

Biotic stability mechanisms in Inner Mongolian grassland

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Proceedings of the Royal Society B: Biological Sciences, 2020, [dio:10.1098/rspb.2020.0675](https://doi.org/10.1098/rspb.2020.0675)

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Appendix 1

Mathematical derivation

1.1 Relating the community temporal coefficient of variation to the species synchrony and the weighted average species temporal coefficient of variation

In this part, we briefly introduce the mathematical derivation for relating the community temporal coefficient of variation (abbreviated as CV, inverse of temporal stability) to the species synchrony and the weighted average species temporal CV used in the current study and refer readers to papers of Loreau and de Mazancourt [1] and Thibaut and Connolly [2] for further details. We used the superscript C and S to designate the community-level and the species-level quantities. Following previous theoretical works [2–4], we consider a community which includes n species and reached a stationary state. Thus, this community can be described with a vector of temporal mean species abundances with elements $u^S(i)$, i.e. the temporal mean abundance of species i , and a temporal variance–covariance matrix of species abundances with elements $v^S(i, j) = cov(u^S(i), u^S(j))$, i.e. the covariance between temporal abundances of species i and j . We next define the temporal mean of the community abundance (u^C) and the temporal variance of total community abundance (v^C) as follows:

$$u^C = \sum_i u^S(i) \quad (\text{eqn. S1a})$$

$$v^C = \sum_{i,j} v^S(i, j) \quad (\text{eqn. S1b})$$

Thus, the community temporal CV can be described as follows:

$$(CV^C)^2 = \frac{v^C}{(u^C)^2} = \frac{\sum_{i,j} v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} \left(\sum_i \frac{u^S(i)}{u^C} \frac{\sqrt{v^S(i,i)}}{u^S(i)} \right)^2 \quad (\text{eqn. S2})$$

Referenced to more recent theoretical works, two terms on the far right-hand side of eqn. S2 were defined as the species synchrony and the weighted average species temporal CV [1,2], which have the following descriptions:

$$\varphi = \frac{\sum_{i,j} v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} \quad (\text{eqn. S3})$$

$$(\widetilde{CV}^S)^2 = \left(\sum_i \frac{u^S(i)}{u^C} \frac{\sqrt{v^S(i,i)}}{u^S(i)} \right)^2 = \left(\sum_i \frac{u^S(i)}{u^C} CV^S(i) \right)^2 \quad (\text{eqn. S4})$$

Thus, the community temporal CV can also be described as follows:

$$(CV^C)^2 = \varphi (\widetilde{CV}^S)^2 \quad (\text{eqn. S5})$$

1.2 Relating the weighted average species temporal coefficient of variation to the mean–variance scaling effect and the overyielding effect

Here, we briefly review the derivations for relating the weighted average species temporal CV to the mean–variance scaling effect and the overyielding effect and refer readers to theoretical work of Thibaut and Connolly [2] for further details. These derivations base on two assumptions. The first assumption is that species temporal variances scale with their temporal means according to the Taylor’s power law [5], which represents the mean–variance scaling effect and can be described as the following:

$$v^S(i, i) = a (u^S(i))^z \quad (\text{eqn. S6})$$

Here, a and z are parameters relating variance to mean abundance of species i . The second assumption is that species and community mean may vary as a function of species richness,

which represent the overyielding effect and can be modeled with the following description [2,3]:

$$u^C = \sum_i u^S(i) = \sum_i \frac{u_1^S(i)}{n^x} \quad (\text{eqn. S7})$$

Here, $u_1^S(i)$ is the abundance of the i th species in monoculture, n is the total species in the community, and x describes how the total community abundance changes with the species richness. If $0 < x < 1$, the total community abundance increases with increasing species richness, resulting in the overyielding effect. If $x > 1$, the total community abundance decreases with the increasing species richness (underyielding) [2,3].

We substitute the right-hand sides of eqn. S6 and eqn. S7 for $v^S(i, i)$ and u^C in eqn. S4.

Then, we have the following descriptions and derivations:

$$\widetilde{CV}^S = \frac{\sum_i \sqrt{v^S(i, i)}}{\sum_i u^S(i)} = \frac{\sum_i \sqrt{a (u_1^S(i))^z}}{\sum_i u^S(i)} = \frac{\sum_i \sqrt{a \left(\frac{u_1^S(i)}{n^x}\right)^z}}{\sum_i \frac{u_1^S(i)}{n^x}} = \frac{\sqrt{\left(\frac{1}{n^x}\right)^z} \sum_i \sqrt{a (u_1^S(i))^z}}{\frac{1}{n^x} \sum_i u_1^S(i)} \quad (\text{eqn. S8})$$

For the far right-hand side of eqn. S8, we simplify its left fraction and derive its right fraction to have the following descriptions:

$$\widetilde{CV}^S = \frac{n^{-xz}}{n^{-x}} \sum_i \frac{u_1^S(i)}{\sum_i u_1^S(i)} \frac{\sqrt{a (u_1^S(i))^z}}{u_1^S(i)} = \sqrt{n^{(2-z)x}} \sum_i \frac{u_1^S(i)}{\sum_i u_1^S(i)} \frac{\sqrt{v_1^S(i, i)}}{u_1^S(i)} = \sqrt{n^{(2-z)x}} \widetilde{CV}_1^S \quad (\text{eqn. S9})$$

Then, we substitute the right-hand side of the eqn. S9 into eqn. S5 to obtain the following equation:

$$(CV^C)^2 = \varphi \left(\sqrt{n^{(2-z)x}} \widetilde{CV}_1^S \right)^2 \quad (\text{eqn. S10})$$

Eqn. S9 and S10 suggest that the mean–variance scaling effect and the overyielding effect can interactively influence the dependences of the weighted average species temporal CV and the community temporal CV on the species richness. These two equations also

suggest that the effect of species richness on the weighted average species temporal CV will be eliminated if the z is close to 2.

1.3 Partitioning the species synchrony into different abundances species groups

Eqn. S2 (eqn. 1a of the main text) showed that the vc can be described with the covariance between species i and j , which facilitates estimations of the effects of different abundance groups on species synchrony. Here, we introduce three vectors, ds , cs and rs , to represent the dominant species, common species and rare species of the community, respectively. We used ds as example to explain these vectors. The length of ds is same to the species number of the community (n) and has elements $ds(i)$, i.e. the i th species of the community. The $ds(i)$ was set to 1 if the i th species of the community is a dominant species, otherwise, it was set to 0. Similar procedures were used to conduct the cs and rs , in which common species and rare species were set to 1, respectively, otherwise they were set to 0.

With these vectors, the species synchrony (eqn. S3) can be described as follows:

$$\begin{aligned} \varphi = & \frac{\sum_{i,j} d^S(i)d^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} + \frac{\sum_{i,j} d^S(i)c^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} + \frac{\sum_{i,j} d^S(i)r^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} \\ & + \frac{\sum_{i,j} c^S(i)c^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} + \frac{\sum_{i,j} c^S(i)r^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} + \frac{\sum_{i,j} r^S(i)r^S(j)v^S(i,j)}{(\sum_i \sqrt{v^S(i,i)})^2} \end{aligned} \quad (\text{eqn. S11a})$$

Using φ_{dd} , φ_{dc} , φ_{dr} , φ_{cc} , φ_{cr} and φ_{rr} to represent the six components on the right-hand side of the eqn. S11a, this equation can be described as follows:

$$\varphi = \varphi_{dd} + \varphi_{dc} + \varphi_{dr} + \varphi_{cc} + \varphi_{cr} + \varphi_{rr} \quad (\text{eqn. S11b})$$

Considering that these six components have the same denominator, we use the numerator to explain them. For example, the first term, $\sum_{i,j} d^S(i)d^S(j)v^S(i,j)$, will only

contribute the species synchrony if both species i and j are dominant species. Thus, this term represents the contributions of the dynamics between dominant species to the community-wide species synchrony. Similar explanations can also be used for the other components. For the following five terms, they represent the contributions of the dynamics between dominant species and common species, between dominant species and rare species, between common species, between common and rare species and between rare species to the community-wide species synchrony.

