Supplementary Information for **Global change effects on plant communities are magnified by time and the number of global change factors imposed**

Kimberly J. Komatsu*; Meghan L. Avolio; Nathan P. Lemoine; Forest Isbell; Emily Grman; Gregory R. Houseman; Sally E. Koerner; David S. Johnson; Kevin R. Wilcox; Juha M. Alatalo; John P. Anderson; Rien Aerts; Sara G. Baer; Andrew H. Baldwin; Jonathan Bates; Carl Beierkuhnlein; R. Travis Belote; John Blair; Juliette M.G. Bloor; Patrick J. Bohlen; Edward W. Bork; Elizabeth H. Boughton; William D. Bowman; Andrea J. Britton; James F. Cahill, Jr.; Enrique Chaneton; Nona Chiariello; Jimin Cheng; Scott L. Collins; J. Hans C. Cornelissen; Guozhen Du; Anu Eskelinen; Jennifer Firn; Bryan Foster; Laura Gough; Katherine Gross; Lauren M. Hallett; Xingguo Han; Harry Harmens; Mark J. Hovenden; Annika Jagerbrand; Anke Jentsch; Christel Kern; Kari Klanderud; Alan K. Knapp; Juergen Kreyling; Wei Li; Yiqi Luo; Rebecca L. McCulley; Jennie R. McLaren; J. Patrick Megonigal; John W. Morgan; Vladimir Onipchenko; Steven C. Pennings; Janet S. Prevéy; Jodi Price; Peter B. Reich; Clare H. Robinson; F. Leland Russell; Osvaldo E. Sala; Eric W. Seabloom; Melinda D. Smith; Nadejda A. Soudzilovskaia; Lara Souza; Katherine Suding; K. Blake Suttle; Tony Svejcar; David Tilman; Pedro Tognetti; Roy Turkington; Shannon White, Zhuwen Xu; Laura Yahdjian; Qiang Yu; Pengfei Zhang; Yunhai Zhang

*corresponding author: komatsuk@si.edu, 443-482-2218

This PDF file includes:

Materials and Methods
Appendix 1 – Table of coauthor contributions.
Appendix 2 – Table of experiment information.
Appendix 3 – Map of experiment locations.
Appendix 4 – Experiment-level predictors of richness and composition responses.
Appendix 5 – Regression coefficients of treatment magnitude effect on community differences.
Appendix 6 – Experiment and Site Acknowledgements

Other supplementary materials for this manuscript include the following:

Datasets S1

www.pnas.org/cgi/doi/10.1073/pnas.1819027116

Materials and Methods

Data Collection

Criteria for inclusion of a dataset in this analysis were as follows: (1) experimentally manipulate a resource (light, CO_2, water, nutrients) relative to a control; (2) collect some measure of abundance for all species in the community (percent cover, pin hits, stem densities, biomass) to allow for calculation of our community metrics; (3) have at least 3 years of experimental manipulation to allow time for the plant community to respond; (4) have at least 4 replicates of each treatment in order to allow a reliable variance estimate to be calculated; and (5) be in an herbaceous ecosystem (grassland, salt marsh, forest understory, etc.) to ensure a response would be observable within the relatively short time frame of most experimental manipulations. All treatments from these experiments (both resource and non-resource manipulation treatments) were included in the database.

Datasets were identified in three ways. First, a comprehensive literature search was performed in Web of Science using the keywords “plant community” combined with one of the following terms: “global change”, “nutrient”, “nitrogen”, “phosphorus”, “potassium”, “micronutrients”, “CO_2”, “carbon dioxide”, “precipitation”, “rainfall”, “water”, “light”. The titles, abstracts, and methods of all papers returned from these searches were examined to determine whether the experiments described therein met our selection criteria. If the experiment did meet our selection criteria, authors were contacted with a request to provide their raw species composition data for this analysis. Second, long-term research stations were solicited to provide datasets that met our selection criteria. Third, investigators who working group members knew to have long-term global change experiments were solicited to provide datasets that met our selection criteria. Overall, we compiled a database of 105 experiments at 52 sites around the world (Appendices 2 and 3). The experiments represented in this database were conducted in intact, native-dominated herbaceous communities, with a few exceptions (highly invaded: Angelo Coast Range Reserve, Sedgewick Reserve, Spindletop Research Farm; assembled communities: Lindenhof Environmental Station LIND, Cedar Creek LTER BioCON, Konza LTER Prairie RHPs; translocated monoliths: Center for Ecology and Hydrology MEGARICH). Removal of the assembled communities from the analysis did not change our results.

