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

3
4 **Running title: Directional trends effects on synchrony**

5
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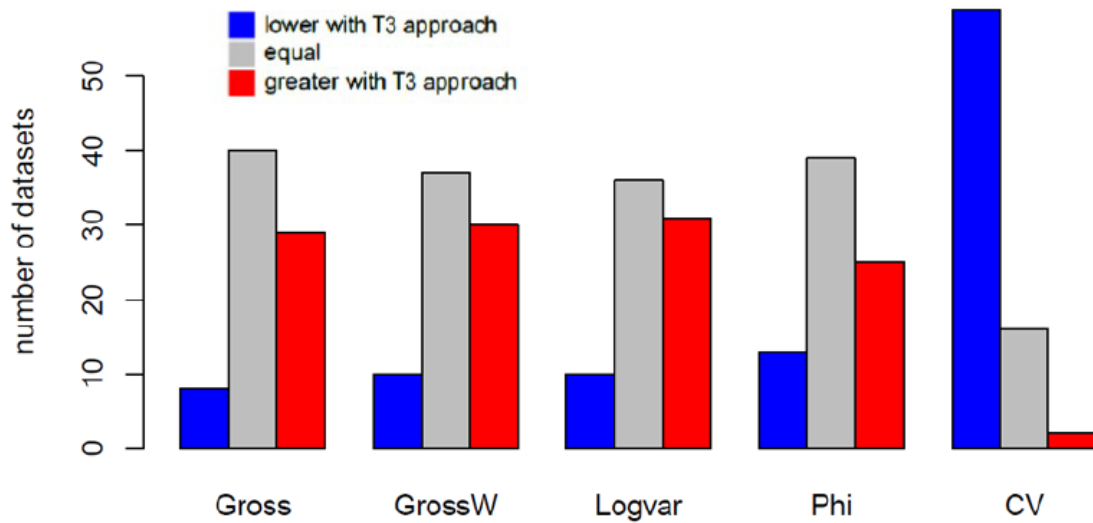
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98 **Web summary**

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



104

105 **Abstract**

106 **Questions**

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

116 **Methods**

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

124 **Results**

125 Accounting for directional trends increased the detection of year-to-year synchronous
126 patterns in all synchrony indices considered. Specifically, synchrony values increased
127 significantly in ~40% of the datasets with the T3 detrending approach while in ~10%
128 synchrony decreased. For the 38 studies with both control and manipulated conditions,

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

131 **Conclusions**

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

138

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

141 **Introduction**

142 Given the challenges posed by rapidly changing environments in the context of global
143 change, it is crucial to understand how biological diversity is maintained over time
144 (Cardinale et al. 2007; Tomimatsu et al. 2013; Tilman, Isbell, & Cowles 2014). There
145 is a general consensus toward the role that synchrony (or lack of) in, e.g., year-to-year
146 population fluctuations between co-existing species plays on species diversity and
147 community stability (Hautier et al. 2014; Craven et al. 2018). On the one hand, a
148 common response to environmental fluctuations (for example changes in temperature
149 or precipitation from one year to another) of most species (synchrony) will tend to
150 destabilize the community biomass or abundance. On the other hand, the opposite
151 pattern (compensatory dynamics, i.e. increases or decreases in the relative abundance
152 of some species that are offset by changes in the relative abundance of others; Hubbell
153 2001; Gonzalez & Loreau 2009) will lead to higher community stability. In this sense
154 asynchrony, i.e. the extent of the deviation from lack of perfect synchrony between
155 species, has been advocated as an important and widespread mechanism that
156 contributes to stability (Loreau & de Mazancourt 2013).

157 While there is a lively debate on the importance of compensatory dynamics on
158 the stability of communities (Houlahan et al. 2007; Blüthgen et al. 2016; Lepš et al.
159 2018) there are also important methodological aspects that can influence the detection
160 of the underlying biological patterns. Recently, Lepš et al. (2019) demonstrated that the
161 study of synchrony between species has traditionally disregarded the possible effects of
162 long-term directional compositional trends in the analysed communities (i.e. a tendency
163 of some species to increase or decrease over time, or to fluctuate cyclically, Wu et al.
164 2007). Species directional trends occur when the abundances of species respond not
165 only to short-term environmental fluctuations, but also to the presence of monotonic or

166 cyclical tendencies over the whole time series considered. Short term environmental
167 fluctuations (Rabotnov 1974), for example on a year-to-year basis, are expected to
168 affect species abundance but also to be largely reversible, so that species would not
169 show long-term directional trends in their abundances. In contrast, long-term
170 environmental changes, such as climate change, nutrient deposition and changes in land
171 use (e.g. abandonment or intensification of agricultural land), generally cause long-
172 term species directional trends (Stevens et al. 2011; Walter et al. 2018). Long-term
173 directional trends can also be the result of the impact of undetermined drivers
174 (Milchunas, Lauenroth, & Burkeal 1998). As repeatedly reported by many authors, long
175 term trends in species abundance are probably omnipresent, and have been
176 demonstrated even in, now, more than 160 years of the Park Grass Experiment
177 (Silvertown et al. 2006).

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

190 Multiple indices have been developed to evaluate the level of synchrony among
191 species in a community (Loreau & de Mazancourt 2008; Gross et al. 2014; Blüthgen et
192 al. 2016; Lepš et al. 2018). Further methodologies have also been developed to assess
193 directional trends, such as spectral or wavelet analyses, however, they are applicable
194 only to very long or highly resolved time series (see Lepš et al. 2019 for an overview
195 of these methods). None of the classically used synchrony indices disentangle, *a priori*,
196 the actual year-to-year fluctuations from the directional trends. However, such indices
197 can be ‘detrended’ using different methods (Wu et al. 2007; Lepš et al. 2019). One
198 appealing a simple solution includes computing synchrony indices over moveable
199 windows of three consecutive years (three-term local variance, ‘T3’, Hill 1973) instead
200 of over the whole sampling period (Lepš et al. 2019). This ‘detrending’ approach, which
201 we call T3 detrending approach, could allow testing the generality of the effect of
202 directional trends on synchrony indices. If the focus of the research is on year-to-year
203 fluctuations, then the minimum number of years to exclude trends and consider yearly
204 fluctuations is 3 years, hence the three-term local variance. With bigger windows the
205 computation of a common linear trend over the time window, and the focus on the
206 deviation from this trend, does recall on the other method proposed by Lepš et al.
207 (2019), using residuals of fitted linear models over a given time period. The first
208 approach has the advantage that it can be computed with any existing index of
209 synchrony and does not require the knowledge of the shape of possible linear trends in
210 species abundance.

211 A widespread assessment of the effect of species directional trends on
212 synchrony has been limited by the scarcity of available long-term data. Indeed, the
213 study of temporal dynamics requires a substantial sampling effort to obtain meaningful
214 data for temporal analyses. Although there are networks and independent groups with

215 long-term ecological data around the world, no major efforts have been made to compile
216 and standardize the existing data in order to achieve a worldwide perspective.
217 Consequently, a global-scale analysis would improve our understanding of both
218 directional trends and year-to-year species fluctuations among the different synchrony
219 indices and across diverse habitats, as well as how they are related with different types
220 of disturbances or stressors. To face this challenge, we compiled plant community data
221 from 77 temporal datasets with at least six sampling years, including almost 7800
222 vegetation plots distributed across the world. First, we evaluated to what extent year-
223 to-year synchrony could be masked by long-term trends, by using the T3 detrending
224 approach for temporal series proposed by Lepš et al. (2019) on commonly used indices
225 of synchrony. Second, we assessed whether synchrony patterns changed in plots in
226 which initial conditions were maintained ('control') vs. plots in which new conditions
227 were applied ('manipulated' plots, see methods), assuming that these new conditions
228 would trigger compositional changes and therefore generate a trend. Third, we
229 evaluated how detrended synchrony values are affected by the duration of the sampling.
230 Finally, we asked if relationships that are commonly assessed in the literature regarding
231 synchrony indices, i.e. the correlation between synchrony and species richness and the
232 correlation between synchrony and community stability, changed markedly depending
233 on whether the T3 detrending approach was applied. Additionally, beside the validation
234 of the T3 approach introduced by Lepš et al. (2019), we further validated (using
235 simulations) the functionality of the approach in the case of both monotonic and cyclical
236 long-term trends and depending on the time series length (Appendix S1). We expect
237 that: (1) directional trends in our datasets can overshadow either asynchrony or
238 synchrony depending on the type of trend; (2) manipulative experiments can give rise
239 to directional trends and therefore reinforce the need for detrended metrics to accurately

240 evaluate and compare community dynamics; (3) longer time series would provide
241 greater chances to detect species directional trends; and (4) the presence of directional
242 trends may affect the strength of the relationship between synchrony indices and species
243 richness or community stability.

244 **Methods**

245 We collected 77 worldwide datasets of aboveground dry biomass, cover percentage, or
246 frequencies of natural or semi-natural plant communities. These datasets consist of
247 7788 permanent and semi-permanent plots sampled between 6 to 53 times over periods
248 of 6 to 99 years. These datasets included plots with different treatments or
249 manipulations. The plots were thus grouped into two categories: control vs.
250 manipulated. In total 38 datasets presented both control and manipulated plots. Control
251 includes those plots where the long-term conditions prior to the establishment of the
252 sampling scheme were maintained throughout the sampling. For example, if the
253 historical conditions in a given site include periodic mowing, this represents the
254 ‘control’. The ‘manipulated’ plots were exposed to different treatments that altered the
255 long-term conditions in their respective sites. These treatments included introduction or
256 exclusion of grazing, mowing, removal of dominant species, fire, fertilization and
257 climate change treatments. These wide categories allowed us to perform broad
258 comparisons between different land-use and management conditions that are expected
259 to influence species trends. The list of datasets, their characteristics in habitat,
260 vegetation type and their available data on location and main manipulations is provided
261 in Appendix S2.

262

263 *Synchrony measures*

264 For each of the 7788 plots, we computed the most common indices of community-level
265 synchrony from existing literature. The main indices fall into two families. The first
266 one is based on correlations between species’ abundances and includes two indices: the
267 one proposed by Gross et al. (2014) and then this modified by Blüthgen et al. (2016),
268 which weighs the contribution of species to community synchrony in terms of their

269 abundance. We call these indices ‘Gross’ and ‘GrossW’, respectively. The second
270 family of indices is based on variance ratios, i.e. the variance in species fluctuations is
271 compared against the null model of independent fluctuations of individual populations,
272 and includes two indices: log variance ratio (‘Logvar’, Lepš et al. 2018) and φ (‘Phi’,
273 Loreau & de Mazancourt 2008).

274 The Gross and GrossW indices range from -1 to +1 and Logvar from *-Inf* to
275 $+\ln(nsp)$, with *nsp* being the number of species in a community. High values indicate a
276 common response of the species (synchrony), while any deviation from perfect
277 synchrony indicates asynchrony; the lowest and negative values indicate that the
278 increases or decreases in some species are compensated by opposite changes in others.
279 For all, Gross, GrossW and Logvar, zero corresponds to a situation where the species
280 fluctuate completely independently of each other. Finally, Phi ranges from 0 to 1, 1
281 being perfect synchrony and any deviation from this value means asynchrony.