1.4 Partitioning the weighted averaged species temporal coefficient of variation into different abundances species groups

Using the vectors, ds , cs and rs , mentioned previously, we can rewrite the eqn. S4 as follows:

$$\widetilde{CV}^S = \sum_i d^S(i) \frac{u^S(i)}{u^C} \frac{\sqrt{v^S(i,i)}}{u^S(i)} + \sum_i c^S(i) \frac{u^S(i)}{u^C} \frac{\sqrt{v^S(i,i)}}{u^S(i)} + \sum_i r^S(i) \frac{u^S(i)}{u^C} \frac{\sqrt{v^S(i,i)}}{u^S(i)} \quad (\text{eqn. S12a})$$

Here, we use \widetilde{CV}_d^S , \widetilde{CV}_c^S and \widetilde{CV}_r^S to represent the three components on the right-hand side of the eqn. S12a, and thus, this equation can be rewritten as follows:

$$\widetilde{CV}^S = \widetilde{CV}_d^S + \widetilde{CV}_c^S + \widetilde{CV}_r^S \quad (\text{eqn. S12b})$$

For the first term on the right-hand side of the eqn. S12, the non-zero elements are composed of only temporal CV of dominant species. Thus, it represents the contribution of the dominant species group to the weighted average species temporal CV of the community. For the following two terms, they represent contributions of the common and rare species groups to the weighted average species temporal CV of the community.

Appendix 2

Statistical analyses for constructing the initial Structure Equation Model

Based on a-priori hypotheses, the exploration of the correlation matrix of directly measured and derived variables and results of multiple linear regressions, we constructed Structure Equation Models (SEMs). We deliberately stayed as close as possible to a-priori hypotheses about causal relationships and fitted models even if they included non-significant relationships but reflected pathways proposed to be essential biotic stability mechanisms (for example see models presented in Thibaut & Connolly [2] and Hallett et al. [6]). Model-fit statistics such as Chi-square tests or goodness-of-fit index (GFI), which compare the deviation of a current SEM to a full SEM without residual degrees of freedom, were only used as an additional guide to avoid searching for a best model post hoc. Symbols and their descriptions can be found in the following box (Box 1).

Box 1: Notations summary	
Symbol	Description
MGP	Mean growing-season precipitation
CV_{MGP}	Temporal coefficient of variation (CV) of annual precipitation
n	Species richness
n_d	Dominant species richness
D	Effective species richness
D_d	Dominant effective species richness
z	Mean-variance scaling power
\widetilde{CV}^S	Weighted average species temporal CV
\widetilde{CV}_d^S	Weighted average dominant species temporal CV
φ	Species synchrony
φ_{dd}	Dominant species synchrony
CV_C	Community temporal CV

The following statistical analyses were used to relate the community temporal CV to biotic stability mechanisms, climatic factors and species diversity indices. Based on the results shown in the correlation matrix and simple linear regressions, we investigated the effects of multiple explanatory variables reflecting biotic stability mechanisms on community temporal CV (CV_C) with two general linear models. Model 2.1.1 showed that growing-season precipitation (MGP), mean-variance scaling power (z), weighted average species temporal CV (\widetilde{CV}^S) and species synchrony (φ), fitted in this sequence, all significantly affected the community temporal CV (CV_C). All these variables were also part of the initial a-priori SEM model (Table S3, Figure S6). In model 2.1.2, the growing-season precipitation (MGP) and the mean-variance scaling power (z) were fitted after the weighted average species temporal CV (\widetilde{CV}^S) and the species synchrony (φ), which explained their effects such that they lost significance. In terms of path analysis this means that the growing-season precipitation (MGP) and the mean-variance scaling power (z) affected the community temporal CV (CV_C) indirectly via the weighted average species temporal CV (\widetilde{CV}^S) and species synchrony (φ), which in turn had direct effects on the community temporal CV.

Model 2.1.1: $CV_C \sim MGP + z + \widetilde{CV}^S + \varphi$

Analysis of variance table for Model 2.1.1:					
	Df	Sum Sq	Mean Sq	F-value	P-value
MGP	1	0.1248	0.1248	39.2071	< 0.001 ***
z	1	0.1475	0.1475	46.3239	< 0.001 ***
\widetilde{CV}^S	1	0.0286	0.0286	8.9845	0.008 **
φ	1	0.1338	0.1338	42.0269	< 0.001 ***
<i>Residuals</i>	18	0.0573	0.0032		
Significance level: '***' $P < 0.001$, '**' $P < 0.01$					

Model 2.1.2: $CV_C \sim \widetilde{CV}^S + \varphi + MGP + z$

Analysis of variance table for Model 2.1.2:					
	Df	Sum Sq	Mean Sq	F-value	P-value
\widetilde{CV}^S	1	0.2440	0.2440	76.6494	< 0.001 ***
φ	1	0.1851	0.1851	58.1417	< 0.001 ***
<i>MGP</i>	1	0.0040	0.0040	1.2449	0.279
<i>z</i>	1	0.0016	0.0016	0.5064	0.486
<i>Residuals</i>	18	0.0573	0.0032		
Significance level: '***' $P < 0.001$					

We then explored explanatory variables predicted to affect the weighted average species temporal CV (\widetilde{CV}^S) (Model 2.1.3 and Model 2.1.4). Biodiversity has been proposed as one such explanatory variable (see e.g. Thibaut & Connolly [2]) and we therefore included it as either the species richness (n) or the effective species richness (D). We also included the growing-season precipitation (*MGP*) as it can be expected to positively affect the species richness (n) or the effective species richness (D) (see e.g. studies of Ma et al. [7] and Hallett et al. [6] and Table 1). Comparing model 2.1.3 with model 2.1.4, we found that the effective species richness (D) had stronger explanatory power than the species richness (n). Thus, we only used the effective species richness (D) as biodiversity measure in SEMs. Furthermore, we found that changing the fitted sequence of growing-season precipitation (*MGP*), effective species richness (D) and mean-variance scaling power (z) (Model 2.1.4 and Model 2.1.5) results in a non-significant effect of effective species richness (D) on the weighted average species temporal CV (\widetilde{CV}^S), suggesting that the effective species richness (D) is less important than growing-season precipitation (*MGP*) and mean-variance scaling power (z) in affecting the weighted average species temporal CV (\widetilde{CV}^S).

Model 2.1.3: $\widetilde{CV}^S \sim MGP + n + z$

Analysis of variance table for Model 2.1.3:					
	Df	Sum Sq	Mean Sq	F-value	P-value
<i>MGP</i>	1	0.1003	0.1003	6.4786	0.02 *
<i>n</i>	1	0.1798	0.1798	11.6164	0.003 **
<i>z</i>	1	0.3089	0.3089	19.9628	< 0.001 ***
<i>Residuals</i>	19	0.2940	0.0155		
Significant level: '***' $P < 0.001$, '**' $P < 0.01$, '*' $P < 0.05$					

Model 2.1.4: $\widetilde{CV}^S \sim MGP + D + z$

Analysis of variance table for Model 2.1.4:					
	Df	Sum Sq	Mean Sq	F-value	P-value
<i>MGP</i>	1	0.1003	0.1003	7.4247	0.013 *
<i>D</i>	1	0.2147	0.2147	15.9015	< 0.001 ***
<i>z</i>	1	0.3115	0.3115	23.0645	< 0.001 ***
<i>Residuals</i>	19	0.2566	0.0135		
Significant level: '***' $P < 0.001$, '*' $P < 0.05$					

Model 2.1.5: $\widetilde{CV}^S \sim z + D + MGP$

Analysis of variance table for Model 2.1.5:					
	Df	Sum Sq	Mean Sq	F-value	P-value
<i>z</i>	1	0.4732	0.4732	35.0414	< 0.001 ***
<i>D</i>	1	0.0165	0.0165	1.2179	0.2835
<i>MGP</i>	1	0.1368	0.1368	10.1314	0.005 **
<i>Residuals</i>	19	0.2566	0.0135		
Significant level: '***' $P < 0.001$, '**' $P < 0.01$					

Furthermore, we investigated explanatory variables predicted to affect φ . Besides biodiversity (effective species richness, D and species richness, n) we expected a positive influence of the interannual variation in precipitation (CV_{MGP}) on the species synchrony (φ). We found that species synchrony was significantly affected by effective species richness (D) (Model 2.1.7), but independent of the species richness (n) (Model 2.1.6). In addition, we founded that changing the fitted sequence of interannual variation in precipitation (CV_{MGP})

and effective species richness (D) (Model 2.1.7 and Model 2.1.8) had no effects on their significances in influencing the species synchrony (φ). Therefore, we used the interannual variation in precipitation (CV_{MGP}) and the effective species richness (D) in SEMs.

