conditions in Hamburger Hallig. In each plot, the species cover was measured annually using the Londo scale (percentage of vegetation cover) from 1997 to 2015 in Hamburger Hallig and from 1995 to 2012 in Westerhever. Dataset owner: Martin Stock (Wadden Sea National Park of Schleswig-Holstein).

72. The dataset is issued from an experiment located on a wooded savanna in Laikipia, Kenya (LAT: 0.28, and LON: 36.87). This dataset consists of 18 plots, where each plot was sampled an average of 14.7 times. The treatments were six combinations (3 replicates) of cattle, wildlife, and mega-herbivore grazing. These either allowed (1) the entry of all large mammalian herbivores, (2) all large mammalian herbivores except mega-herbivores (elephants *Loxodonta africana* and giraffe *Giraffa camelopardis*) to enter, or (3) excluded all large herbivores. In each plot, vegetation was assessed annually by counting the number of pins hit by each species over a ten-point pin frame at each station. More information: Veblen et al. (2016).

73. The dataset is issued from an experiment located on a coastal heathland in Lurekalven, Norway (LAT: 60.70, and LON: 5.08). This dataset consists of 42 plots, where each plot was sampled an average of 6.0 times. In each plot, all vascular plants, bryophytes and lichens were recorded annually using frequencies (1 m x 1 m metal frame divided into 16 subplots). More information: Vandvik et al. (2005).

74. The dataset is issued from an experiment located in Bonanza Creek LTER, Alaska, USA (LAT: 65.00, and LON: -148.00). This dataset consists of 59 plots, where each plot was sampled an average of 12.0 times. In each plot, the species cover (%) was visually estimated. More information: Viereck et al. (2010) and https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-bnz.174.19.

75. The dataset is issued from an experiment located on desert steppes in Gobi Gurvan Saykhan National Park, Mongolia (LAT: 43.61, and LON: 104.13). This dataset consists of 18 plots, where each plot was sampled an average of 7.1 times. The experiment evaluated two treatments: 1) exclusion of large ungulates, and 2) no exclusion of large ungulates. In each plot, the species cover (%) was visually estimated annually. More information: Wesche et al. (2010).

76. The 9dataset is issued from an experiment located on a floodplain grassland on formerly arable land (LAT: 51.78, and LON: -1.31). From 1989 the site was divided into nine plots of c. 0.4 ha over which three contrasting grazing management practices (control, cattle and sheep) were randomly superimposed. These nine plots were monitored in June of each year from 1991-2009. More information: Woodcock et al. (2011).

77. The dataset is issued from an experiment located on a grassland in southeast Estonia (LAT: 58.11, and LON: 27.07). This dataset consists of 55 plots, where each plot was sampled an average of 8.9 times. The treatments were: fertilizer, sucrose and control. In each plot, the species cover (%) was visually estimated annually. More information: Liira et al. (2012).

Figure Table S2. Characteristics of the study sites.

ID	Country	Biome	Habitats	Duration	CP	MP
1	USA	TGD	Grassland	12.5	NO	YES
2	USA	WS	Grassland	34.5	YES	YES
3	USA	TGD	Grassland	13.5	YES	YES
4	USA	SD	Grassland	11.2	YES	YES
5	USA	TGD	Savanna	21.5	YES	YES
6	USA	TGD	Grassland	8.0	YES	YES
7	USA	TGD	Grassland and Shrubland	11.5	YES	YES
8	South Africa	SD	Grassland	10.7	YES	NO
9	South Africa	SD	Savanna	15.8	YES	NO
10	South Africa	TGD	Savanna	14.7	YES	NO
11	South Africa	SD	Savanna	16.0	YES	NO
12	Hungary	WS	Savanna	14.5	YES	YES
13	USA	TF	Grassland	7.0	YES	YES
14	USA	TF	Savanna	6.2	YES	YES
15	USA	TF	Grassland	24.8	YES	NO
16	USA	TF	Grassland	22.0	YES	YES
17	USA	TF	Grassland	14.8	YES	YES
18	USA	TGD	Grassland	13.5	YES	YES
19	Germany	WS	Grassland	6.0	YES	NO
20	United Kingdom	WS	Shrubland	6.0	NO	YES
21	USA	TRF	Forest	21.4	YES	YES
22	Australia	SD and WS	Savanna	10.2	YES	NO
23	United Kingdom	WS	Grassland	8.0	YES	YES
24	France	WS	Grassland	28.0	NO	YES
25	Russia	BF	Grassland	24.3	YES	NO
26	United Kingdom	TF	Shrubland	12.0	YES	YES
27	USA	TF	Grassland	10.0	YES	NO
28	USA	TGD	Grassland	27.8	YES	NO
29	Czech Republic	TF	Grassland	16.8	YES	NO
30	Czech Republic	TF	Grassland	29.8	YES	NO
31	USA	WS	Grassland	18.9	YES	YES
32	Spain	WS	Grassland	12.0	YES	YES
33	USA	Tu	Grassland	6.0	YES	YES
34	USA	Tu	Grassland	6.0	YES	NO
35	Germany	WS	Grassland	7.7	YES	YES
36	Czech Republic	WS	Grassland	8.0	YES	NO
37	France	TF	Grassland	13.0	NO	YES
38	USA	TGD	Grassland	9.0	YES	YES
39	Czech Republic	WS	Grassland	16.0	YES	YES
40	France	WS	Grassland	8.0	YES	YES
41	USA	TGD	Grassland, Shrubland and Savanna	14.3	YES	NO
42	United Kingdom	TF	Grassland	6.8	YES	YES
43	United Kingdom	TF and TRF	Grassland	6.0	YES	YES