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

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

292

293
$$T3 = \frac{\sum_i^{n-2} (x_i - 2x_{i+1} + x_{i+2})^2}{6(n-2)}$$

294

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

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

310

311 *Data analysis*

312 To assess to what extent the synchrony indices were affected by directional trends we
313 followed different approaches. First, we correlated (across plots within each dataset)
314 synchrony values with and without the T3 detrending approach. Specifically, for each
315 dataset we retained a Rho coefficient from the Spearman correlation between indices
316 calculated using the T3 detrending approach and their respective indices calculated
317 without the T3 approach. Then, to test consistency across datasets another Spearman

318 test was run on the average of each synchrony index per dataset to test if the ranking in
319 synchrony between datasets was maintained.

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

339 Third, we assessed whether synchrony values were affected by directional
340 trends depending on the presence of an experimental manipulation changing abruptly
341 the ecological conditions in a plot. To do this, we evaluated the effect of T3 using the
342 t-statistic of the paired t-test within dataset (see above), separately in control and

343 manipulated plots within datasets. This analysis was restricted to those 38 datasets (out
344 of 77) in which both control and manipulated plots were present and with at least three
345 plots in each category. The same approach was used to test the effect of the duration
346 (number of years) of the sampling period. This was undertaken using a linear model to
347 test the relationship between the t-statistic (resulting from the paired-test) and number
348 of years sampled in each dataset. We also used a similar LMM as described above to
349 jointly evaluate the effects of the duration of the sampling period and experimental
350 manipulation on the difference between the synchrony values with and without the T3
351 detrending approach in these 38 datasets. In this model, we used the number of years
352 of sampling, the experimental manipulation (manipulated vs. control plots) and their
353 interaction as fixed factor, while each dataset was considered as a random factor. When
354 a significant interaction was found, we split the database in control and manipulated
355 plots and evaluated the effects of duration of the sampling period on both groups of
356 plots.

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

364 For simplicity, we mostly present the results of one index (GrossW) in the main
365 text because it is widely applied in the literature. However, most of the results for the
366 other indices considered are shown in Appendix (S3 and S4). Similarly, all results

367 concerning simulations are also included as Supporting Information material (Appendix
368 S1). All the analysis were run in R (R Development Core Team 2018).

369 **Results**

370 The ranking of synchrony values with and without the T3 detrending approach was
371 relatively consistent, both within and across datasets (Fig. 1). The Spearman Rho values
372 computed within each of the 77 datasets were mostly positive and significant (Fig. 1a,
373 for GrossW as an example; similar patterns were obtained for the other indices,
374 Appendix S3). For example, in 44 out of the 77 datasets, the Spearman Rho was above
375 0.5. This indicates a moderate correspondence in the ranking in synchronicity values
376 across plots within datasets. Nevertheless, notable exceptions were present, for example
377 in six datasets (~8% of the cases) Rho was below 0.1. However, in five out of these six
378 datasets, either the number of manipulated plots was greater than the control plots, or
379 the control plots were entirely absent. Overall, the Spearman ranking test done on the
380 mean synchrony values indicated that greater synchrony without the T3 approach also
381 provided greater synchrony with the T3 approach (Fig. 1b: $Rho = 0.81$ and $p < 0.001$).
382 Most importantly, synchrony mean values were frequently greater where the T3
383 detrending approach was applied than without its use (paired t-test $p < 0.001$; Fig. 1b
384 and Appendix S3).

385 We generally found a greater synchrony when accounting for long-term trends
386 with the T3 methods than without. A significant increase in synchrony values was found
387 for over 1/3 of the datasets (~30 datasets of 77, i.e. in ~40% of datasets synchrony
388 significantly increase, $p < 0.05$, after correcting p-values for multiple tests with the
389 Benjamini & Hochberg correction for false discovery rate within each synchrony index,
390 Fig. 2; all significant tests reported in this section account for this p-value correction).
391 Conversely, in around 10 datasets (13%, depending on the indices) synchrony values
392 decreased using the T3 approach. In total around 50% of the datasets showed a
393 significant change in synchrony values when using or not using the T3 detrending

394 approach. The pattern described for GrossW index was similar for all other synchrony
395 indices. The number of datasets showing greater synchrony with the T3 approach was
396 lower using Phi, which also showed a higher number of datasets showing lower
397 synchrony with the T3 approach. In the majority of datasets (around 60) the CV
398 computed using the T3 approach was significantly lower compared to the one computed
399 without the T3 approach.

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

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

413 As expected, detrending had greater impacts on measures of synchrony in
414 experimental plots than controls. Specifically evaluating ‘control’ vs. ‘manipulated’
415 plots (using 38 datasets in which there were both types of plots), showed a greater
416 number of cases in which the T3 approach produced significant changes in synchrony
417 in the manipulated than in the control plots (Fig. 3 for the GrossW and Appendix S4
418 for the other synchrony indices): 21 significant datasets (60%) in the manipulated plots

419 but only 10 (27%) in the control plots. Moreover, the effect of the sampling period
420 length (number of years plots were sampled) was significantly related to the change in
421 mean synchrony with the T3 approach only in the case of the manipulated plots (Fig. 3,
422 using, as dependent variable, the t-values resulting by comparing synchrony with and
423 without T3 approach using the paired t-tests within plot described above). Specifically,
424 in the manipulated plots a longer sampling period improved the predictive ability of the
425 effect of T3 approach on synchrony (increased detection of synchrony over long-term
426 periods and increased detection of asynchrony in short-time periods). We confirmed
427 these results using an LMM in which the difference of synchrony with and without T3
428 were computed for each plot. This analyses showed a significant interaction between
429 sampling period length and experimental manipulation. Sampling period length
430 significantly increased the difference between synchrony values with and without the
431 T3 approach only in manipulated plots ($\chi^2 = 10.37$; $p = 0.001$, $n = 3414$).

432 Finally, we found that overall the relationships between synchrony and both
433 species richness and community stability were similar (Appendix S5). Nevertheless
434 there were slightly more frequent significant cases after detrending for Gross and
435 GrossW (Appendix S5). For instance, the relationship between species richness and
436 synchrony (i.e. when considering GrossW) was found significant in 15 and 11 datasets
437 (out of 77) respectively when using or not using the T3 detrending approach (in both
438 cases correcting for false discovery rates). However, this relationship, with LogVar,
439 was found significant in 4 datasets less when using the T3. Further, with GrossW the
440 expected positive relationship between synchrony and community CV was significant
441 in 58 and 54 datasets while using or not using the T3 detrending, respectively (we did
442 not detect significant negative relationship between CV and synchrony). The strength
443 of these relationships, however, was not affected by the detrending approach. In neither

444 the (i) species richness and synchrony correlations, nor the (ii) community CV and
445 synchrony correlations, did we detect significant differences when using or not using
446 the T3 detrending approach (in both cases $p > 0.2$). This implies that the use of the T3
447 detrending approach did not systematically produce greater or weaker correlations
448 when analyzing these common relationships.

449 **Discussion**

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

465 In ~40% of the datasets, and in the overall model across all plots, synchrony
466 using the T3 detrending approach was significantly greater than synchrony without
467 using it (Fig. 2). The ~40% estimate is, furthermore, a conservative one as we account
468 for Type I errors. Overall, the mean values of synchrony computed with the T3
469 detrending approach were higher than without it in the majority of cases, both within
470 and across datasets (Fig. 1b, and LMM). This is an important finding because it suggests
471 that our appreciation of the importance of asynchrony, and therefore compensatory
472 dynamics, may have been possibly overestimated, leading to wrong conclusions about
473 synchrony-asynchrony in communities. These findings highlight the necessity of

474 evaluating the effects of possible directional trends on synchrony to accurately estimate
475 the importance of ecological mechanisms regulating compensatory dynamics. The
476 difference between the indices calculated using T3 detrending approach and without it
477 were higher in grasslands and meadows, possibly because in the absence of slow-
478 growing, less dynamic, woody species. In these communities temporal trends can thus
479 be more easily detected compared to other types of vegetation. The increase in
480 synchrony after detrending also suggests the presence of opposite trends of species
481 abundances in time, such as when one species is decreasing steadily and another
482 increasing. For example, trends could be the result of species responding differently to
483 disturbance or to an increase in nutrient availability. Such opposite trends could be
484 monotonic or following waves in time (Wu et al. 2007), e.g. resulting from periodic
485 climate events such as “El Niño”, or intrinsic cycling of particular functional groups
486 such as legumes (Herben et al. 2017). These results are partially expected because our
487 datasets comprised natural or semi-natural well-established plant communities but
488 included experimental conditions in which changes in abundance or composition of
489 species are common.

490 When considering datasets with both control and manipulated plots (~50% of
491 the datasets) the effect of the T3 approach was more frequently significant in
492 manipulated plots than in control plots (Fig. 3). These plots were more prone to be
493 affected by a directional trend promoted by the specific manipulation imposed. This
494 result agrees with our hypothesis that events like soil-nutrient alteration (e.g. by
495 fertilization) and recovery from disturbance might promote directional trends. This
496 result was expected as some of the experimental manipulations were designed to
497 directly alter species composition, in order to test their effects on community
498 synchrony. However, such prompted changes, often due to colonization-competition

499 trade-offs in species composition, can mask year-to-year fluctuations, and hence these
500 experiments should disentangle these biologically different effects on synchrony. For
501 these reasons, we recommend that any index of synchrony should be computed with
502 and without the T3 approach to properly evaluate the corresponding effects of long-
503 term experimental treatments and year-to-year fluctuations. Our result reinforces the
504 assumption that the effect of the T3 approach could be stronger in changing
505 environments/communities and the combination of indices with and without the T3
506 approach can be important to distinguish the mechanisms causing differential long-term
507 species responses to changes in environmental conditions from the differential species
508 responses to short-term species fluctuations on synchrony/asynchrony relationships.

509 The effect of detrending on synchrony values was particularly pronounced in
510 the case of succession. During succession the majority of species will increase their
511 abundance, which will cause them to be ultimately positively correlated in time.
512 However, these same species can compensate each other or vary independently on a
513 year-by-year basis, even if they all generally increase in time, so the existing synchrony
514 indices would tend to overestimate their actual year-to-year synchrony between species
515 within such communities. In fact, among the seven datasets with a Rho below 0.1 (Fig.
516 1a), the majority were characterised by being exposed to intense disturbance regimes
517 that triggered some type of successional process. For instance, plots of four datasets
518 had been exposed to a fire before or during the experiment, and two evaluated the effect
519 of herbivory exclusion (where the reduction in grazing intensity allowed the
520 development of higher vegetation like shrubs and trees). Both treatments are good
521 examples of environmental conditions promoting species directional trends (Pardo et
522 al. 2015) and thus affect synchrony values.