Model 2.1.6: $\varphi \sim CV_{MGP} + n$

Analysis of variance table for Model 2.1.6:					
	Df	Sum Sq	Mean Sq	F-value	P-value
CV_{MGP}	1	0.1668	0.1668	10.1484	0.005 **
n	1	0.0186	0.0186	1.1334	0.300
<i>Residuals</i>	20	0.3287	0.0164		
Significant level: '**' $P < 0.01$					

Model 2.1.7: $\varphi \sim CV_{MGP} + D$

Analysis of variance table for Model 2.1.7:					
	Df	Sum Sq	Mean Sq	F-value	P-value
CV_{MGP}	1	0.1668	0.1668	14.3938	0.001 **
D	1	0.1156	0.1156	9.9742	0.005 **
<i>Residuals</i>	20	0.2317	0.0116		
Significant level: '**' $P < 0.01$					

Model 2.1.8: $\varphi \sim D + CV_{MGP}$

Analysis of variance table for Model 2.1.8:					
	Df	Sum Sq	Mean Sq	F-value	P-value
D	1	0.1234	0.1234	10.6540	0.004 **
CV_{MGP}	1	0.1589	0.1589	13.7140	0.001 **
<i>Residuals</i>	20	0.2317	0.0116		
Significant level: '**' $P < 0.01$					

Owing to the interannual variation in precipitation (CV_{MGP}) and the effective species richness (D) have not been included in Model 2.1.1 and Model 2.1.2, we furtherly examined whether they only have indirect effects on the community temporal CV (CV_C) via the species

synchrony (φ) with Model 2.1.9–2.1.11. These three models showed non-significant effects of the interannual variation in precipitation (CV_{MGP}) and the effective species richness (D) and significant effect of the species synchrony on the community temporal CV (CV_C) no matter with the fitted sequence. In addition, our correlation (Figure 1) and regression (Figure 2) analyses also showed that the interannual variation in precipitation (CV_{MGP}) and the effective species richness (D) had non-significant effects on the community temporal CV (CV_C) but significant effects on the species synchrony (φ), suggesting their indirect effects on the community temporal CV (CV_C) via the species synchrony (φ).

Model 2.1.9: $CV_C \sim \varphi + CV_{MGP} + D$

Analysis of variance table for Model 2.1.9:					
	Df	Sum Sq	Mean Sq	F-value	P-value
φ	1	0.1449	0.1449	8.230	0.010 **
CV_{MGP}	1	0.0055	0.0055	0.311	0.583
D	1	0.0070	0.0070	0.397	0.536
<i>Residuals</i>	19	0.3346	0.0176		
Significant level: ‘**’ $P < 0.01$					

Model 2.1.10: $CV_C \sim CV_{MGP} + D + \varphi$

Analysis of variance table for Model 2.1.10:					
	Df	Sum Sq	Mean Sq	F-value	P-value
CV_{MGP}	1	0.0243	0.0243	1.382	0.025
D	1	0.0187	0.0187	1.059	0.316
φ	1	0.1144	0.1144	6.497	0.020 *
<i>Residuals</i>	19	0.3346	0.0176		
Significant level: ‘*’ $P < 0.05$					

Model 2.1.11: $CV_C \sim D + CV_{MGP} + \varphi$

Analysis of variance table for Model 2.1.11:					
	Df	Sum Sq	Mean Sq	F-value	P-value

<i>D</i>	1	0.0199	0.0199	1.128	0.302
<i>CV_{MGP}</i>	1	0.0231	0.0231	1.313	0.266
φ	1	0.1144	0.1144	6.497	0.020 *
<i>Residuals</i>	19	0.3346	0.0176		
Significant level: ‘*’ $P < 0.05$					

Above analyses were carried out with all species or only the dominant species included in biodiversity measures and derived explanatory variables.

Supplementary references

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Supplementary Tables

Table S1 Site characteristics. The geographical location (LAT for latitude and LON for longitude), vegetation type, mean annual precipitation (*MAP*), mean growing-season precipitation (*MGP*), mean annual air temperature (*MAT*), mean growing-season temperature (*MGT*), mean community biomass, species richness and dominant species with their Latin names, functional groups and relative species biomass (*RSB*) for each site have been shown.

Site	LAT	LON	Vegetation	MAP (mm)	MGP (mm)	MAT (°C)	MGT (°C)	Community biomass (g m ⁻²)	Species richness (<i>n</i>)	Dominant species		
										Latin name	Functional group	RSB (%)
S01	49.89	119.99	Meadow steppe	431.4	398.0	-1.0	12.9	147.2	23.1	<i>Stipa baicalensis</i>	Grass	36.93
										<i>Carex duriuscula</i>	Sedge	35.69
S02	49.35	120.12	Meadow steppe	391.6	362.9	-0.1	13.1	180.9	25.1	<i>Leymus chinensis</i>	Grass	21.55
										<i>Stipa baicalensis</i>	Grass	13.86
										<i>Artemisia frigida</i>	Forb	9.97
										<i>Carex duriuscula</i>	Sedge	7.75
										<i>Plantago depressa</i>	Forb	5.63
S03	48.84	118.87	Typical steppe	357.7	316.8	0.1	13.8	147.5	16.6	<i>Leymus chinensis</i>	Grass	52.02
										<i>Stipa sareptana</i>	Grass	16.24
										<i>Artemisia sphaerocephala</i>	Forb	6.21
S04	47.87	118.78	Typical steppe	378.9	340.4	0.8	13.9	153.9	19.7	<i>Cleistogenes squarrosa</i>	Grass	34.25
										<i>Leymus chinensis</i>	Grass	11.87
										<i>Artemisia frigida</i>	Forb	7.51
										<i>Stipa grandis</i>	Grass	7.26
										<i>Allium bidentatum</i>	Forb	5.74
S05	49.46	118.24	Typical steppe	359.9	325.2	1.1	14.3	116.1	15.5	<i>Stipa grandis</i>	Grass	20.34
										<i>Cleistogenes squarrosa</i>	Grass	14.45
										<i>Koeleria macrantha</i>	Grass	11.87

										<i>Artemisia sphaerocephala</i>	Forb	8.21
										<i>Serratula centauroides</i>	Forb	7.21
										<i>Artemisia frigida</i>	Forb	5.02
S06	49.55	117.57	Typical steppe	325.1	296.6	0.8	14.0	107.1	14.4	<i>Cleistogenes squarrosa</i>	Grass	33.38
										<i>Leymus chinensis</i>	Grass	22.47
										<i>Stipa grandis</i>	Grass	14.78
										<i>Artemisia frigida</i>	Forb	5.94
S07	49.10	116.99	Typical steppe	289.3	261.9	1.0	14.2	77.4	13.5	<i>Stipa sareptana</i>	Grass	55.22
										<i>Leymus chinensis</i>	Grass	13.07
										<i>Allium polyrhizum</i>	Forb	9.57
S08	48.77	116.23	Typical steppe	286.0	260.3	1.6	14.5	134.6	12.0	<i>Stipa sareptana</i>	Grass	73.71
										<i>Cleistogenes squarrosa</i>	Grass	10.15
										<i>Agropyron cristatum</i>	Grass	5.87
S09	48.58	116.95	Typical steppe	300.3	273.3	1.6	14.5	100.0	13.3	<i>Stipa sareptana</i>	Grass	70.04
										<i>Allium polyrhizum</i>	Forb	10.78
										<i>Cleistogenes squarrosa</i>	Grass	6.49
										<i>Artemisia frigida</i>	Forb	5.76
S10	45.75	118.23	Meadow steppe	374.9	339.7	2.3	14.6	101.6	10.7	<i>Stipa sareptana</i>	Grass	43.73
										<i>Leymus chinensis</i>	Grass	23.36
										<i>Cleistogenes hackelii</i>	Grass	15.47
										<i>Convolvulus ammannii</i>	Forb	10.64
S11	45.73	117.59	Typical steppe	342.4	307.3	2.4	14.8	130.0	12.2	<i>Leymus chinensis</i>	Grass	35.08
										<i>Cleistogenes squarrosa</i>	Grass	15.46
										<i>Stipa grandis</i>	Grass	14.43
										<i>Lespedeza bicolor</i>	Forb	8.27
										<i>Astragalus melilotoides</i>	Legume	5.11
S12	45.42	116.98	Typical steppe	327.5	293.7	2.8	15.0	78.0	9.9	<i>Stipa sareptana</i>	Grass	64.49