For each dataset, we utilized both control and treatment plots for our analyses. Treatments included global change manipulations ranging from one to five simultaneously manipulated factors. The relative abundance of each species was determined for each plot in each year by dividing the species abundance by the sum of all species abundances.

Statistical Analysis

Four metrics of plant community differences were calculated for every year for each treatment within each experiment: (1) ln Response Ratio (lnRR) of richness differences; (2) percent (%) richness differences; (3) lnRR of effective species number (eH) differences; and (4) composition differences between the treatment and the control plots. lnRR of richness and effective species number differences were calculated as the natural log of the quotient of average richness or eH between treatment and control plots. Percent richness differences were calculated as the difference in average richness between treatment and control plots divided by the average richness of the control plots (*i.e.*, proportional difference). lnRR of richness differences, percent richness differences, and lnRR of eH differences were qualitatively similar, and therefore results are presented for lnRR of richness differences throughout, with the exception of Table 2 where all three response metrics are shown. Composition differences were calculated using multivariate_difference function of the codyn package in R (Hallet, Avolio et al). Briefly, we used Bray-Curtis as our dissimilarity metric to study compostional differences. Our dissimilarity matrix was used to make a PCoA for each year of an expperiment and composition responses were calculated as the Euclidean distance between the centroids of the plant communities in the control (*i.e.*, unmanipulated) plots. These composition responses are bounded between 0 and 1, and can be altered by (a) species reordering; (b) species turnover; (c) differences in species richness; and (d) differences in evenness (1).

Responses of the metrics of plant community differences to explanatory variables at the treatment- and experiment-levels were evaluated. At the treatment level, the treatment type (*e.g.*, CO_2 increase, nutrient addition, irrigation, drought, altered consumer pressure, burning, temperature increase, etc; see Appendix 2) was used as the sole explanatory variable. At the experiment level, gamma diversity and productivity were included as explanatory variables. Gamma diversity was estimated for each experiment in our dataset as the rarefied number of species identified across all control plots in all years of the experiment. Rarefied species number was calculated using the vegan package (2) in R version 3.4.4 by first deriving species accumulation curves for each experiment through resampling of the species richness across all control plots in all years within each experiment using 100 permutations, and second determining the rarified richness estimate at a sample size of 12 (the lowest sampling effort of control plots across all experiments included in our dataset). Productivity was calculated as the average aboveground biomass in the control (*i.e.*, unmanipulated) plots across all years of the experiment. For experiments where biomass data were not collected (36 of 105 experiments), individual investigators provided productivity estimates for the experiment based on expert knowledge and the primary literature. At a single research site (*e.g.*, an LTER site), both gamma diversity and productivity varied across experiments, but not across treatments within experiments. At the site level, mean annual precipitation (MAP) was obtained from the WorldCLIM database (http://www.worldclim.org/) using the latitude and longitude of the study sites. MAP varied across sites, but not across treatments or experiments within sites.

We used a Bayesian, multivariate, hierarchical model to analyze richness responses and composition responses. The two response variables (richness and composition responses) constitute a $N \times K$ response matrix Y_{jl}, where N is the number of observations, K is the number of response variables, and j denotes the j^{th} experiment from the l^{th} site. We assumed that the response variables were multivariate-normally distributed around predicted values:

$$Y_{jl} \sim MVN\left(\hat{Y}_{jl}, \sum Y\right)$$

where $\hat{Y}_{jl}$ is the matrix of predicted values for the j^{th} experiment at the l^{th} site, and $\sum Y$ is the covariance matrix of the response variables.