523 Interestingly, the effect of the T3 approach on the synchrony measured in
524 manipulated plots depended on the period length of the sampling scheme. Manipulated
525 plots sampled over longer time periods revealed higher synchrony values when using
526 the T3 detrending approach (Fig. 3). In other words, the longer is the sampling period
527 the greatest chance that there is a difference between T3 synchrony and synchrony
528 without T3 in manipulated plots. Longer time series likely increased the chances that
529 some species will have opposite trends in response to manipulation, with some
530 increasing over time and others decreasing. In a shorter time series, on the contrary, the
531 time lag in species responses (particularly extinction debt, Helm, Hanski, & Partel
532 2006; Lepš 2014) could cause that some species increase quickly in response to
533 manipulation, while others might respond more slowly. The T3 detrending approach,
534 therefore, will affect those species with a similar temporal trend in response to short-
535 term manipulations. Consequently, the duration of the sampling period stands out as a
536 key factor in the evaluation of temporal dynamics. We showed that, in the case of
537 manipulated communities, classical methods tended to overestimate year-to-year
538 synchrony when the sampling period was shorter, and underestimate it when the
539 sampling period was longer. This highlights the importance of T3 approach for a correct
540 evaluation of year-to-year synchrony between species. However, further research is
541 required to find the causes and consequences of these results.

542 Finally, we generally found that the T3 detrending approach did not cause strong
543 changes in the correlation between synchrony and both species richness and community
544 stability, two of the most iconic relationships in temporal dynamics studies (Hautier et
545 al. 2014; Blüthgen et al. 2016). However, there were more cases of significant
546 correlations with the T3 approach and strength of the correlations could vary
547 considerably (i.e. $R < 0.6$) across datasets. In summary, this suggests that while the

548 applications of the T3 detrending approach did not produce systematically greater or
549 weaker correlations on commonly used tests in ecology, the strength of the relationships
550 could differ. These results confirm that the use of T3 approach to detrend the synchrony
551 indices is far from trivial. As such, the conclusions obtained previously from studies
552 that did not apply the method are not necessarily incorrect. Therefore, applying the
553 detrended and non-detrended methods in a complementary way might bring us closer
554 to understanding the directional changes in community dynamics. For instance,
555 divergent trends, e.g. due to differential response to global warming with some species
556 increasing and other decreasing, might stabilize communities and could maintain
557 ecosystem functions unaltered in response to global warming, even if there are no short-
558 term compensatory mechanisms between species. Hence, it is important to consider
559 both the synchrony with and without detrending approach for teasing apart different
560 causes of stability, or instability, in response to global change drivers.

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

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598

599

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601 F.B., T.G and L.G. collected the data used in this analysis. E.V. and T.G. assembled
602 data. F.B. performed the analyses. E.V. and F.B. wrote the first draft of the manuscript
603 and all the authors (especially L.G. and J. L.) contributed substantially to the revisions.

604

605 **Data accessibility**

606 The data that support the findings of this study are available at Figshare (Valencia et al.
607 2019).

608

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610

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- 734
- 735

736 **Figure legend**

737

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

747

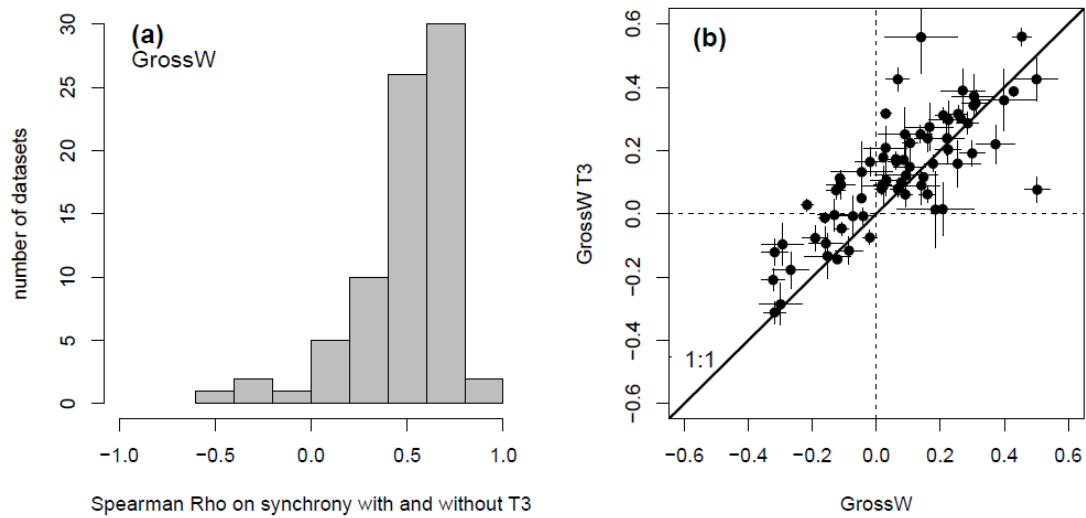
748 **Figure 2.** Summary of the directional effects of the T3 detrending approach on various
749 synchrony indices and on CV. The bar plots indicate the numbers of datasets (n=77) in
750 which the T3 approach significantly increased (red bars) or decreased (blue bars)
751 synchrony values using a paired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

753

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

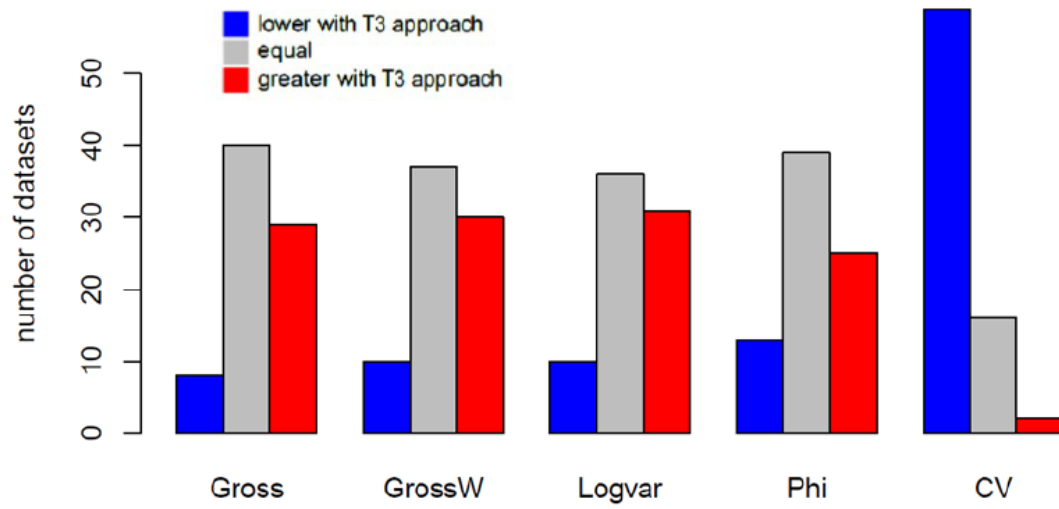
765

766 **Figure 1.**
767



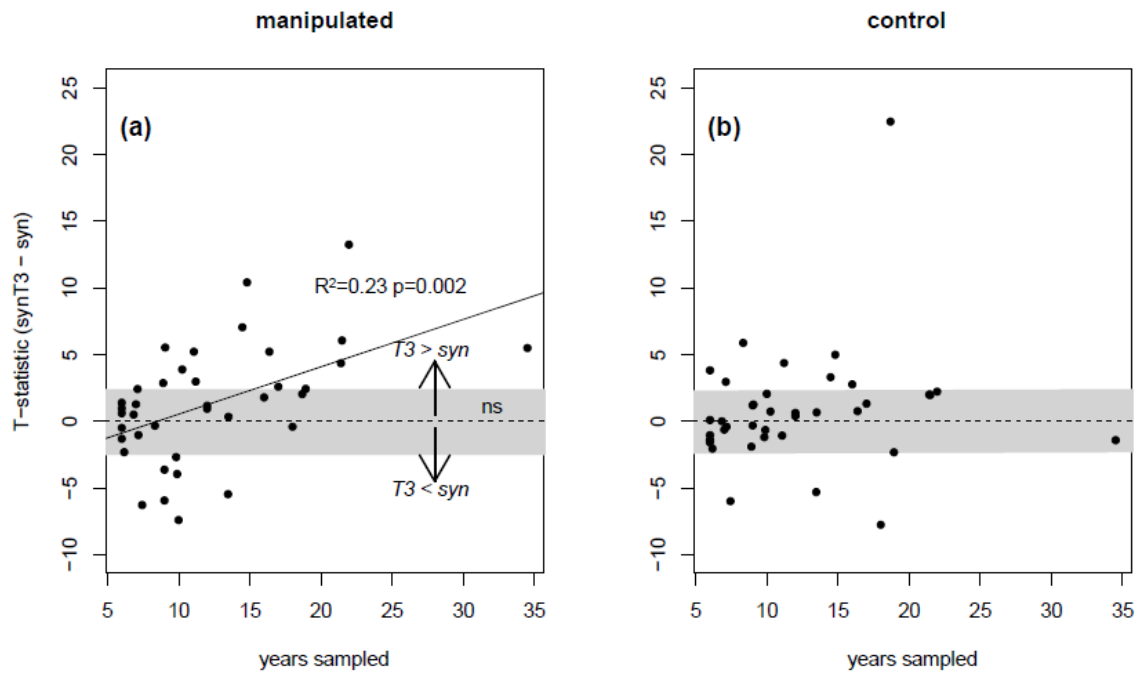
768

769 **Figure 2.**
770



771

772 **Figure 3.**
773



774

775 **Supporting Information**

776 Additional Supporting Information may be found in the online version of this article:
777

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

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

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

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

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

1 Supporting Information to the paper
2 Valencia et al. Directional trends in species composition over time can lead to a
3 widespread overestimation of asynchrony. *Journal of Vegetation Science*.
4
5 **Appendix S1.** *Simulating long term trends in artificial communities to validate*
6 *effectiveness of the T3 approach*

7 We created artificial temporal community data with desired patterns of temporal
8 fluctuations (prevailing synchrony or asynchrony) using the “syngenr” R function
9 (Lepš et al. 2019). This function offers the possibility to build simulated communities,
10 fixing some parameters, such as the years of the time series (100 years) and the
11 number of species (8 species). Once the communities were established, communities
12 fluctuating in time were created according to the following scenarios: prevailing
13 synchrony or prevailing asynchrony. A synchronous pattern was simulated by having
14 a common response for all species to a hypothetical environmental cue. Accordingly,
15 an asynchronous pattern was created by having half of the species responding
16 positively and the other half negatively to the environmental cue. Furthermore, we
17 simulated directional (monotonic) and cyclical long term trends for these artificial
18 communities. First, we simulated a case where most species had a common long-term
19 positive trend (monotonic) leading to a steady increase of individual species over
20 time. This would lead to detect synchrony with the synchrony indices (unmodified),
21 even if the species are actually behaving asynchronous. Second, we simulated the
22 opposite case, where species either increase or decrease in time, with the
23 increase/decrease for each species defined by a combined bimodal distribution from
24 two normal distributions with -1 and 1 as means, and random subset from half of the
25 species more probably have a positive long-term trend and the other half of the
26 species more probably a negative long-term trend. Finally, we simulated a case were
27 the directional long-term had cyclical tendencies. The cyclical long term trends were