44	United Kingdom	TF	Grassland	7.0	YES	YES
45	United Kingdom	TF	Grassland	6.0	YES	YES
46	United Kingdom	TF	Shrubland	6.0	NO	YES
47	United Kingdom	TF	Savanna	6.0	YES	YES
48	Spain	BF	Grassland	19.0	YES	YES
49	Spain	TGD	Grassland	11.5	YES	NO
50	Spain	WS	Shrubland	17.0	YES	YES
51	USA	TGD	Grassland, Shrubland and Savanna	24.0	YES	NO
52	United Kingdom	TF	Savanna	6.0	NO	YES
53	United Kingdom	TF	Shrubland	10.0	YES	YES
54	United Kingdom	TF and WS	Grassland, Savanna and Forest	11.1	YES	NO
55	USA	TF	Forest	10.0	YES	NO
56	United Kingdom	WS	Grassland	9.9	YES	YES
57	Spain	TGD	Savanna	6.0	YES	YES
58	Germany	WS	Grassland	14.9	YES	NO
59	Germany	WS	Grassland	38.0	NO	YES
60	Switzerland	BF	Grassland and Forest	12.2	NO	YES
61	USA	TGD	Savanna	9.8	YES	YES
62	USA	TGD	Grassland, Shrubland and Savanna	9.2	YES	YES
63	USA	TGD	Grassland	7.7	YES	YES
64	USA	TGD	Forest	13.0	YES	NO
65	USA	TGD	Grassland and Savanna	16.4	YES	YES
66	USA	TGD	Grassland and Shrubland	8.2	YES	NO
67	Germany	WS	Forest	18.0	YES	YES
68	Czech Republic	WS	Grassland	10.3	YES	YES
69	Netherlands	WS	Grassland	28.9	NO	YES
70	China	WS	Grassland	9.0	YES	YES
71	Germany	WS	Salt marsh	18.7	YES	YES
72	Kenya	WS	Savanna	14.7	NO	YES
73	Norway	TRF	Grassland	6.0	NO	YES
74	USA	BF	Grassland and Savanna	12.0	YES	NO
75	Mongolia	TGD	Grassland	7.1	YES	YES
76	United Kingdom	WS	Grassland	18.0	NO	YES
77	Estonia	WS	Grassland	8.9	YES	YES