Time was standardized to a mean of 0 prior to analysis for each treatment. The predicted values were quadratic functions of this standardized metric of time:

$$\hat{Y}_{jl} = X_{jl}B_{jl}$$

whereX_{jl} is the design matrix containing the intercept, linear, and quadratic terms for experiment year, and B_{jl} is a $3 \times K$ matrix containing parameter estimates for both responses. The random experiment effects were multivariate-normally distributed around the predicted experiment effect, which was based on site and the type of treatment manipulation. For example, the random effects for overall community difference are denoted B_{jl} and were modeled as:

$$B_{jl1} \sim MVN\left(G_{l1} + Z_{jl}U_1, \sum B_1\right)$$

This equation states that the predicted value of the time series parameters in the j^{th} experiment were the site-level time series parameters (G_{l1}), modified by treatment type. The design matrix Z_{jl} contains information on the type of treatment manipulated in the j^{th} experiment. Treatment type was an effects-coded variable, such that the intercept G_{l1} represents the overall average time series parameters for a site, and the parameters U_1 are the deviations from the mean caused by global change treatment (as well as interactions with site-level ANPP/gamma diversity). The coefficients U_1 were treated as fixed, and therefore constant for every experiment and site.

Mean community parameters were then multivariate-normally distributed around overall parameter estimates, augmented by site-level ANPP and rarefied gamma diversity:

$$G_{l1} \sim MVN\left(T_1 + E_l D_1, \sum G_1\right)$$

Here, E_l contains ANPP and gamma diversity for the l^{th} site, and D_1 contains the parameter estimates for ANPP and gamma diversity effects on each parameter. Because ANPP and gamma diversity were standardized to a mean of 0 prior to analysis, the vector T_1 contains the average intercept, linear, and quadratic estimates in a site of average ANPP and gamma diversity. These analyses were identical for each response variable (*i.e.,* change subscript 1 to 2), and both response variables were standardized prior to analysis.

We placed weakly informative priors of $N(0,1)$ on all parameter estimates for B, U, D and T (3). These priors state that it is unlikely to find an effect yielding greater than a one standard deviation change in the response variable, and enable us to make multiple comparisons without need for *post-hoc* corrections (http://www.stat.columbia.edu/gelman/research/published/multiple2f.pdf). We also placed weakly informative priors $LKJ\ (2)$ on all covariance matrices. All models were also run using non-informative priors, and qualitatively similar results were obtained.

For each parameter, the 95% Bayesian credible interval (CI) was calculated from the posterior simulations. Parameters were considered to be significant if their 95% CI excluded zero. For all models, intercepts (*i.e.,* the initial magnitude of responses) were within the range of variability among control plots (*i.e.*, background variation) and are therefore not presented.

Effect size estimates for both metrics of community differences in the final year of each experiment for each treatment were also calculated, as described above. These effect sizes were used to compare the responsiveness of both metrics of plant community differences to global change manipulations using a Bayesian regression analysis examining the effect of the magnitude of either (a) N, (b) drought, or (c) irrigation treatment level on the effect sizes, as well as their interactions with mean annual precipitation (MAP). No other global change treatment in the CoRRE database included enough different levels to perform a similar regression. The N treatment magnitude was included in the model as the absolute amount of N added (g m^{-2}), while the drought and irrigation treatment magnitudes were included as a percent change from MAP at the site. Global change manipulations were categorized into treatment categories (single resource, single non-resource, two-way interactions with both treatments manipulating resources, two-way interactions with both treatments manipulating non-resources, two-way interactions with one resource and one non-resource manipulation, three or more way interactions with all treatments manipulating resources, and three or more way interactions with both resource and non-resource manipulations). The number of significant and non-significant temporal trends (either significant linear or quadratic effect sizes) across all treatments were tallied for richness and composition responses by single-factor global change treatment type (*e.g.*, nitrogen, phosphorus, irrigation, drought, etc) and category (*i.e.*, single resource, single non-resource, resource*resource, non-resource*non-resource, resource*non-resource, three or more resources, and three or more resources and non-resources). The number of significant vs non-significant temporal trends for richness and composition responses were compared by treatment type and category using a Test of Equal Proportions, with post-hoc comparisons made using Fisher's Exact Test in R version 3.4.4. All Bayesian analyses were performed using Python version 3.6.5.

Data availability: All data is available in the supplementary materials and Tables 2 and 3. All statistical code is archived on github in the following respository: https://github.com/klapierre/community_difference_synthesis.