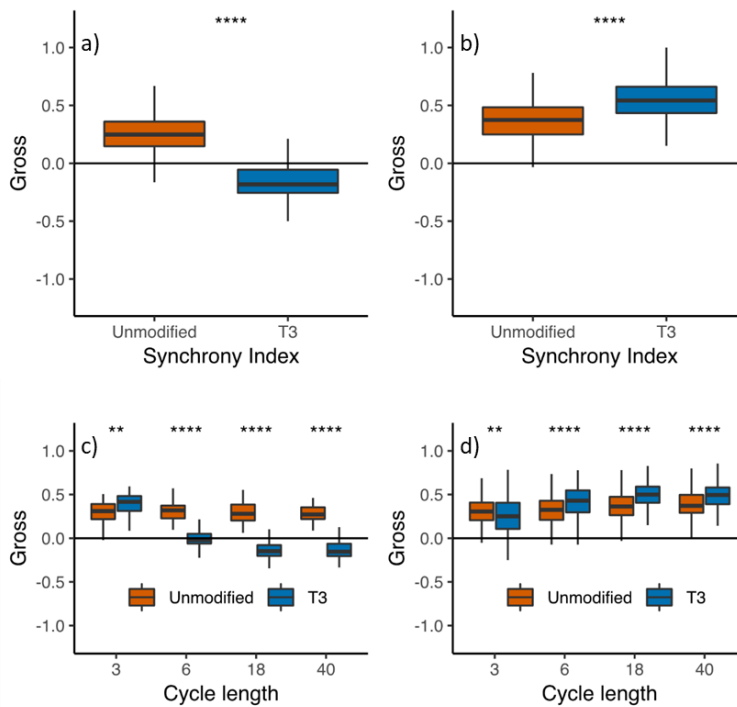
28 evaluated with different cycle length: 3, 6, 18 and 40 years. These cycle lengths
29 reflect some known potential long term cycles that drive communities across the
30 world, such as the El Niño Oscillation or Pacific Decadal Oscillation, which have
31 intervals of 3-6 years and 10-20 year, respectively. In summary, we simulated two
32 scenarios of year-to-year species fluctuations (prevailing synchrony or prevailing
33 asynchrony) and three types of long-term directional trends (i.e. monotonic with a
34 common or contrasted trend, and cyclical trends), resulting in six possible
35 combinations of trend–fluctuation scenarios. In all these simulated communities, we
36 calculated the different synchrony indices (Gross, GrossW, Logvar and Phi), with or
37 without the use of the T3 detrending approach, using the “calc_sync” R function
38 (Lepš et al. 2019).

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

53 and without the T3 detrending approach, but with a less pronounced effect (Figure
 54 Appendix S1b and S1d).

55
 56 **Figure Appendix S1.** Results of synchrony indices (Gross, GrossW Logvar, and Phi)
 57 (Loreau & de Mazancourt 2008; Gross et al. 2014; Blüthgen et al. 2016; Lepš et al.
 58 2018), with or without the use of the T3 detrending approach, in artificial temporal
 59 communities where long term trends were simulated. The panels report results for a
 60 common long-term directional trend (a) (i.e. creating synchrony; all species increasing
 61 in time), a contrasted long-term trend (b) (i.e. half species increasing, the other half
 62 decreasing, creating asynchrony) and a cyclical trend (c and d). Within each of these
 63 scenarios we considered two scenarios: year to year asynchrony (a and c) and
 64 synchrony (b and d). The cyclic trends also included different cycle length (3, 6, 18
 65 and 40 years). The created communities had a total of 8 species. Asterisks above and
 66 between boxes depict significant differences among the synchrony indices with or
 67 without the T3 approach as assessed with a paired t-test. *: $P < 0.05$; **: $P < 0.01$;
 68 ***: $P < 0.001$; ****: $P < 0.0001$.

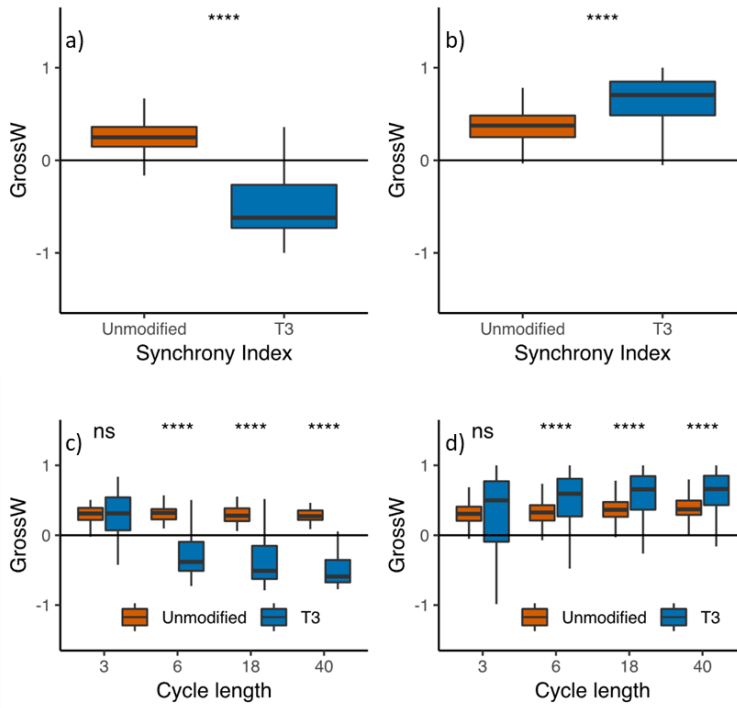
69
 70 **Gross**



71
 72

73 **GrossW**

74

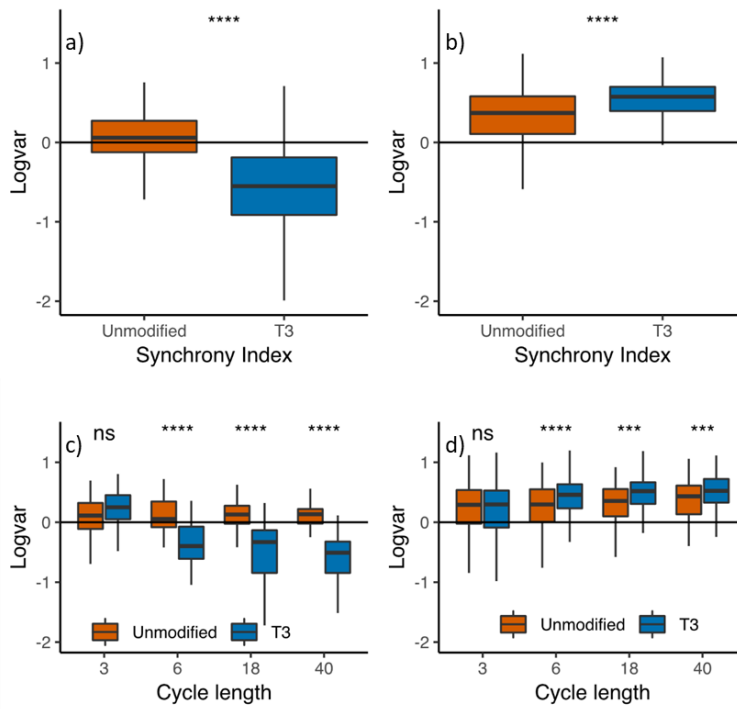


75

76

77 **Logvar**

78

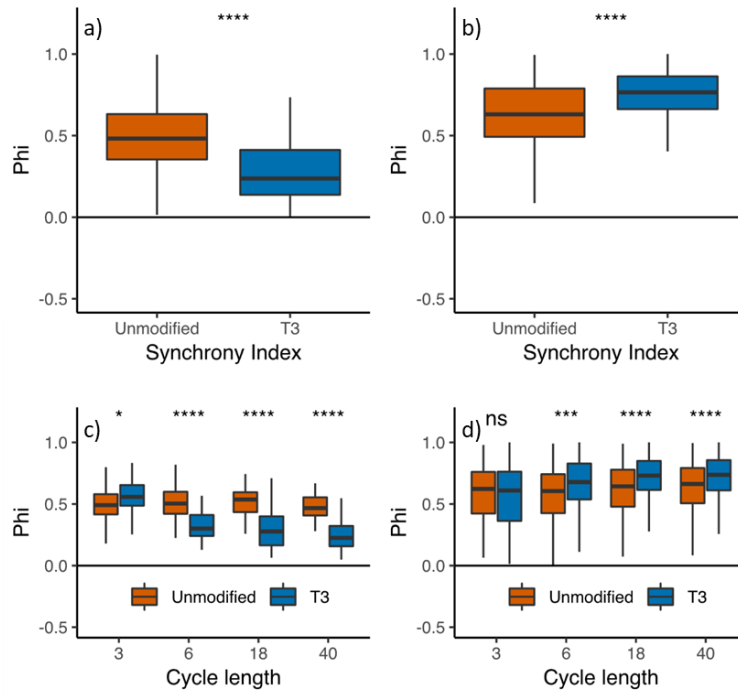


79

80

81

82 **Phi**
83



84
85

86 Supporting Information to the paper
87 Valencia et al. Directional trends in species composition over time can lead to a
88 widespread overestimation of asynchrony. *Journal of Vegetation Science*.
89

90 **Appendix S2.** Descriptions of each dataset, highlighting the treatments of the datasets
91 with ‘control’ and ‘manipulated’ plots. LAT: latitude (WGS84 datum), and LON:
92 longitude (WGS84 datum).