										<i>Allium ramosum</i>	Forb	17.11
										<i>Allium polyrhizum</i>	Forb	5.38
S13	45.02	116.33	Typical steppe	323.9	287.9	2.6	14.8	52.3	5.6	<i>Reaumuria soongarica</i>	Forb	48.86
										<i>Convolvulus ammannii</i>	Forb	18.55
										<i>Allium polyrhizum</i>	Forb	14.50
										<i>Leymus chinensis</i>	Grass	5.67
S14	44.77	117.46	Typical steppe	359.4	322.5	3.1	14.9	110.7	10.8	<i>Stipa grandis</i>	Grass	45.06
										<i>Leymus chinensis</i>	Grass	23.81
										<i>Anemarrhena asphodeloides</i>	Forb	15.54
										<i>Cleistogenes hackelii</i>	Grass	6.27
S15	44.51	117.36	Typical steppe	373.8	333.6	2.9	14.5	139.0	8.3	<i>Stipa grandis</i>	Grass	42.90
										<i>Cleistogenes hackelii</i>	Grass	19.18
										<i>Leymus chinensis</i>	Grass	18.33
										<i>Anemarrhena asphodeloides</i>	Forb	8.40
										<i>Agropyron cristatum</i>	Grass	7.98
S16	44.13	116.33	Typical steppe	352.9	311.9	3.4	14.9	124.8	7.3	<i>Stipa grandis</i>	Grass	71.41
										<i>Cleistogenes hackelii</i>	Grass	12.82
										<i>Leymus chinensis</i>	Grass	9.58
S17	43.99	114.85	Typical steppe	293.4	265.3	3.3	15.2	110.2	11.2	<i>Kochia prostrata</i>	Forb	25.86
										<i>Artemisia frigida</i>	Forb	21.27
										<i>Leymus chinensis</i>	Grass	16.03
										<i>Allium bidentatum</i>	Forb	8.51
										<i>Convolvulus ammannii</i>	Forb	8.46
										<i>Stipa sareptana</i>	Grass	6.65
S18	43.83	113.86	Desert steppe	243.2	221.6	4.2	15.9	42.6	13.4	<i>Salsola collina</i>	Forb	15.89
										<i>Stipa caucasica</i>	Grass	15.63
										<i>Stipa sareptana</i>	Grass	12.64

										<i>Artemisia frigida</i>	Forb	10.15
										<i>Heteropappus altaicus</i>	Forb	9.76
										<i>Convolvulus ammannii</i>	Forb	7.86
										<i>Agropyron mongolicum</i>	Grass	7.34
S19	43.82	113.45	Desert steppe	234.6	213.6	4.4	16.1	31.4	8.9	<i>Allium polyrhizum</i>	Forb	25.37
										<i>Carex duriuscula</i>	Sedge	18.66
										<i>Salsola collina</i>	Forb	15.62
										<i>Stipa caucasica</i>	Grass	12.94
										<i>Convolvulus ammannii</i>	Forb	11.11
										<i>Allium mongolicum</i>	Forb	5.30
S20	43.63	112.18	Desert steppe	204.5	186.2	4.3	16.0	20.9	6.3	<i>Salsola collina</i>	Forb	36.85
										<i>Allium mongolicum</i>	Forb	14.45
										<i>Cleistogenes songorica</i>	Grass	14.15
										<i>Salsola collina</i>	Forb	11.18
										<i>Asparagus cochinchinensis</i>	Forb	9.45
										<i>Convolvulus ammannii</i>	Forb	7.61
S21	42.88	112.57	Desert steppe	224.9	203.3	5.4	16.4	25.0	7.7	<i>Stipa caucasica</i>	Grass	79.81
S22	41.79	111.83	Typical steppe	309.0	276.8	5.8	15.9	70.9	11.0	<i>Artemisia frigida</i>	Forb	24.35
										<i>Stipa sareptana</i>	Grass	15.11
										<i>Stipa breviflora</i>	Grass	11.23
										<i>Convolvulus ammannii</i>	Forb	9.93
										<i>Kochia prostrata</i>	Forb	9.23
										<i>Allium polyrhizum</i>	Forb	5.19
S23	39.56	107.56	Desert steppe	229.0	193.0	8.7	18.4	43.7	8.4	<i>Stipa breviflora</i>	Grass	74.81
										<i>Neopallasia pectinata</i>	Forb	15.69

Table S2. Results (F -values) of the linear regression between community biomass and the sampling year for each site. No detrending was done because only 1 of the 23 sites showed a significant linear relationship.

Site	F -value	P -value	Site	F -value	P -value	Site	F -value	P -value
S01	$F_{1,2} = 61.66$	0.02	S09	$F_{1,2} = 0.36$	0.61	S17	$F_{1,3} = 3.36$	0.16
S02	$F_{1,1} = 0.46$	0.62	S10	$F_{1,3} = 2.64$	0.20	S18	$F_{1,3} = 0.11$	0.76
S03	$F_{1,3} = 5.25$	0.11	S11	$F_{1,3} = 1.92$	0.26	S19	$F_{1,3} = 2.60$	0.21
S04	$F_{1,3} = 2.39$	0.22	S12	$F_{1,2} = 0.79$	0.47	S20	$F_{1,3} = 1.97$	0.26
S05	$F_{1,2} = 0.56$	0.53	S13	$F_{1,2} = 0.14$	0.75	S21	$F_{1,3} = 1.12$	0.37
S06	$F_{1,2} = 0.76$	0.48	S14	$F_{1,3} = 4.90$	0.11	S22	$F_{1,3} = 0.14$	0.73
S07	$F_{1,3} = 0.34$	0.60	S15	$F_{1,2} = 5.65$	0.14	S23	$F_{1,1} = 45.85$	0.09
S08	$F_{1,3} = 3.11$	0.18	S16	$F_{1,2} = 0.03$	0.88			

Table S3. Results of the initial structural equation model illustrated in Figure S6. Given are the standard coefficients of pathways, standard errors of regression (S.E.), Z-value and the level of significance for the regression weight (*P*-value).