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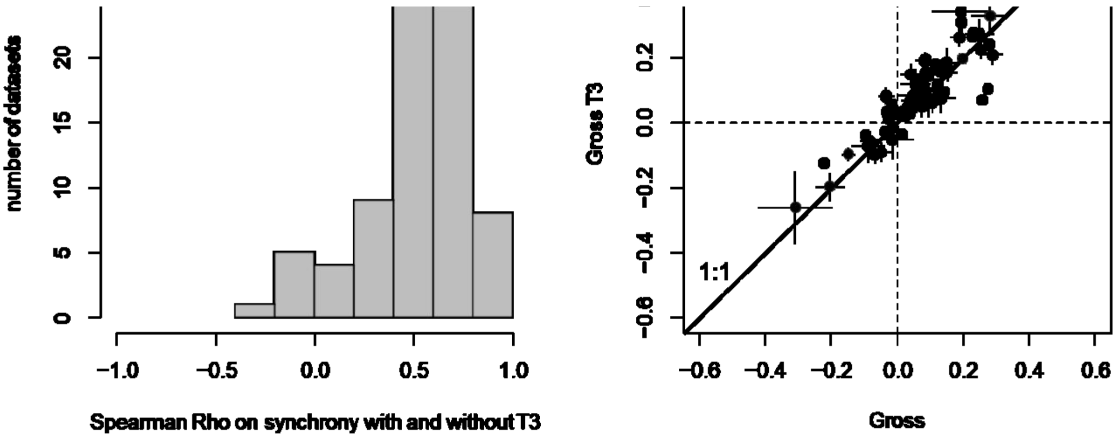
ID: Identification of the data set, biomes (TGD: temperate grassland desert, SD: subtropical desert, WS: woodland shrubland, TF: temperate forest, BF: boreal forest, Tu: Tundra, and TRF: temperate rain forest), Duration: Average number of years of the dataset, CP: presence of plots where the long-term conditions prior to the establishment of the sampling scheme were maintained throughout the sampling, MP: presence of plots exposed to different treatments that altered the long-term conditions.

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

Appendix S3. Application of the analyses shown in Fig. 1 of the main text to the three remaining indices of synchrony.

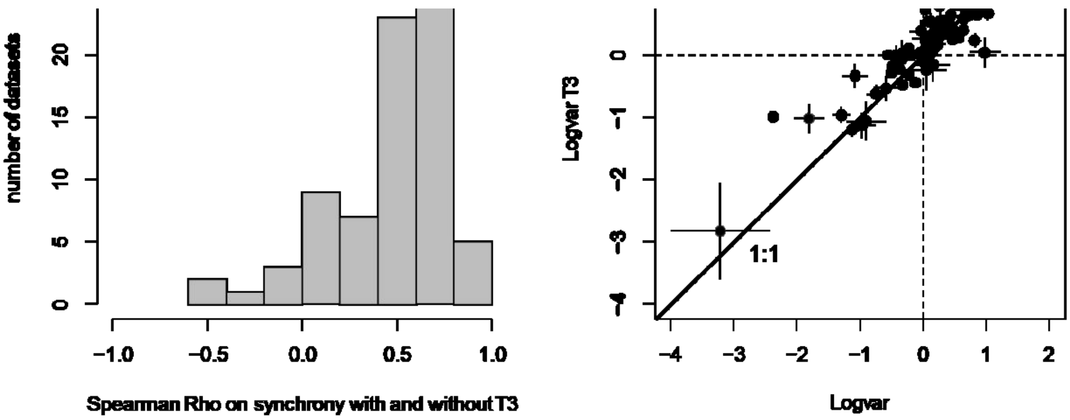
Gross

Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach ($p < 0.001$, paired t-test)



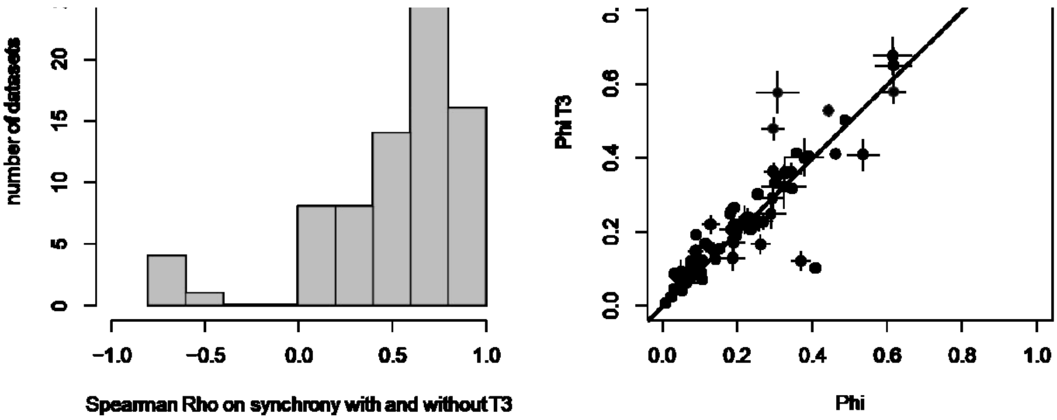
Logvar

Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach ($p < 0.06$, paired t-test)