93

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

99

100 **2.** The dataset is issued from an experiment located on a mixed grass prairie in Hays,
101 Kansas, USA (LAT: 38.80, and LON: -99.30). This dataset consists of 51 plots, where
102 each plot was sampled an average of 34.5 times. In each plot, individual plants were
103 quantified and mapped. Thirty-six permanent quadrats were located inside livestock
104 exclosures and 15 in grazed areas. More information:

105 [https://web.archive.org/web/20150128015820/http://esapubs.org:80/archive/ecol/E08](https://web.archive.org/web/20150128015820/http://esapubs.org:80/archive/ecol/E088/161/default.htm)
106 [8/161/default.htm](https://web.archive.org/web/20150128015820/http://esapubs.org:80/archive/ecol/E088/161/default.htm)

107

108 **3.** The dataset is issued from an experiment located on a shortgrass steppe of North
109 America in Nunn, Colorado, USA (LAT: 40.85, and LON: -104.71). This dataset
110 consists of 24 plots, where each plot was sampled an average of 13.5 times. In each
111 plot, individual plants were quantified and mapped. The quadrats were established in
112 six grazed and ungrazed study sites on the Central Plains Experimental Range. There
113 were four treatments combining past and present grazing status: ungrazed in the past
114 and at present (ungrazed/ungrazed), grazed by livestock in the past and present
115 (grazed/grazed), grazed in the past and ungrazed during the experiment
116 (grazed/ungrazed), and ungrazed in the past and grazed during the experiment
117 (ungrazed/grazed). More information:

118 [https://web.archive.org/web/20150502183659/http://www.esapubs.org/archive/ecol/E0](https://web.archive.org/web/20150502183659/http://www.esapubs.org/archive/ecol/E094/128/)
119 [94/128/](https://web.archive.org/web/20150502183659/http://www.esapubs.org/archive/ecol/E094/128/)

120

121 **4.** The dataset is issued from an experiment located on semi-desert grasslands at the
122 Santa Rita Experimental Range, Arizona, USA (LAT: 31.83, and LON: -110.88). This
123 dataset consists of 160 plots, where each plot was sampled an average of 11.2 times.
124 In each plot, individual plants were quantified and mapped. Quadrats were located in
125 exclosures (ungrazed) and in pastures grazed by livestock (grazed). More information:
126 [https://web.archive.org/web/20150502183207/http://esapubs.org:80/archive/ecol/E09](https://web.archive.org/web/20150502183207/http://esapubs.org:80/archive/ecol/E093/132/default.htm)
127 [3/132/default.htm](https://web.archive.org/web/20150502183207/http://esapubs.org:80/archive/ecol/E093/132/default.htm)

128

129 **5.** The dataset is issued from an experiment located in sagebrush steppe in eastern
130 Idaho, USA (LAT: 44.20, and LON: -112.20). This dataset consists of 23 plots, where
131 each plot was sampled an average of 21.5 times. In each plot, individual plants were
132 quantified and mapped. These permanent quadrats were located in both grazed (4
133 quadrats) and ungrazed units (18 quadrats), and one quadrat was grazed in the past
134 and ungrazed during the experiment. More information:

135 [https://web.archive.org/web/20150128015825/http://esapubs.org/archive/ecol/E091/24](https://web.archive.org/web/20150128015825/http://esapubs.org/archive/ecol/E091/243/default.htm)
136 [3/default.htm](https://web.archive.org/web/20150128015825/http://esapubs.org/archive/ecol/E091/243/default.htm).

137

138 **6.** The dataset is issued from an experiment on the Jornada Long-Term Ecological
139 Research site in southern New Mexico, USA (LAT: 32.83, and LON: -107.33). This
140 dataset consists of 222 plots, where each plot was sampled an average of 8.0 times.
141 Previously grazing domestic livestock was excluded from the area where three
142 permanent transects (2.7 km) were established. One of the transects received
143 fertilization of 10 g/m² of nitrogen. One of the two control transects (not fertilized),
144 was sampled at 40 stations, the other two transects had 91 stations each. At each
145 station abundance of each species was estimated by point-intercept method along a 30
146 m transect perpendicular to each of the three permanent transects. More information:
147 <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-jrn.2100119001.50>.

148

149 **7.** The dataset is issued from an experiment on the Jornada Basin Long-Term
150 Ecological Research Program (LTER) site in the Chihuahuan desert, New Mexico,
151 USA (LAT: 32.93, and LON: -107.36). This dataset consists of 1001 plots, where
152 each plot was sampled an average of 11.5 times. On the grassland site, three exclusion
153 treatment levels were set in addition to the control treatment left open to all grazers.
154 The first level excluded only domestic animals (cattle), the second excluded

155 lagomorphs, and the third excluded rodents. In the shrubland site, only lagomorph-
156 and rodent-exclusion treatments were set in addition to the control. In each treatment
157 of each site, 4 grids of 36 permanent plots (1 m²) were sampled (visual estimated
158 cover). More information:

159 <https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100086002.39>.
160

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

166

167 **9.** The dataset is issued from an experiment located in the Succulent Karoo in
168 Soebatsfontein, South Africa (LAT: -30.19, and LON: 17.54). This dataset consists of
169 24 plots, where each plot was sampled an average of 15.8 times. The cover values (%)
170 of all individual plant species were estimated annually. More information: Jürgens et
171 al. (2010).

172

173 **10.** The dataset is issued from an experiment located in the Succulent Karoo, near
174 Leliefontein, South Africa (LAT: 18.28, and LON: -30.40). This dataset consists of 42
175 plots, where each plot was sampled an average of 14.7 times. The cover values (%) of
176 all individual plant species were estimated annually. More information: Jürgens et al.
177 (2010).

178

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

184

185 **12.** The dataset is issued from an experiment on the Kiskun LTER located in Bugac
186 and Orgovány sites of Kiskunság National Park, Hungary (LAT: 46.73, and LON:
187 19.54). This dataset consists of 380 plots, where each plot was sampled an average of
188 14.5 times. Half of the plots were fenced to control grazing pressure. In each plot, the

189 cover values (%) were visually estimated annually. More information: Kertész et al.
190 (2017).

191

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

201 <http://cedarcreek.umn.edu/research/data/dataset?acze247>.

202

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

211 <http://cedarcreek.umn.edu/research/data/dataset?herbe133>.

212

213 **15.** The dataset is issued from an experiment located in the Cedar Creek LTER
214 Ecosystem Science Reserve, Minnesota, USA (LAT: 45.41, and LON: -93.19). This
215 dataset consists of 60 plots, where each plot was sampled an average of 24.8 times. In
216 each plot, the biomass of individual plants was recorded from 4 plots (0.3 m²) per
217 field until 2013. More information:

218 <http://cedarcreek.umn.edu/research/data/dataset?ple054>.

219

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

223 The experiment combines different levels of fertilization on 4 fields that were
224 abandoned for different periods (14, 25, 48 years and never ploughed before the
225 experiment started in 1982) and where mammal grazers were excluded. In each plot,
226 individual plant biomass was recorded on 5 to 6 replicate plots of different
227 fertilization treatments (from 0 to 40 g/m² of nitrogen) per field every year. More
228 information: <http://cedarcreek.umn.edu/research/data/dataset?ple001>.

229

230 **17.** The dataset is issued from an experiment located in the Cedar Creek LTER
231 Ecosystem Science Reserve, Minnesota, USA (LAT: 45.40, and LON: -93.20). This
232 dataset consists of 237 plots, where each plot was sampled an average of 14.8 times.
233 The experiment combines 9 levels of fertilization (from 0 to 40 g/m² of nitrogen) and
234 prescribed burning on three fields that were abandoned since 14, 25 and 48 years, and
235 where mammal grazers were excluded. All 3 fields had 6 replicate plots of the 9
236 fertility treatments from 1982. From 1992 half of the plots in field B were burned
237 every spring, and half of the plots in field A and C stopped receiving the fertilization
238 treatment. To maintain continuity of the treatments within plots the 1992-2011 period
239 of those plots were entered in the database as separate plots of the same data set.
240 Individual plant biomass was measured. More information:
241 <http://cedarcreek.umn.edu/research/data/dataset?ple002>.

242

243 **18.** The dataset is issued from an experiment located in the Shortgrass Steppe LTER
244 in the Central Plains Experimental Range, Colorado, USA (LAT: 40.85, and LON: -
245 104.77). This dataset consists of 795 plots, where each plot was sampled an average
246 of 13.5 times. Plots were distributed across four combinations of past/current
247 management: grazed/grazed, ungrazed/ungrazed, grazed/ungrazed and
248 ungrazed/grazed. In 1998, additional plots were added in a fifth treatment with fences
249 excluding both large and small grazers (rodent exclusion). More information:
250 <https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-sgs.527.1>.

251

252 **19.** The dataset is issued from an experiment located in sandy semi-natural grasslands
253 of the Elbe valley in H6hbeck, Germany (LAT: 53.05, and LON: 11.41). This dataset
254 consists of 96 plots, where each plot was sampled an average of 6.0 times. The
255 vegetation was surveyed once a year in 1 m² plots using the Londo scale (Londo
256 1976). More information: Schuhmacher & Dengler (2013).

257

258 **20.** The dataset is issued from an experiment located near Dufftown, Morayshire,
259 United Kingdom (LAT: 57.73, and LON: -3.10). This dataset consists of 12 plots,
260 where each plot was sampled an average of 6.0 times. Each species was measured in a
261 transect, using the inclined-point quadrat method (Tinney et al. 1937) (32.5° to the
262 horizontal). All contacts with 5 pins were recorded in 20 quadrat positions per plot.
263 More information: Pakeman et al. (2003).

264

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

272

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

280

281 **23.** The dataset is issued from an experiment located on a pasture in Fasque, United
282 Kingdom (LAT: 56.87, and LON: -2.60). This dataset consists of eight plots, where
283 each plot was sampled an average of 8.0 times. Inclined-point quadrat method (32.5°
284 to the horizontal) was used to record each species in a transect, with a minimum of 20
285 point contacts at 18 locations per plot (i.e. a minimum of 360 contacts per plot). More
286 information: Marriott et al. (2002).

287

288 **24.** The dataset is issued from an experiment located on La Fage French National
289 Institute for Agricultural Research (INRA) experimental station, close to Millau,
290 France (LAT: 43.92, and LON: 3.10). This dataset consists of 16 plots, where each

291 plot was sampled an average of 28.0 times. Individual plants were identified using the
292 point intercept method on 5 m permanent lines (1 point/10 cm, i.e. 50 points/line).
293 More information: Chollet et al. (2014) and Garnier et al. (2018).

294

295 **25.** The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 483 and 497-
296 ITEX Dataset 5 - Teberda (Malaya Alpine-Snowbed and Geranium Hedysarum
297 Meadow) and ITEX Dataset 19 - Teberda (Festuca Varia Grassland, Malaya Alpine
298 Lichen-Heath). The dataset is issued from an experiment located in Teberda State
299 Reserve, a part of the Karachaevo-Cherkessian Republic in the northwestern
300 Caucasus, Russia (LAT: 43.45, and LON: 41.69). This dataset consists of 145 plots,
301 where each plot was sampled an average of 24.3 times. In each plot, the cover of each
302 plant species was recorded as number of shoots per m². More information:
303 Onipchenko *et al.* (1998).

304

305 **26.** The dataset is issued from an experiment located a moorland in the Clocaenog
306 Forest, United Kingdom (LAT: 53.06, and LON: -3.47). This dataset consists of 9
307 plots, where each plot was sampled an average of 12.0 times. The experiment was
308 designed with three treatments: control, drought (~20% reduction in total annual
309 rainfall) and warming (~64% reduction in heat loss during night and 14% reduction in
310 total annual rainfall). Three quadrats per plot were chosen, and in each quadrat
311 vegetation was quantified using a grid of 100 pins (pin-point methodology). Pin hits
312 were then converted to biomass (g m⁻²) using a biomass calibration-conversion. More
313 information: [https://catalogue.ceh.ac.uk/documents/5b39a644-d614-4f2b-8df6-](https://catalogue.ceh.ac.uk/documents/5b39a644-d614-4f2b-8df6-202ed440b4ab)
314 [202ed440b4ab](https://catalogue.ceh.ac.uk/documents/5b39a644-d614-4f2b-8df6-202ed440b4ab). Doi: [https://doi.org/10.5285/5b39a644-d614-4f2b-8df6-](https://doi.org/10.5285/5b39a644-d614-4f2b-8df6-202ed440b4ab)
315 [202ed440b4ab](https://doi.org/10.5285/5b39a644-d614-4f2b-8df6-202ed440b4ab).