Pathway			Standard coefficients	S.E.	Z-value	P-value
Effective species richness (<i>D</i>)	←	Growing-season precipitation (<i>MGP</i>)	0.519	0.178	2.914	0.004
Weighted average species temporal CV (\widetilde{CV}^S)	←	Growing-season precipitation (<i>MGP</i>)	-0.473	0.132	-3.580	< 0.001
Weighted average species temporal CV (\widetilde{CV}^S)	←	Mean–variance scaling (<i>z</i>)	0.617	0.113	5.456	< 0.001
Weighted average species temporal CV (\widetilde{CV}^S)	←	Effective species richness (<i>D</i>)	0.398	0.132	3.027	0.002
Species synchrony (φ)	←	Precipitation CV (CV_{MGP})	0.556	0.140	3.968	< 0.001
Species synchrony (φ)	←	Effective species richness (<i>D</i>)	-0.474	0.140	-3.384	0.001
Community temporal CV (CV_C)	←	Mean–variance scaling (<i>z</i>)	0.088	0.101	0.880	0.379
Community temporal CV (CV_C)	←	Growing-season precipitation (<i>MGP</i>)	-0.119	0.083	-1.434	0.152
Community temporal CV (CV_C)	←	Weighted average species temporal CV (\widetilde{CV}^S)	0.654	0.115	5.709	< 0.001
Community temporal CV (CV_C)	←	Species synchrony (φ)	0.570	0.076	7.496	< 0.001

Supplementary Figures

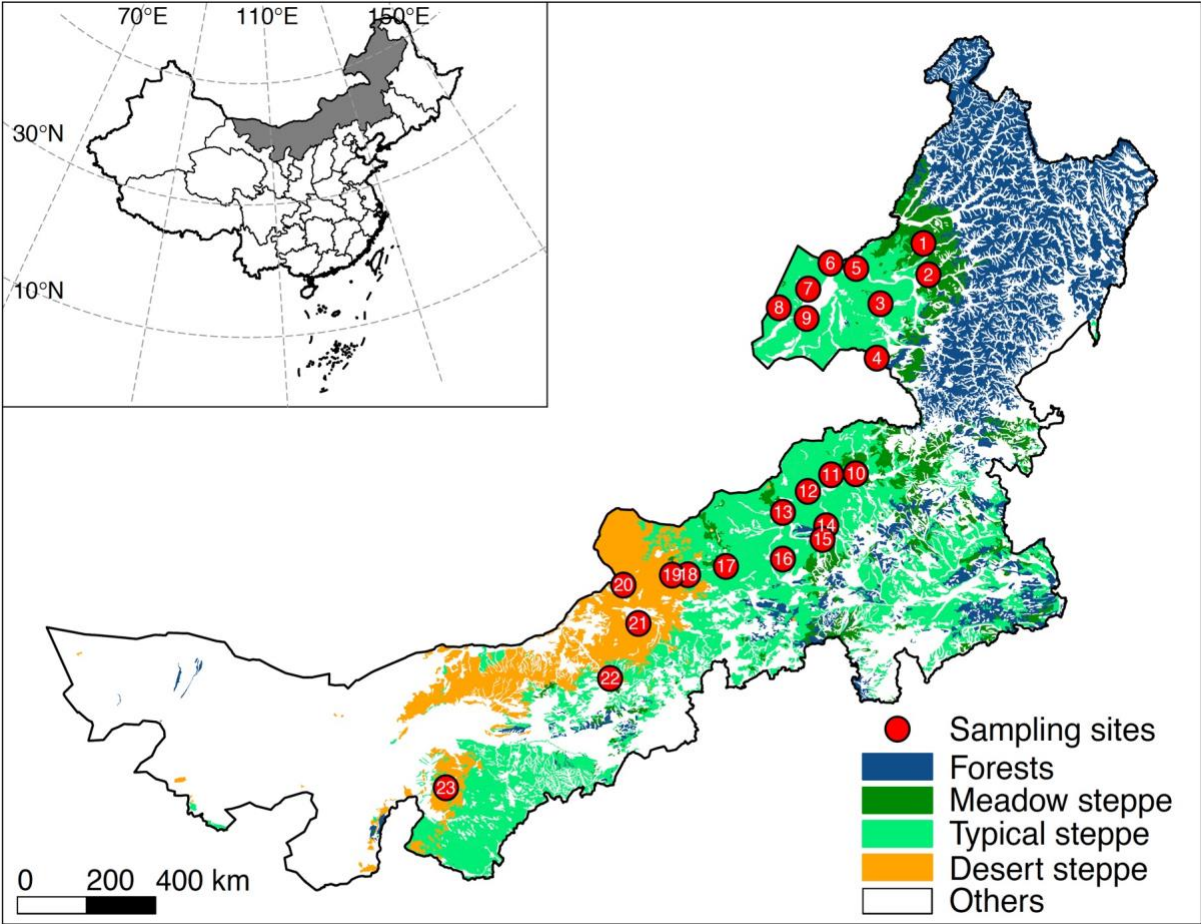


Figure S1. Geographical distribution of study sites and vegetation map of the natural temperate steppes of Inner Mongolia. Site numbers are shown in this figure.

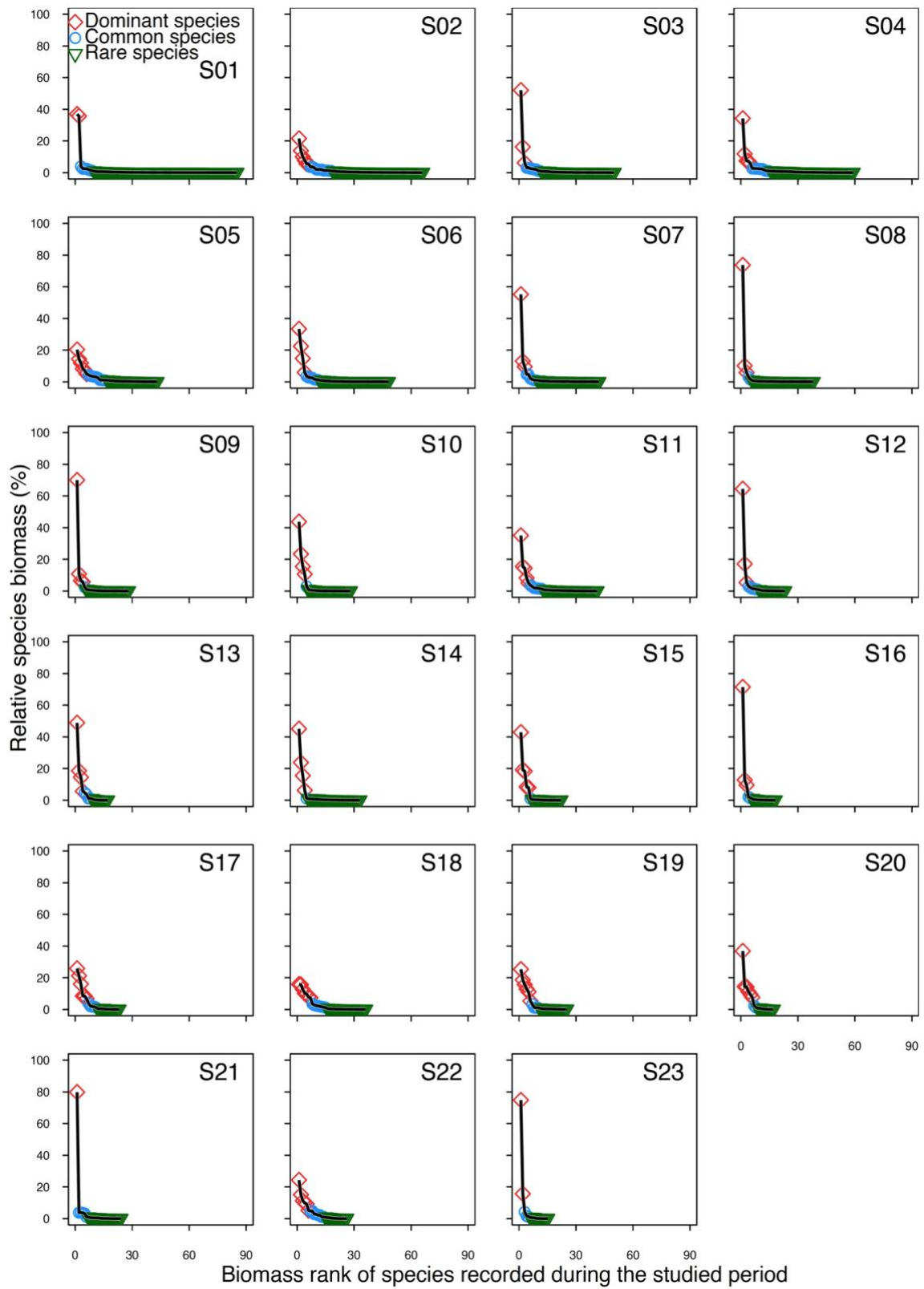


Figure S2. Descending order of relative species biomass, based on data of all species recorded in each site during 2012-2016.