1. Avolio ML, et al. (2015) A framework for quantifying the magnitude and variability of community responses to global change drivers. *Ecosphere* 6(12):1–14.
2. Oksanen J, et al. (2018) Vegan: community ecology package. *R Package Version 2 4-6*. doi:10.1093/molbev/msv334.
3. Lemoine NP, et al. (2016) Underappreciated problems of low replication in ecological field studies. *Ecology* 97(12):3308–3314.

Appendix 1. Author contributions

Author	CoRRE Leader	CoRRE Member	CoRRE Database	Provided Raw Data	Developed Research Questions	Analyzed Data	Contributed to Data Analyses	Wrote Paper	Contributed to Paper Writing
Kimberly J. Komatsu	x	x	x	x	x	x	x	x	x
Meghan L. Avolio	x	x	x	x	x	x	x		x
Nathan P. Lemoine		x			x	x	x		x
Forest Isbell		x		x	x	x	x		x
Emily Grman		x			x	x	x		x
Gregory R. Houseman		x		x	x		x		x
Sally E. Koerner		x		x	x		x		x
David S. Johnson		x		x	x		x		x
Kevin R. Wilcox		x		x	x		x		x
Juha M. Alatalo				x			x		
John P. Anderson				x					
Rien Aerts				x					x
Sara G. Baer				x					x
Andrew H. Baldwin				x					x
Jonathan Bates				x					x
Carl Beierkuhnlein				x					x
R. Travis Belote				x					x
John Blair				x					
Juliette M. G. Bloor				x			x		x
Patrick J. Bohlen				x					
Edward W. Bork				x					x
Elizabeth H. Boughton				x					x
William D. Bowman				x					
Andrea J. Britton				x			x		x
James F. Cahill, Jr.				x			x		
Enrique Chaneton				x			x		x
Nona Chiariello				x			x		
Jimin Cheng				x					

Author	CoRRE Leader	CoRRE Member	CoRRE Database	Provided Raw Data	Developed Research Questions	Analyzed Data	Contributed to Data Analyses	Wrote Paper	Contributed to Paper Writing
Scott L. Collins				x					x
J. Hans C. Cornelissen				x			x		
Guozhen Du				x					
Anu Eskelinen				x			x		x
Jennifer Firn				x			x		x
Bryan Foster				x					x
Laura Gough				x			x		x
Katherine Gross				x					x
Lauren M. Hallett				x					x
Xingguo Han				x					
Harry Harmens				x			x		x
Mark J. Hovenden				x					x
Annika K. Jagerbrand				x					
Anke Jentsch				x					x
Christel Kern				x			x		
Kari Klanderud				x					
Alan K. Knapp				x					x
Juergen Kreyling				x			x		x
Wei Li				x					
Yiqi Luo				x					
Rebecca L. McCulley				x			x		x
Jennie R. McLaren				x			x		x
J. Patrick Megonigal				x			x		
Ulf Molau				x					
John Morgan				x			x		x
Vladimir Onipchenko				x			x		
Steven C. Pennings				x			x		x
Janet S. Prevéy				x					x
Jodi N. Price				x			x		x

Author	CoRRE Leader	CoRRE Member	CoRRE Database	Provided Raw Data	Developed Research Questions	Analyzed Data	Contributed to Data Analyses	Wrote Paper	Contributed to Paper Writing
Peter Reich				x					x
Clare H. Robinson				x					
F. Leland Russell				x					x
Osvaldo E. Sala				x			x		
Eric W. Seabloom				x			x		x
Melinda D. Smith				x					x
Nadia A. Soudzilovskaia				x			x		x
Lara Souza				x			x		x
Katherine Suding				x					x
K. Blake Suttle				x			x		x
Tony Svejcar				x					x
David Tilman				x					x
Pedro Tognetti				x			x		x
Roy Turkington				x					
Shannon R. White				x					
Zhuwen Xu				x			x		
Laura Yahdjian				x					x
Qiang Yu				x					
Pengfei Zhang				x					x
Yunhai Zhang				x					x

Appendix 2. Details about experiments included in these analyses. Experiment indicates the name of the experiment included in the analysis. Site:Community Type indicates the experimental site at which the experiment is housed, and if the site has multiple community types sampled then which community types were considered. Lat and Long indicate the latitude and longitude of the site, respectively. Years indicates length of experiment in years; # trt indicates the number of treatments from the experiment that were included in our analysis; manipulation indicates the types of global change driver the experiment manipulated (B=burning, C=CO_2, H=herbivore presence, L=tilling, M=mowing/clipping, N=nutrients, P=plant manipulation, T=temperature, W=water); MAP indicates mean annual precipitation at the site (mm); MAT indicates mean annual temperature at the site (°C); gamma diversity indicates the rarefied number of species across all plots and years within each experiment; ANPP indicates average aboveground net primary productivity (g m^{-2}) under control conditions within the experiment.