316

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

322

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

325 32.62, and LON: -106.67). This dataset consists of 68 plots, where each plot was
326 sampled an average of 27.8 times. Density of individuals per species and per plot was
327 recorded. More information:

328 <https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.210351002.75>.

329

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

334

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

339

340 **31.** The data sourced from BioTIME (Dornelas et al. 2018), Study_ID 243 - Virginia
341 Coast Reserve Long-Term Ecological Research. The dataset is issued from an
342 experiment located in the coastal sand dunes of Hog island, Virginia, USA (LAT:
343 37.67, and LON: -75.67). This dataset consists of 28 plots, where each plot was
344 sampled an average of 18.9 times. Half of the plots received nitrogen fertilization each
345 year in the form of urea nitrogen (30% uncoated (46-0-0) and 70% (40-0-0) coated for
346 slow release). The fertilizer was applied evenly in a dry form (15 g/m² of nitrogen). In
347 each plot, species cover (%) was visually estimated in five 0.25 m² plots. More
348 information: Day et al. (2016).

349

350 **32.** The dataset is issued from an experiment located on a grassland near Napal, Spain
351 (LAT: 42.72, and LON: -1.22). This dataset consists of 12 plots, where each plot was
352 sampled an average of 12.0 times. The experimental area was fenced and shrubs were
353 removed. Six plots were fertilized (sewage sludge to the soil surface with 5000 g/m²)
354 and six plots were used as controls. All vascular plant species were measured annually
355 using frequencies. To do so, each plot was divided into 100 subplots, and the
356 presence/absence of each species was recorded. More information: Gazol et al.
357 (2016).

358

359 **33.** The data were sourced from BioTIME (Dornelas et al. 2018), Study_ID 491 -
360 ITEX Dataset 13 - Toolik (Dry, Moist). The dataset is issued from an experiment
361 located on tundra vegetation near Toolik, Alaska, USA (LAT: 68.62, and LON: -
362 149.61). This dataset consists of eight plots, where each plot was sampled an average
363 of 6.0 times. The plots are divided between dry tundra with control and warming
364 treatments and moist tundra with only control treatment. Biomass estimates were
365 obtained using a fixed 75 cm² point frame, with 100 measurements spaced 7 cm apart.
366

367 **34.** The data was sourced from BioTIME (Dornelas et al. 2018), Study_ID 492 -
368 ITEX Dataset 14 - Toolik (LTER Heath, LTER Moist acidic tussock, LTER non-
369 acidic tussock, LTER wet sedge, SAG wet sedge2, Tussock 1981 plots). The dataset
370 is issued from an experiment located in Toolik, Alaska, USA (LAT: 68.63, and LON:
371 -149.58). This dataset consists of four plots, where each plot was sampled an average
372 of 6.0 times. In each plot, species biomass was assessed by clipping of four or five
373 0.25 m x 0.25 m plots, and sorting to species level.
374

375 **35.** The dataset is issued from an experiment located on a grassland in Bayreuth,
376 Germany (LAT: 49.92, and LON: 11.59). This dataset consists of 15 plots, where
377 each plot was sampled an average of 7.7 times. Three treatments were applied: 1)
378 control (ambient condition), 2) winter warming (October–March), and 3) summer
379 warming (April–September). In each plot, species cover (%) was visually estimated
380 annually. More information: Grant et al. (2017).
381

382 **36.** The dataset is issued from an experiment located on a grassland in the Czech
383 Republic (LAT: 48.87, and LON: 16.64). This dataset consists of seven plots, where
384 each plot was sampled an average of 8.0 times. In each plot (1 m²), the species cover
385 (%) was visually estimated annually from 1993 to 2001. Dataset owner: Jiří Danihelka
386 (Department of Botany and Zoology, Masaryk University and Department of
387 Vegetation Ecology, Institute of Botany, The Czech Academy of Sciences).
388

389 **37.** The dataset is issued from an experiment located on a grassland in Laqueuille,
390 France (LAT: 45.64, and LON: 2.73). This dataset consists of 10 plots, where each
391 plot was sampled an average of 13.0 times. Half of the plots were located in an
392 intensively managed grassland (10-15 animals ha⁻¹ yr⁻¹ and 20 g/m² of nitrogen), and

393 the other half were located in a neighbouring grassland under extensive management
394 (5-8 animals ha⁻¹ yr⁻¹ and no fertilization). In each plot, presence/absence of each
395 species was recorded in 40 pin-points regularly spaced (pin-point methodology.
396 Dataset owner: Katja Klumpp (INRA, Grassland Ecosystem Research Unit).

397

398 **38.** The dataset is issued from an experiment located on Shortgrass Steppe (SGS-
399 LTER) in the Central Plains Experimental Range Nunn, Colorado, USA (LAT: 40.85,
400 and LON: -104.71). This dataset consists of 48 plots, where each plot was sampled an
401 average of 9.0 times. The experiment evaluated four treatments: control inside
402 enclosure, control outside enclosures, *Bouteloua gracilis* removal inside enclosure and
403 *Bouteloua gracilis* removal outside enclosure. Species density was measured in a
404 quadrat (1 m²) using vegetation point intercept method (40 points of contact was
405 recorded for each quadrat). More information:

406 <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.703.1>.

407

408 **39.** The dataset is issued from an experiment located on a wet meadow in Ohrazeni,
409 Czech Republic (LAT: 48.95, and LON: 14.59). This dataset consists of 12 plots,
410 where each plot was sampled an average of 16.0 times. The experiment evaluated four
411 treatments: control, mowing (annually in the second half of June), fertilization (65
412 g/m² of commercial NPK fertilizer) and dominant removal (*Molinia caerulea* plants
413 were manually removed annually). In each plot, the biomass of each species was
414 measured annually. More information: Lepš (2014).

415

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

427 visual estimation of their volume. Dataset owner: Frédérique Louault (INRA-UREP).
428 More information: Louault et al. (2017).

429

430 **41.** The dataset is issued from an experiment belonging to the Sevilleta LTER and
431 located on Chihuahuan desert in Sevilleta National Wildlife Refuge, New Mexico,
432 USA (LAT: 34.27, and LON: -106.68). This dataset consists of six plots, where each
433 plot was sampled an average of 14.3 times. More information:

434 <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.200.174699>.

435

436 **42.** The dataset is issued from an experiment located on hyper-oceanic coastal
437 grasslands in United Kingdom (LAT: 57.27, and LON: -7.40). This dataset consists of
438 48 plots, where each plot was sampled an average of 6.8 times. The experiment
439 evaluated six treatments: 1) vertebrate grazing exclusion, 2) burial box with no sand
440 added, 3) buried to 10 cm, 4) buried to 20 cm, 5) windbreak - shelter from prevailing
441 SW winds, 6) no treatment. The cover values (%) of all individual plant species were
442 estimated annually from 2004 to 2010. Data owners: Robin Pakeman (James Hutton
443 Institute, Aberdeen) and Jack J. Lennon (School of Biological Sciences, Queen's
444 University Belfast).

445

446 **43.** The dataset is issued from an experiment located on a grassland in Cleish and
447 Kirkton, United Kingdom (LAT: 56.29, and LON: -4.07). This dataset consists of 16
448 plots, where each plot was sampled an average of 6.0 times. The experiment evaluated
449 ungrazed and sheep-grazed plots to maintain three different levels of sward height. In
450 each plot, the inclined-point quadrat method (32.5° to the horizontal) at 20 locations
451 (with a minimum of 25 contacts per location) was used to measure each species. More
452 information: Hulme et al. (1999).

453

454 **44.** The dataset is issued from an experiment located on a grassland in Bell Hill and
455 Cleish, United Kingdom (LAT: 55.80, and LON: -2.84). This dataset consists of eight
456 plots, where each plot was sampled an average of 7.0 times. In each plot, the inclined-
457 point quadrat method (32.5° to the horizontal) at 20 locations (with a minimum of 25
458 contacts per location) was used to measure each species. More information: Grant et
459 al. (1996a).

460

461 **45.** The dataset is issued from an experiment located on a grassland in Cleish and
462 Sourhope, United Kingdom (LAT: 55.81, and LON: -2.86). This dataset consists of
463 seven plots, where each plot was sampled an average of 6.0 times. There were
464 different treatments where cattle or sheep density was adjusted twice a week to
465 maintain the vegetation height between tussocks. In each plot, the inclined-point
466 quadrat method (32.5° to the horizontal) at 20 locations (with a minimum of 25
467 contacts per location) was used to measure each species. More information: Grant et
468 al. (1996) and Common et al. (1998).

469

470 **46.** The dataset is issued from an experiment located on a moorland previously on the
471 Burnhead heft at the Redesdale Experimental Farm in Northumberland, United
472 Kingdom (LAT: 55.37, and LON: -2.45). This dataset consists of 12 plots, where each
473 plot was sampled an average of 6.0 times. The 12 plots were divided in three areas
474 with different grazing treatments: ungrazed, sheep-grazed (three levels: 0.4, 0.8 and
475 $1.2 \text{ ha}^{-1} \text{ yr}^{-1}$). In each plot, the inclined-point quadrat method (32.5° to the horizontal)
476 at 20 locations (with a minimum of 25 contacts per location) was used to measure
477 each species. More information: Pakeman & Nolan (2009).

478

479 **47.** The dataset is issued from an experiment located on a heather moorland at
480 Dundonnell near Ullapool and at Claonaig, near Tarbert Loch Fyne, Argyll and Bute,
481 United Kingdom (LAT: 57.35, and LON: -5.55). This dataset consists of 17 plots,
482 where each plot was sampled an average of 6.0 times. The experiment had different
483 sheep grazing and exclusion treatments: 1) low at $0.4 \text{ sheep ha}^{-1} \text{ yr}^{-1}$, 2) moderate at
484 $0.8 \text{ sheep ha}^{-1} \text{ yr}^{-1}$, 3) high at $1.2 \text{ sheep ha}^{-1} \text{ yr}^{-1}$, 4) fenced against both cattle and
485 sheep, and 5) fenced against cattle, also 6) sheep and cattle recorded from the open
486 hill. In each plot, the inclined-point quadrat method (32.5° to the horizontal) at 20
487 locations was used to measure each species. More information: Pakeman & Nolan
488 (2009).

489

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

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

497

498 **49.** The dataset is issued from an experiment located in Soto de Viñuelas, Spain
499 (LAT: 40.60, and LON: -3.63). This dataset consists of 68 plots, where each plot was
500 sampled an average of 11.5 times. In each plot, all plant species was recorded using
501 presence/absence data in five quadrats of 400 cm² each from 1980 to 1995. Dataset
502 owner: Begoña Peco (Ecology Department Autonomous, University of Madrid).

503

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

511

512 **51.** The dataset is issued from an experiment belong to the Jornada LTER (JRN-
513 LTER) and located in Chihuahuan desert, Jornada Basin Experimental Range, New
514 Mexico, USA (LAT: 32.00, and LON: -106.00). This dataset consists of 734 plots,
515 where each plot was sampled an average of 24.0 times. In each plot, the biomass of
516 each species was calculated from field measurement of individual species cover and
517 height. More information:

518 <https://portal.lternet.edu/nis/metadataviewer?packageid=knb-lter-jrn.2100011001.49>.