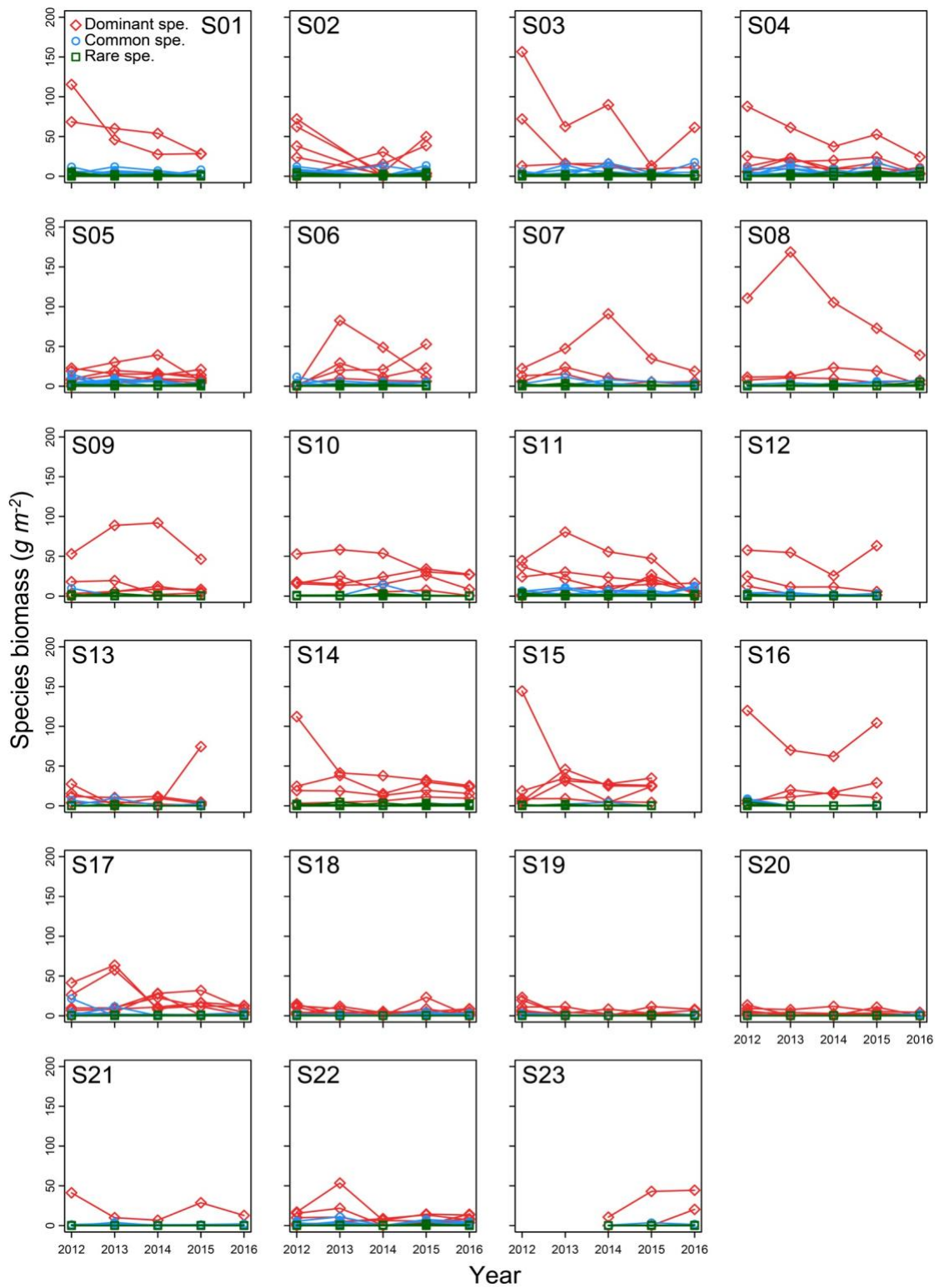


Figure S3. Time series of plant species biomass in each site.

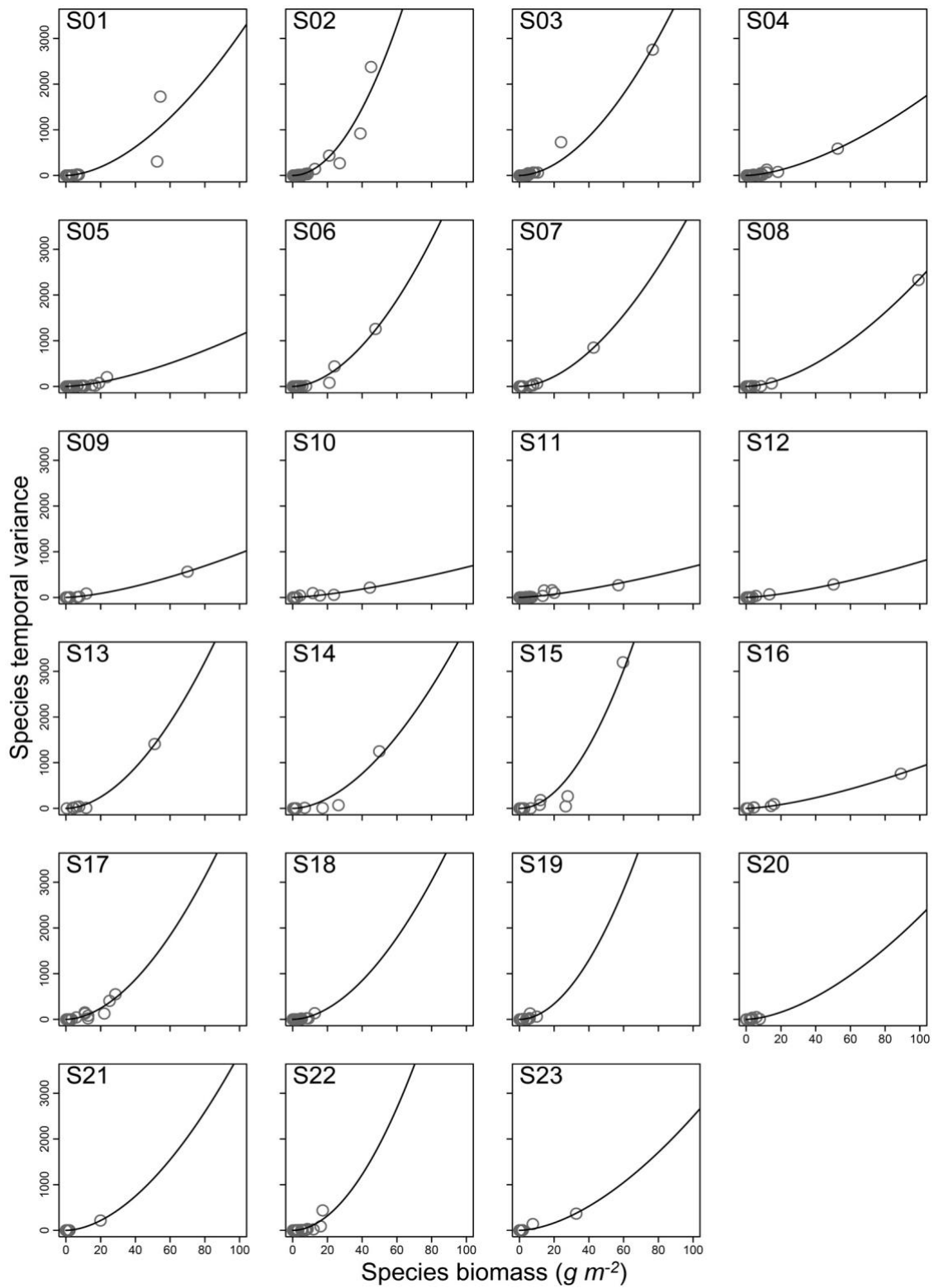


Figure S4. Mean-variance scaling relationship (showed by solid line) in each site.