Phi

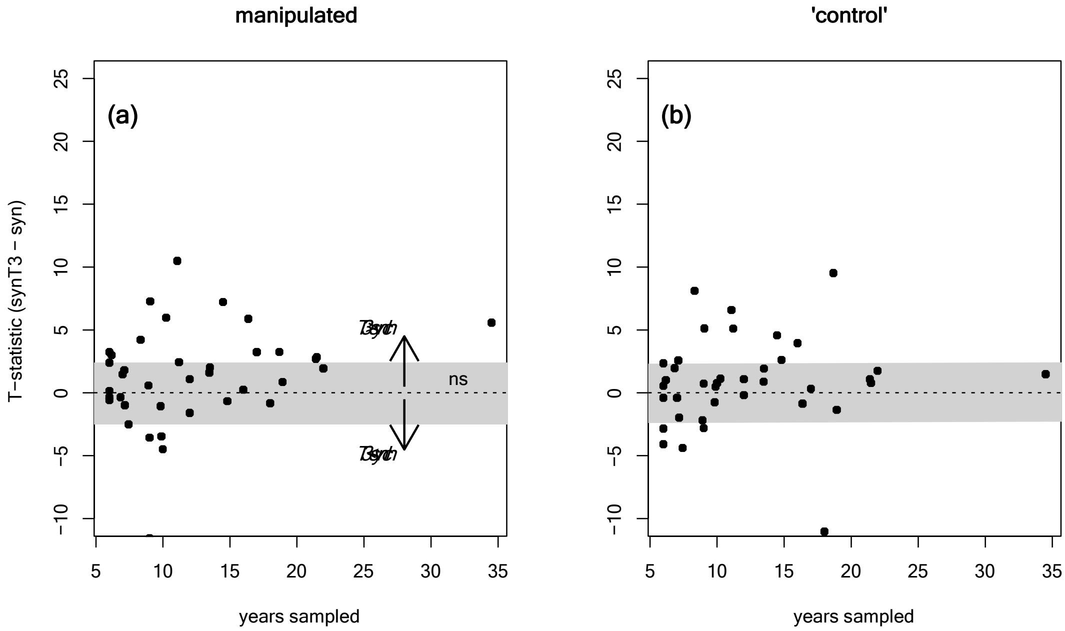
Note: on panel (b) the mean synchrony values with the T3 approach per datasets are significantly higher than without the T3 approach ($p < 0.22$, paired t-test)



Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

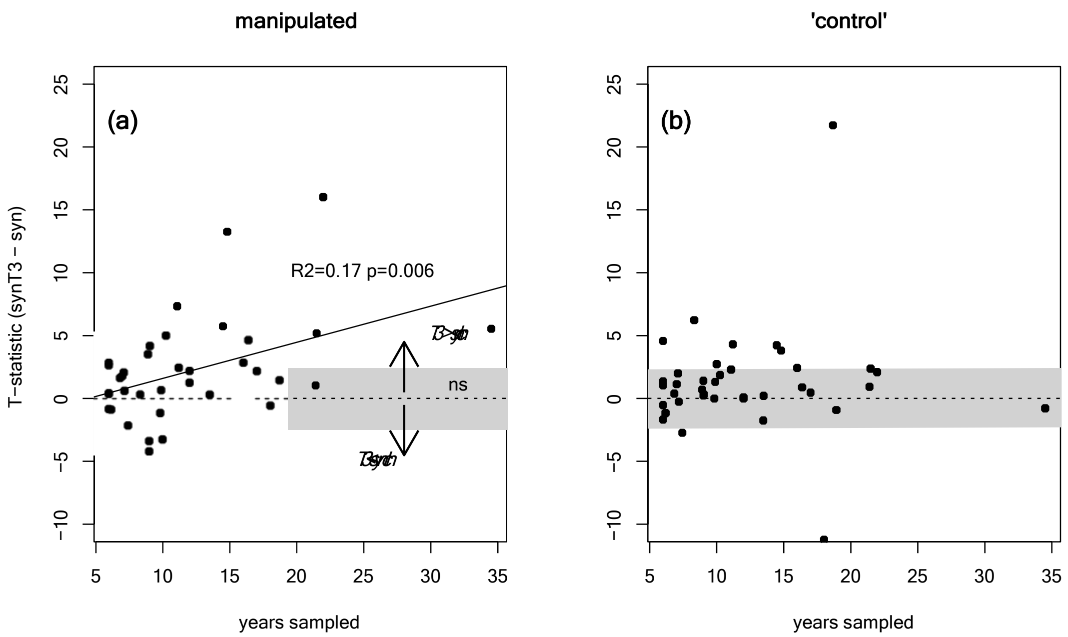
Appendix S4. Application of the analyses shown in Fig. 3 of the main text to the three remaining indices of synchrony. For each index, also, a table of number of datasets with either positive or negative significant t-statitstic values is reported for both manipulated and control plots (positive means that the T3 approach increased synchrony; negative means that the T3 approach decreased synchrony). The grey area in each panel reports and approximate are where t-statistic values were not significant ('*ns*').