Experiment	**Site:Community Type**	**Lat.**	**Long.**	**years**	**# trt**	**manipulation**	**MAP**	**MAT**	**gamma diversity**	**ANPP**
246Nfert	Niwot Ridge LTER:--	40.05	-105.58	11	3	N	705	-1	43	126
BFFert	Kluane Lake:--	61.07	-138.38	10	3	H, N	369	-4	28	145
BGP	Konza LTER:--	39.08	-96.58	25	15	B, M, N	866	12	60	407
BioCON	Cedar Creek LTER:--	45.40	-93.20	14	3	C, N	750	6	14	397
Bowman	Niwot Ridge LTER:dry meadow	40.05	-105.58	11	3	N	705	-1	50	152
Bowman	Niwot Ridge LTER:wet meadow	40.05	-105.58	7	3	N	705	-1	32	265
CCD	Gap Prairie Farm Rehabilitation Administration:--	49.34	-104.66	3	11	M, T, W	357	3	18	132
CCD	Kinsella Research Ranch:--	53.00	-111.52	3	17	M, T, W	430	1	20	191
CCD	Riding Mountain National Park:--	50.66	-99.97	3	11	M, T, W	513	0	28	282
CLIP	Latnjajaure Field Station:heath	69.35	18.48	7	3	N, T	818	1	7	476
CLIP	Latnjajaure Field Station:meadow	69.35	18.48	7	3	N, T	818	1	7	383
Clonal	Allegan State Game Area:--	42.55	-85.99	10	7	N, P	940	8	46	211
Culardoch	Culardoch Experimental Site:--	57.07	-3.33	6	7	B, M, N	1118	4	23	105
CXN	Smithsonian Environmental Research Center:--	38.87	-76.55	10	3	C, N	1072	13	3	637
e001	Cedar Creek LTER:Field A	45.40	-93.20	31	3	N	750	6	27	511