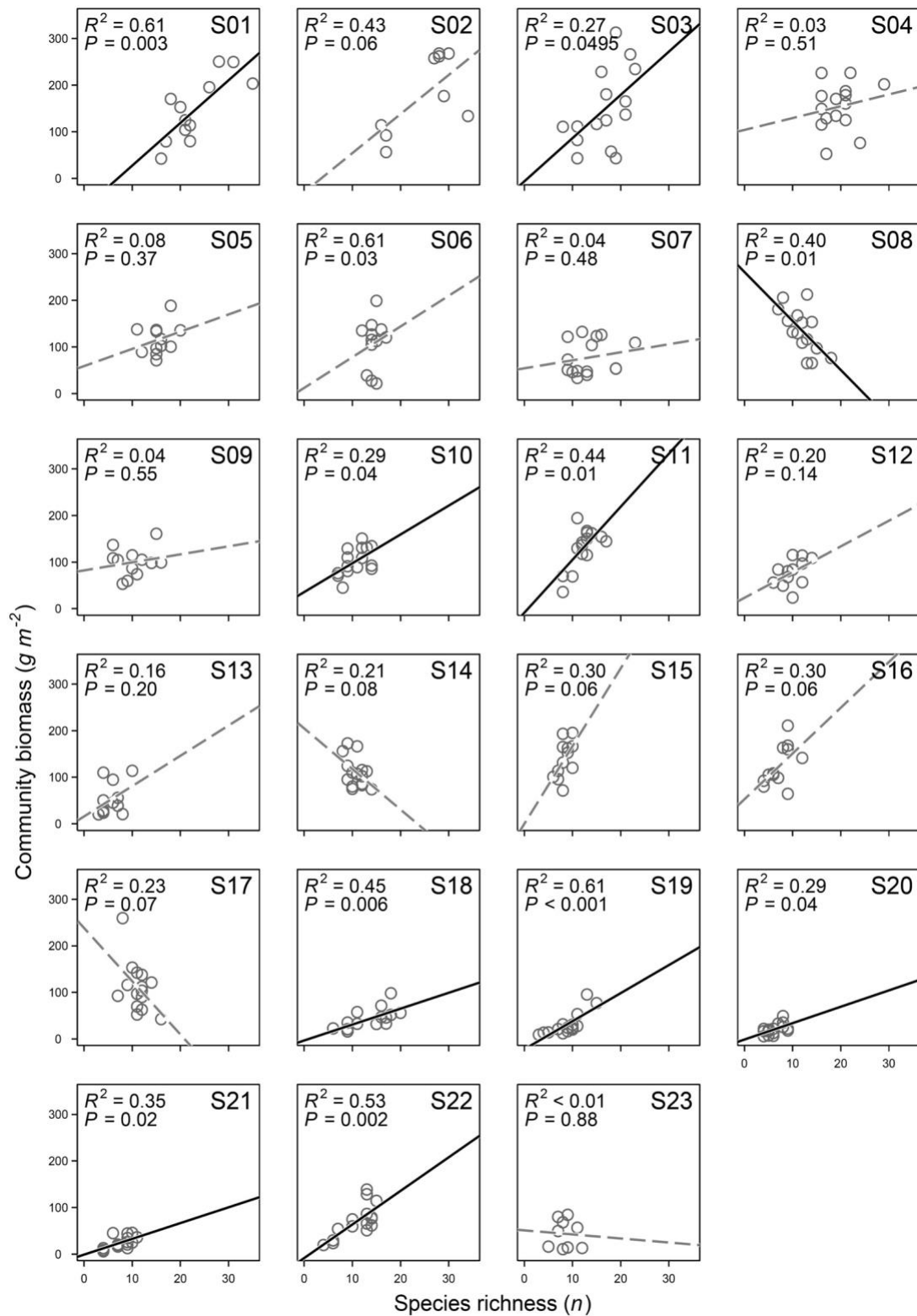


Figure S5. Community biomass in relation to species richness in each site. Results of regression analyses are showed in each subfigure. The solid lines represent significant ($P < 0.05$) linear relationships between variables, and the dashed grey lines represent non-significant ($0.05 < P < 0.10$) linear relationships between variables.

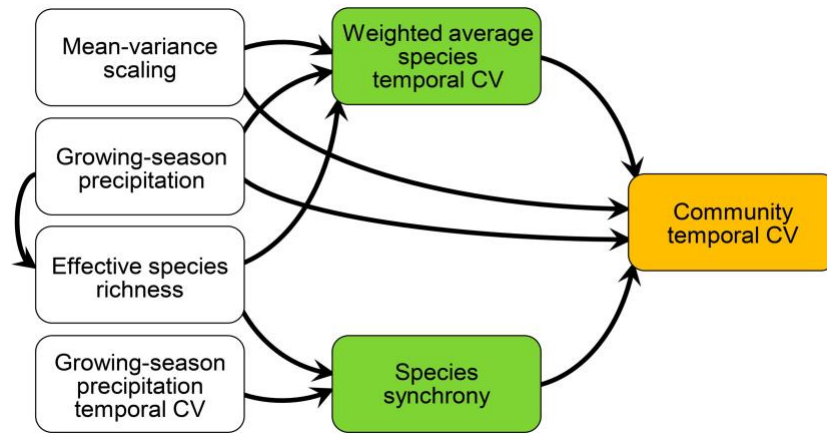


Figure S6. The initial structural equation model. This model considered the effects of abiotic factors, e.g. the growing-season precipitation and its interannual variation (estimated with the temporal coefficient of variation (CV)), biotic factor, e.g. effective species richness, and biotic mechanisms, e.g. the mean–variance scaling, the weighted average species temporal CV and the species synchrony, on the community temporal CV via all pathways derived from correlation matrix, simple linear regressions and statistical analyses in Appendix 2.

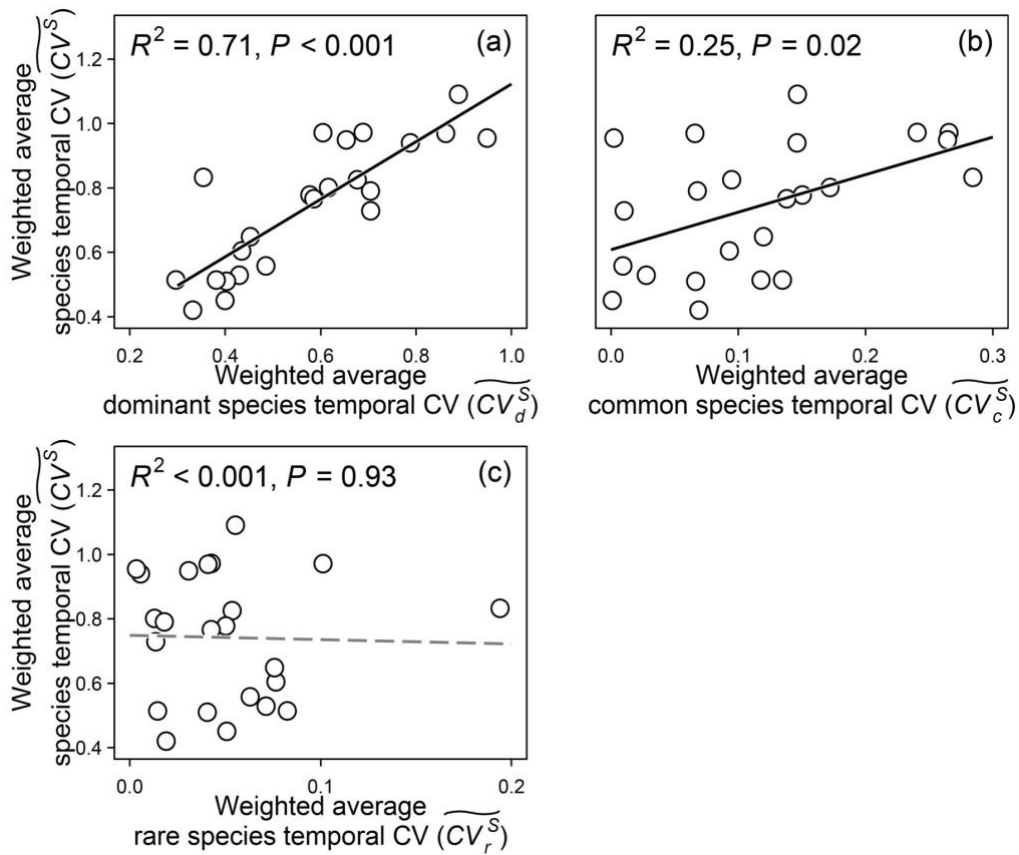


Figure S7. The weighted average species temporal coefficient of variation (CV) in relation to the weighted average dominant (a), common (b) and rare (c) species temporal CVs. Results of linear regression analyses are showed in each scatter plot. Black solid lines represent significant linear relationships ($P < 0.05$) and grey dashed line represents non-significant linear relationships ($P > 0.05$).