519

520 **52.** The dataset is issued from an experiment located on a moorland on the Burnhead
521 heft at the Redesdale Experimental Farm in Northumberland, United Kingdom (LAT:
522 55.37, and LON: -2.45). This dataset consists of 10 plots, where each plot was
523 sampled an average of 6.0 times. The experiment had different grazing treatments:
524 summer grazing, winter grazing or year-round grazing (0.7 sheep ha⁻¹ yr⁻¹), year-
525 round grazing (1.4 sheep ha⁻¹ yr⁻¹), and no grazing. In each plot, the inclined-point
526 quadrat method (32.5° to the horizontal) at 20 locations (with a minimum of 25

527 contacts per location) was used to measure each species. More information: Hulme et
528 al. (2002) and Pakeman & Nolan (2009).

529

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

542

543 **54.** The dataset is issued from an experiment belonging to the Environmental Change
544 Network (ECN) and located in the United Kingdom (LAT: 53.95, and LON: -3.23).
545 This dataset consists of 198 plots, where each plot was sampled an average of 11.1
546 times. In each plot (ten quadrats of 0.16 m²), the inclined-point quadrat method was
547 used to evaluate the vegetation annually. More information: Rennie et al. (2016) and
548 <https://catalogue.ceh.ac.uk/documents/b98efec8-6de0-4e0c-85dc-fe4cdf01f086> and
549 <https://catalogue.ceh.ac.uk/documents/d349babc-329a-4d6e-9eca-92e630e1be3f>.

550

551 **55.** The dataset is issued from an experiment belonging to the Andrews Forest LTER
552 (AND-LTER) and located in a forest in the Oregon Cascade Range, USA (LAT:
553 44.22, and LON: -122.25). This dataset consists of 5 plots, where each plot was
554 sampled an average of 10.0 times. The vegetation cover (%) was visually estimated 10
555 times in a quadrat of 4 m² for trees (vegetation > 60 cm tall) and 9 quadrats (0.1 m²)
556 for herb and low shrub (< 60 cm tall). More information: Rothacher (Rothacher 2013)
557 and <https://portal.lter.net.edu/nis/mapbrowse?packageid=knb-lter-and.3190.7>.

558

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

561 0.37). This dataset consists of 74 plots, where each plot was sampled an average of
562 9.9 times. The purpose of the experiment was to evaluate different fertility and lime
563 treatments. Herbage was taken from six randomly located quadrats measuring 0.5 m x
564 0.25 m within each plot, resulting in a total sampling area of 0.75 m² within each plot.
565 In each plot, the biomass of each species was measured annually in quadrats
566 (sampling area: 0.75 m²). More information: Crawley et al. (2005) and
567 <http://www.era.rothamsted.ac.uk/Park>.

568

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

576

577 **58.** The dataset is issued from an experiment located in Central Germany (LAT:
578 51.55, and LON: 10.07). This dataset consists of 14 plots, where each plot was
579 sampled an average of 14.9 times. In each plot, species vegetation cover (%) was
580 visually estimated. More information: Schmidt (2007).

581

582 **59.** The dataset is issued from an experiment located on a former arable field in the
583 Experimental Botanical Garden of the University of Göttingen, Germany (LAT:
584 51.56, and LON: 9.96). This dataset consists of six plots, where each plot was
585 sampled an average of 38.0 times. In each plot, species vegetation cover (%) was
586 visually estimated. More information: Schmidt (Schmidt 2006) and Bernhardt-
587 Römermann et al. (2011).

588

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

594

595 **61.** The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-
596 LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT:
597 34.31, and LON: -106.49). This dataset consists of 95 plots, where each plot was
598 sampled an average of 9.8 times. The experiment was designed to evaluate the effect
599 of prescribed burning (two areas were left unburned as control treatments, and the
600 other plots were burned in different dates) and grazing exclusion (fenced and
601 unfenced). In each plot, the individuals present in 36 quadrats (0.1 m²) were recorded.
602 More information: <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.148.131885>.

604

605 **62.** The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-
606 LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT:
607 34.33, and LON: -106.74). This dataset consists of 81 plots, where each plot was
608 sampled an average of 9.2 times. The experiment had three treatments: 1) control
609 plots (natural rainfall regime) 2) drought was induced by rainfall shelters, and 3)
610 watering was applied by redirecting the water from the nearby rainfall shelters. In
611 each plot, the plant cover (%) was estimated every spring. More information:
612 <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.147.167839>.

613

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

621

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

628

629 **65.** The dataset is issued from an experiment belonging to the Sevilleta LTER (SEV-
630 LTER) and located in Sevilleta National Wildlife Refuge, New Mexico, USA (LAT:
631 34.37, and LON: -106.58). This dataset consists of 100 plots, where each plot was
632 sampled an average of 16.4 times. The experiment evaluated three treatments: 1)
633 control plots (untouched vegetation), 2) removal of all three dominant species (*Larrea*
634 *tridentata*, *Bouteloua eriopoda*, *Bouteloua gracilis*), and 3) removal of one dominant
635 species. In each plot, the plant cover (%) was visually estimated annually. More
636 information: [https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-](https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.168.192543)
637 [sev.168.192543](https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sev.168.192543).
638

639 **66.** The dataset is issued from an experiment belonging to the Shortgrass Steppe
640 LTER (SGS-LTER) and located on grasslands and shrublands in Central Plains
641 Experimental Range, Colorado, USA (LAT: 40.85, and LON: -104.77). This dataset
642 consists of 18 plots, where each plot was sampled an average of 8.2 times. In each
643 plot, the plant cover was recorded on three permanent transects (1 m²: sum of plots
644 along the transect). More information: Stapp (Stapp 2013) and
645 <https://portal.lternet.edu/nis/mapbrowse?packageid=knb-lter-sgs.140.17>.
646

647 **67.** The dataset is issued from an experiment located in a beech forest near Göttingen,
648 Central Germany (LAT: 51.57, and LON: 10.32). This dataset consists of seven plots,
649 where each plot was sampled an average of 18.0 times. Four plots had a fertilization
650 treatment (NP addition) and three were the control plots. In each plot, the species
651 cover (%) was visually estimated. More information: Schmidt (2009).
652

653 **68.** The dataset is issued from an experiment located on a meadow near Zvíkov,
654 Czech Republic (LAT: 48.99, and LON: 14.61). This dataset consists of 40 plots,
655 where each plot was sampled an average of 10.3 times. The experiment evaluated four
656 treatments: 1) control (intact vegetation), 2) mycorrhizal grasses and forbs left, non-
657 mycorrhizal species weeded out, 3) mycorrhizal forbs remaining, everything else
658 weeded out, and 4) mycorrhizal grasses remaining, everything else weeded out. In
659 each plot, the species cover (%) was visually estimated annually. More information:
660 Šmilauer & Šmilauerová (2013).
661

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

668

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

675

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

685

686 **72.** The dataset is issued from an experiment located on a wooded savanna in
687 Laikipia, Kenya (LAT: 0.28, and LON: 36.87). This dataset consists of 18 plots,
688 where each plot was sampled an average of 14.7 times. The treatments were six
689 combinations (3 replicates) of cattle, wildlife, and mega-herbivore grazing. These
690 either allowed (1) the entry of all large mammalian herbivores, (2) all large
691 mammalian herbivores except mega-herbivores (elephants *Loxodonta africana* and
692 giraffe *Giraffa camelopardis*) to enter, or (3) excluded all large herbivores. In each
693 plot, vegetation was assessed annually by counting the number of pins hit by each
694 species over a ten-point pin frame at each station. More information: Veblen et al.
695 (2016).

696

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

702

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

708

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

715

716 **76.** The dataset is issued from an experiment located on a floodplain grassland on
717 formerly arable land (LAT: 51.78, and LON: -1.31). From 1989 the site was divided
718 into nine plots of c. 0.4 ha over which three contrasting grazing management practices
719 (control, cattle and sheep) were randomly superimposed. These nine plots were
720 monitored in June of each year from 1991-2009. More information: Woodcock et al.
721 (2011).

722

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

728

729 **Figure Table S2.** Characteristics of the study sites.
730

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

731

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

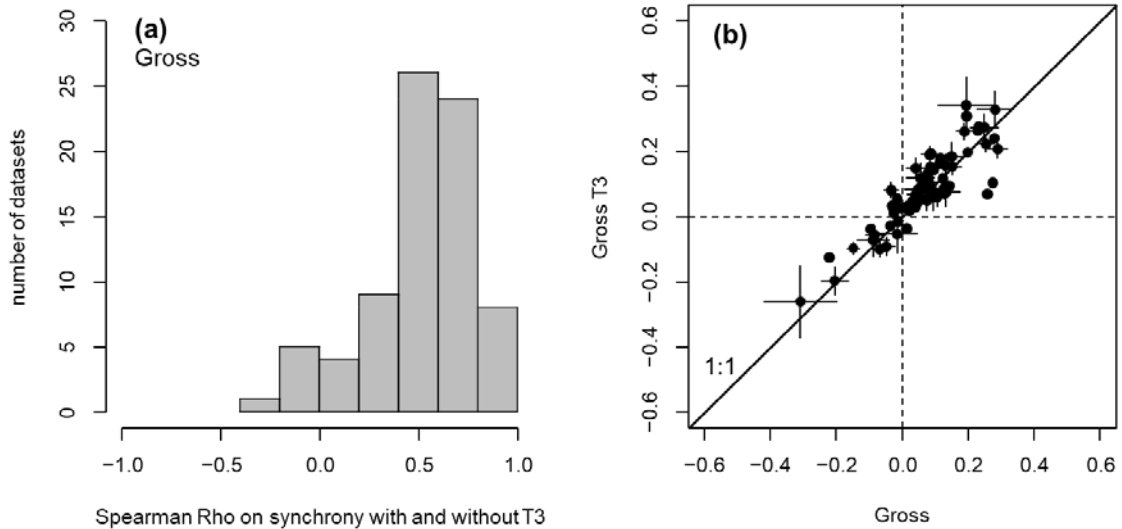
738 Supporting Information to the paper
739 Valencia et al. Directional trends in species composition over time can lead to a
740 widespread overestimation of asynchrony. *Journal of Vegetation Science*.

741
742 **Appendix S3.** Application of the analyses shown in Fig. 1 of the main text to the
743 three remaining indices of synchrony.