Gross



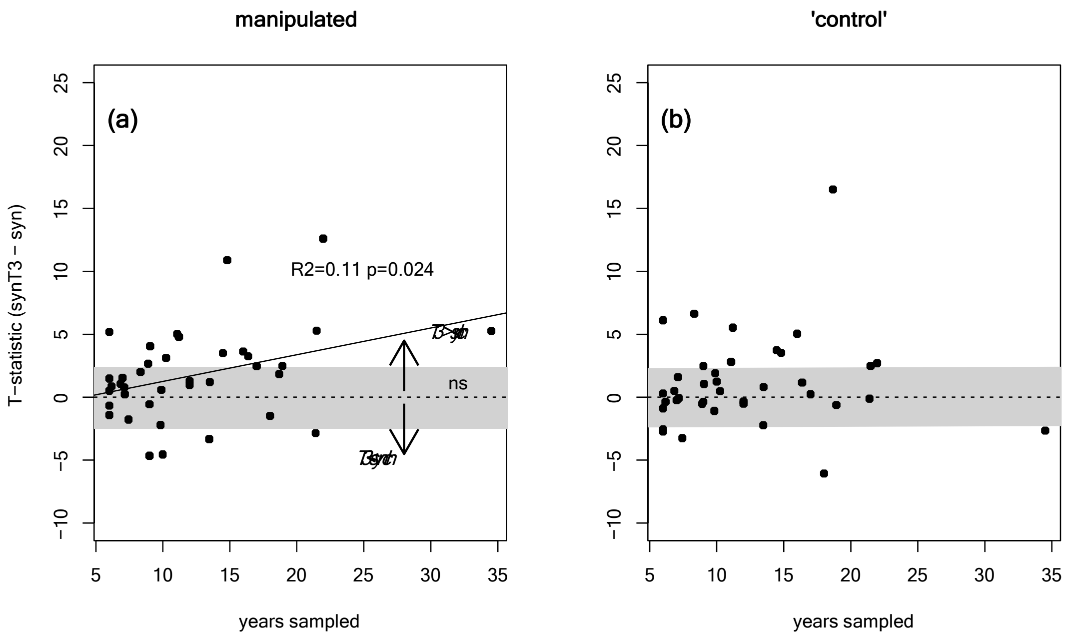
Manipulated		Control	
-	+	-	+
5	13	2	9

Logvar



Manipulated		Control	
-	+	-	+
4	13	2	7

Phi



Manipulated		Control	
-	+	-	+
5	14	3	8

Supporting Information to the paper
Valencia et al. Directional trends in species composition over time can lead to a widespread overestimation of asynchrony. *Journal of Vegetation Science*.

Appendix S5. Results of the correlation between synchrony indices with species richness or with the *CV* of total abundance. Each table reports the number of datasets with a significant correlations between either Synchrony ~ richness or CV~richness (after correction for false discovery rates, see main text). The number of positive correlations is provided in parenthesis.

Gross

	Richness ~ synchrony	CV~synchrony
Without T3	11 (+7)	42 (+42)
With T3	13 (+8)	48 (+42)

Logvar

	Richness ~ synchrony	CV~synchrony
Without T3	21 (17)	52 (+52)
With T3	16 (13)	59 (+59)

Phi

	Richness ~ synchrony	CV~ synchrony
Without T3	31 (1)	66 (+66)
With T3	30 (1)	65 (65)

References and Notes

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