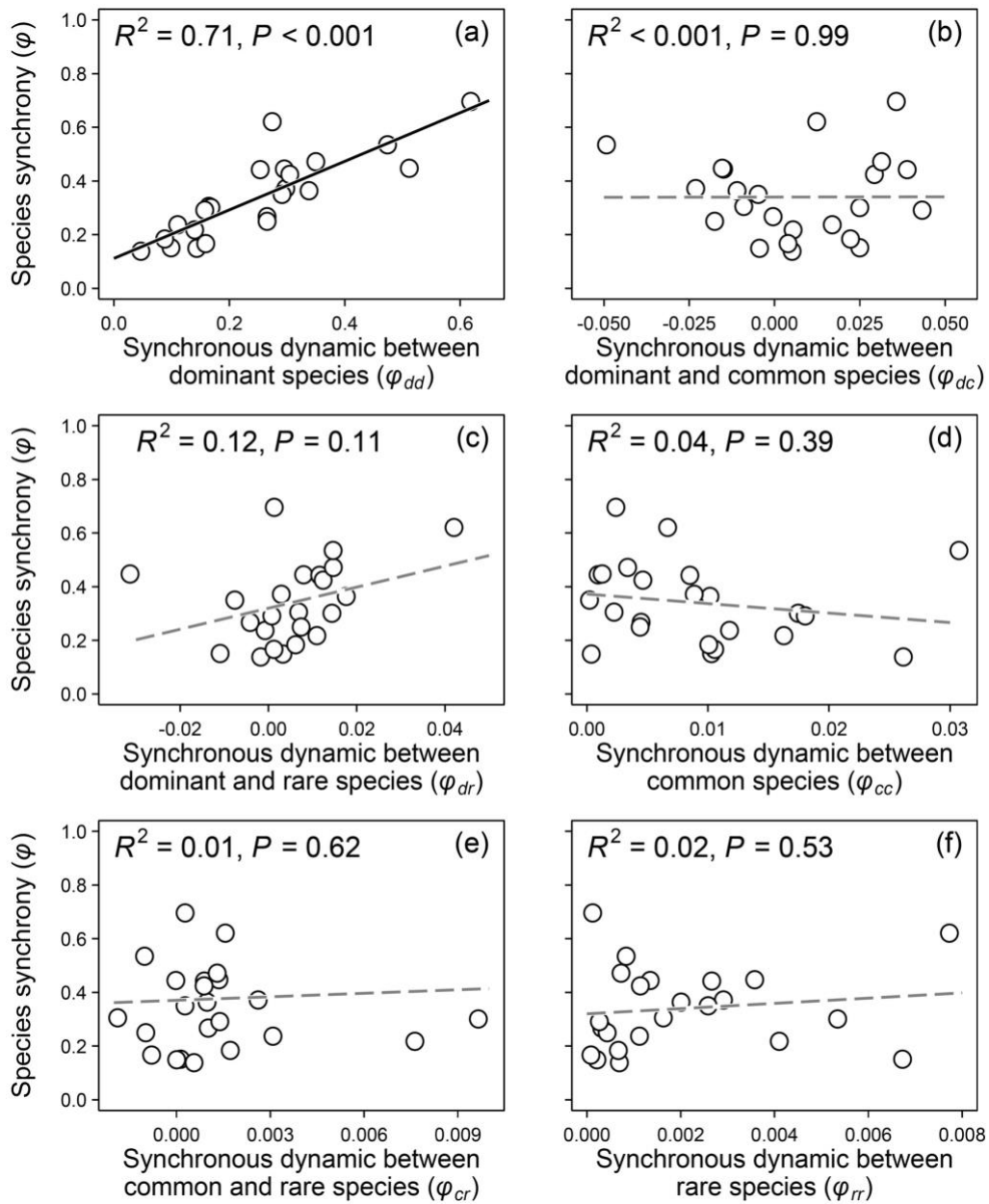


Figure S8. The species synchrony in relation to the synchrony between dominant species (a), between dominant and common species (b), between dominant and rare species (c), between common species (d), between common and rare species (e) and between rare species (f). Results of linear regression analyses are shown in each scatter plot. Black solid line represents significant linear relationships ($P < 0.05$) and grey dashed lines represent non-significant linear relationships ($P > 0.05$).

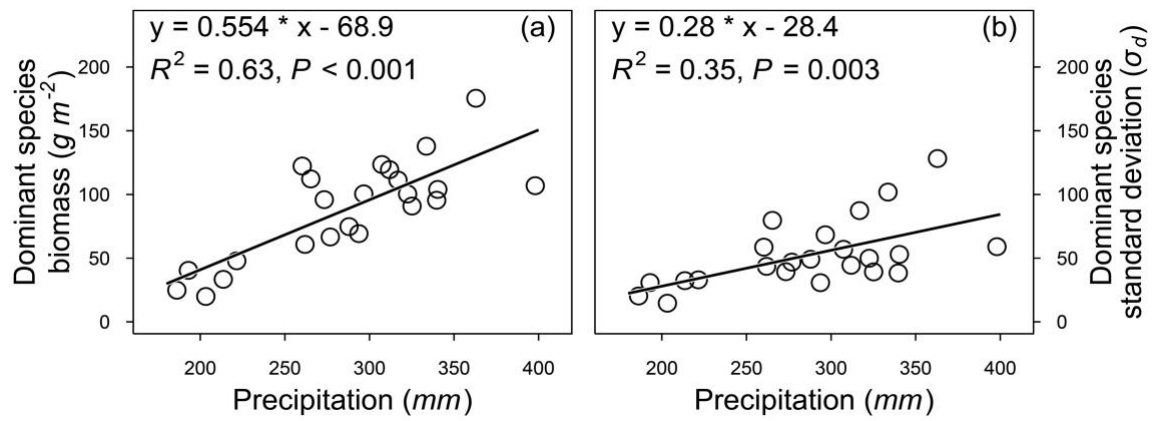


Figure S9. Biomass (a) of dominant species group and its temporal standard deviation (b) in relation to mean growing-season precipitation. Results of linear regression analyses are showed in each scatter plot. Black solid line represents significant linear relationships ($P < 0.05$).

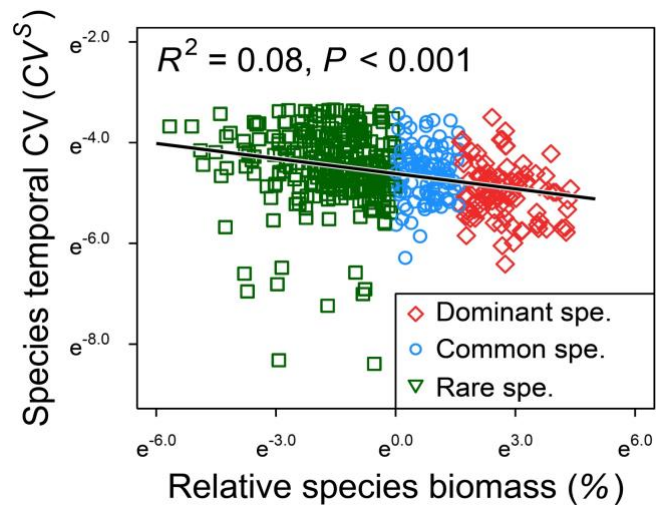


Figure S10. Relationship between species temporal coefficient of variation (CV) and relative species biomass. Solid line shows a significant linear relationship. Results of regression analyses were showed in this figure.