744
745 **Gross**

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

748

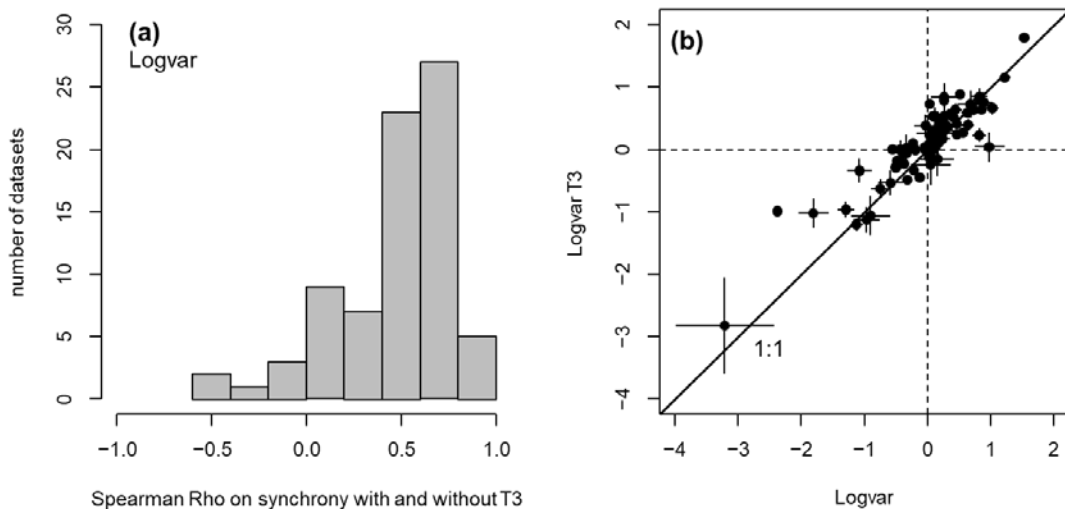


749
750

751 **Logvar**

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

754

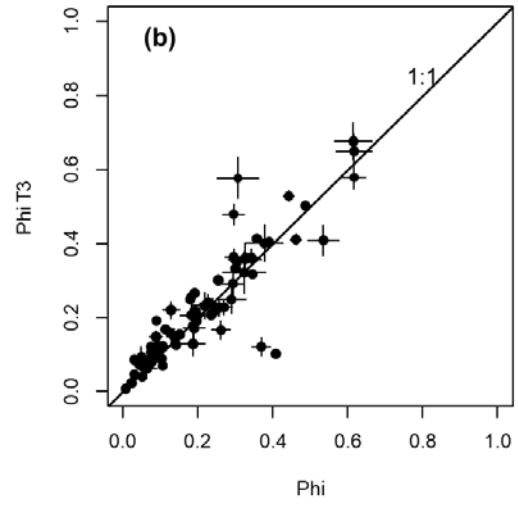
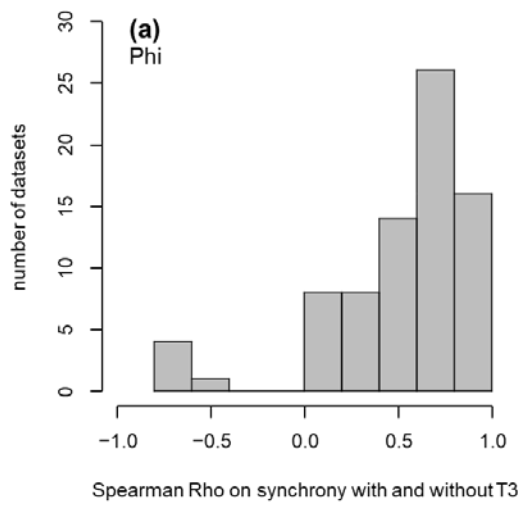


755
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758
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760
761

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)

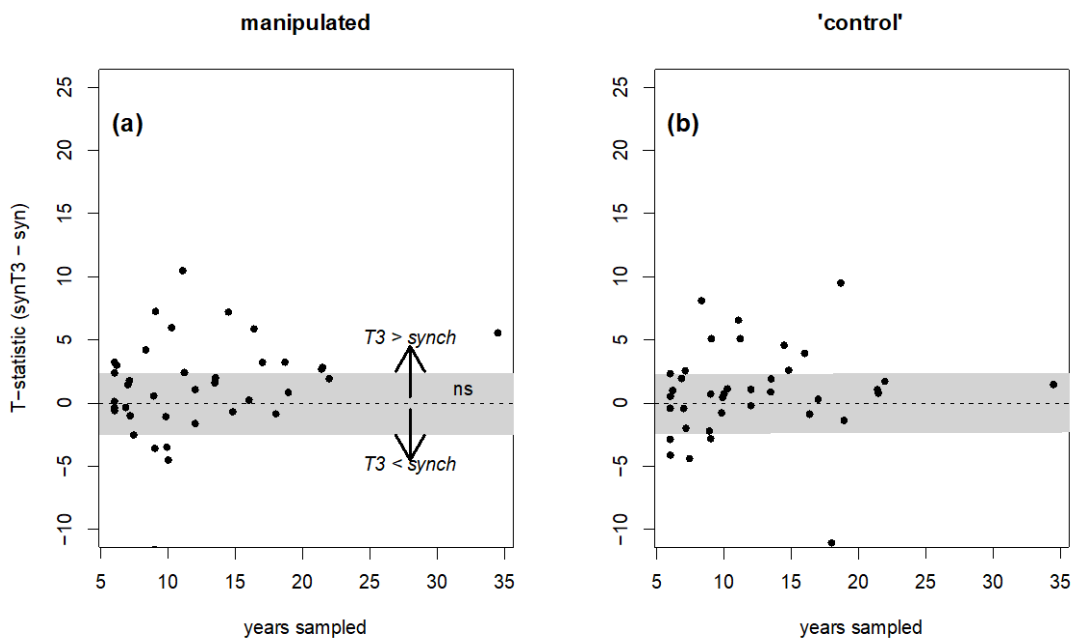


762

763 Supporting Information to the paper
 764 Valencia et al. Directional trends in species composition over time can lead to a
 765 widespread overestimation of asynchrony. *Journal of Vegetation Science*.
 766

767 **Appendix S4.** Application of the analyses shown in Fig. 3 of the main text to the
 768 three remaining indices of synchrony. For each index, also, a table of number of
 769 datasets with either positive or negative significant t-statistic values is reported for
 770 both manipulated and control plots (positive means that the T3 approach increased
 771 synchrony; negative means that the T3 approach decreased synchrony). The grey area
 772 in each panel reports and approximate are where t-statistic values were not significant
 773 ('ns').
 774

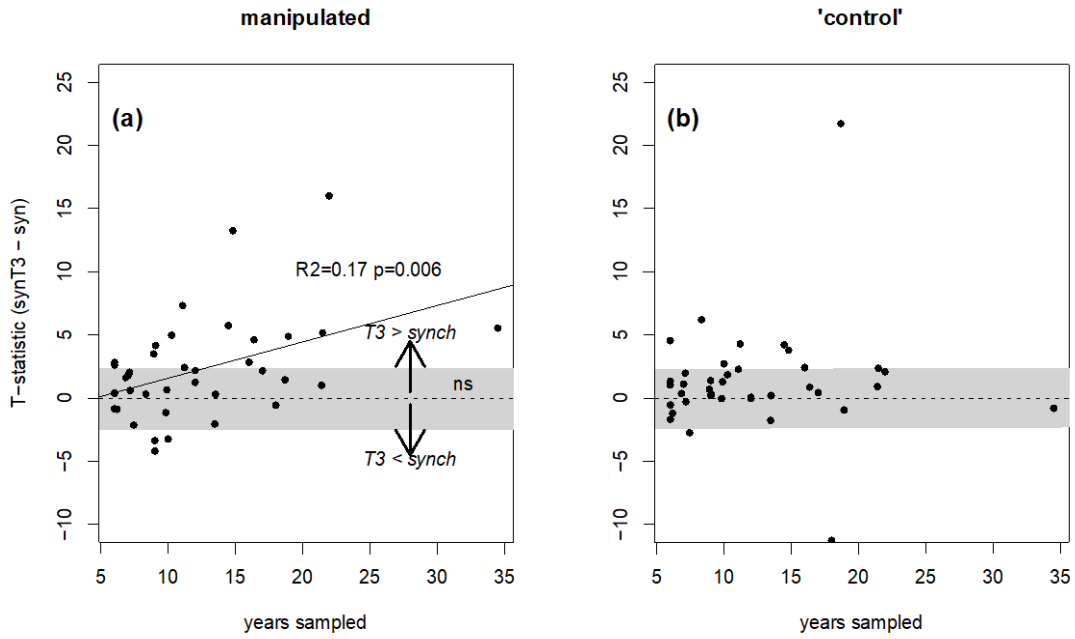
775 **Gross**



776
 777
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 782
 783

Manipulated		Control	
-	+	-	+
5	13	2	9

784 **Logvar**
785

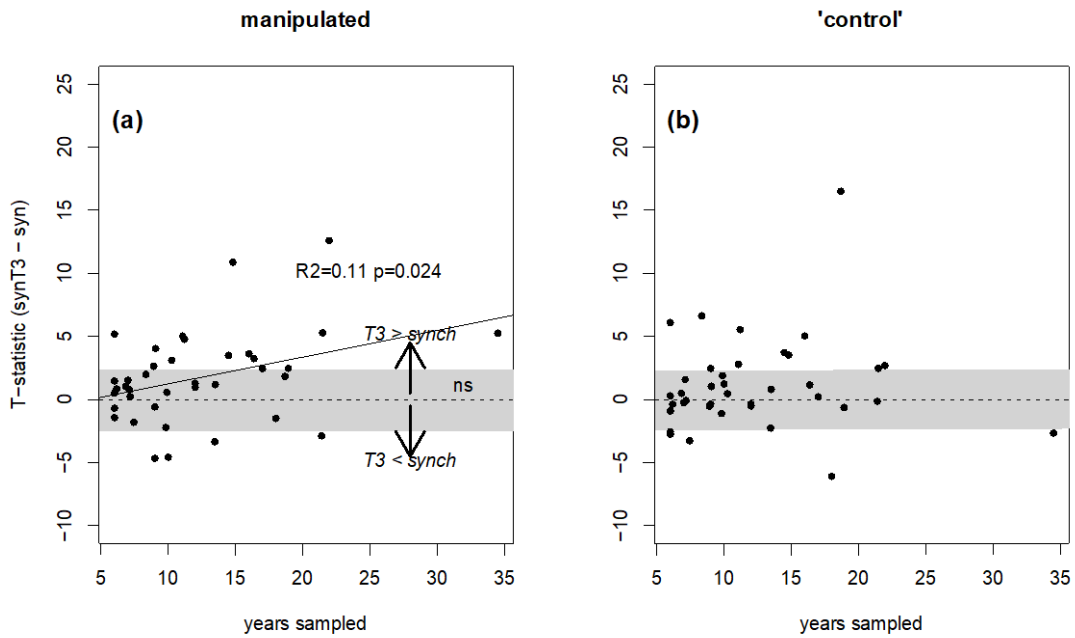


786

Manipulated		Control	
-	+	-	+
4	13	2	7

787
788
789

Phi



790
791

Manipulated		Control	
-	+	-	+
5	14	3	8

792

793 Supporting Information to the paper

794 Valencia et al. Directional trends in species composition over time can lead to a

795 widespread overestimation of asynchrony. *Journal of Vegetation Science*.

796

797

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

803

804

Gross

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

805

806

Logvar

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

807

808

Phi

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

809

810 **References and Notes**

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