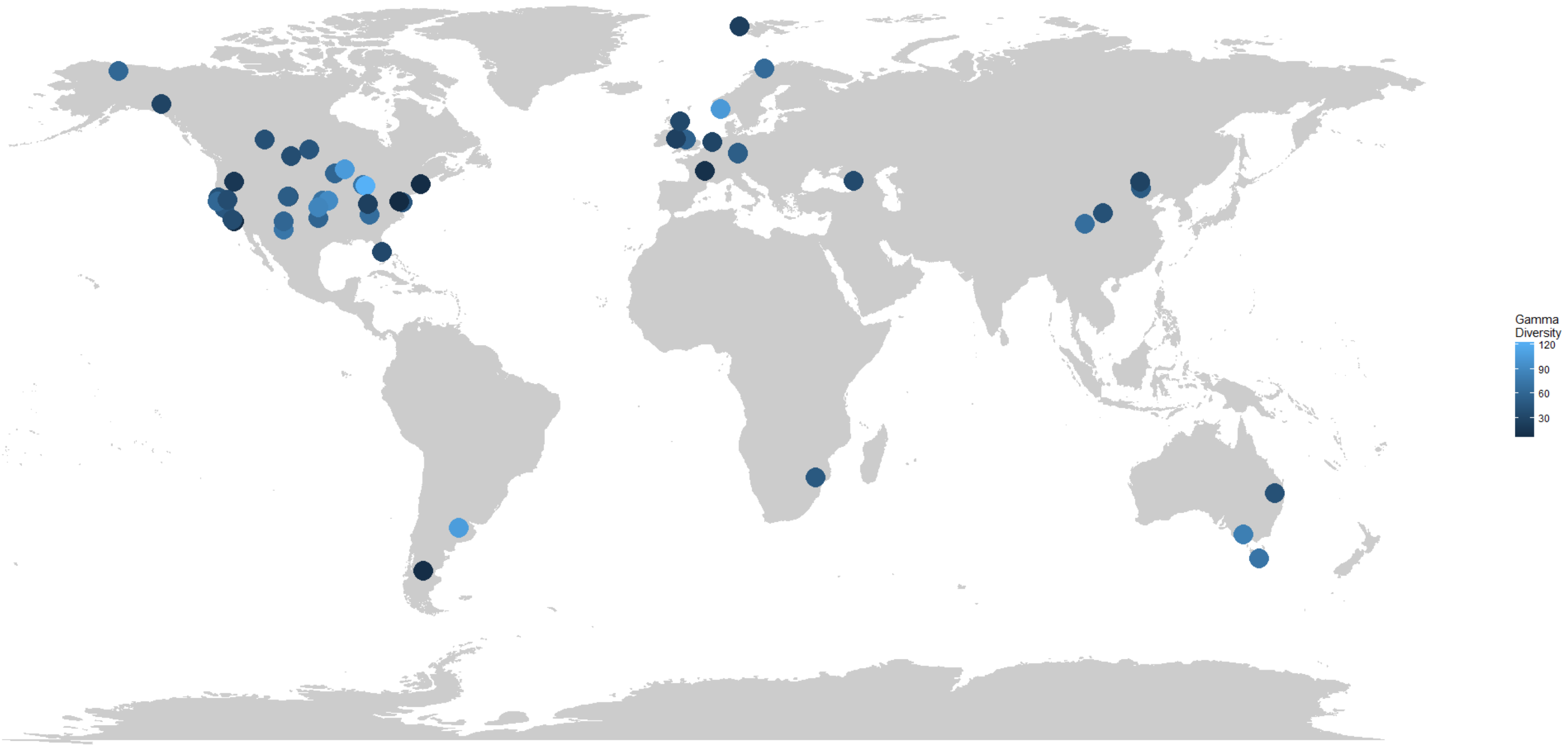
Experiment	Site:Community Type	Lat.	Long.	years	# trt	manipulation	MAP	MAT	gamma diversity	ANPP
e001	Cedar Creek LTER:Field B	45.40	-93.20	31	3	N	750	6	27	422
e001	Cedar Creek LTER:Field C	45.40	-93.20	31	3	N	750	6	34	614
e001	Cedar Creek LTER:Field D	45.40	-93.20	31	3	N	750	6	46	519
e002	Cedar Creek LTER:Field A	45.40	-93.20	10	3	N	750	6	23	170
e002	Cedar Creek LTER:Field B	45.40	-93.20	10	3	N	750	6	24	230
e002	Cedar Creek LTER:Field C	45.40	-93.20	10	3	N	750	6	42	288
E6	Kansas University Field Station:type 1	39.05	-95.20	11	7	N	965	12	11	301
E6	Kansas University Field Station:type 2	39.05	-95.20	11	7	N	965	12	11	301
EDGE	Central Plains Experimental Range:--	40.82	-104.57	4	2	W	366	10	42	94
EDGE	High Plains Grassland Research Station:--	41.18	-104.90	4	2	W	415	8	55	137
EDGE	Konza LTER:--	39.08	-96.58	4	2	W	866	12	43	413
EDGE	Saline Experimental Range:--	39.09	-99.14	4	2	W	581	12	68	246
EDGE	Sevilleta LTER:EB	34.40	-106.67	5	3	W	231	12	47	66
EDGE	Sevilleta LTER:EG	34.40	-106.67	5	3	W	231	12	36	98
EVENT2	Ecological-Botanical Garden:--	49.92	11.58	5	3	W	674	8	34	612
Exp1	Allegan State Game Area:--	42.55	-85.99	8	5	N, P	940	8	36	141
FACE	Pontville Small Arms Range Complex:--	-42.70	147.27	8	3	C, T	647	11	20	285
FACE	Oak Ridge National Laboratory:--	35.90	-84.33	11	1	C	1356	13	32	169
Fireplots	Macarthur Agro-Ecological Research Center:--	27.15	-81.20	9	15	B, H, N	1218	22	58	967
GANE	Svalbard:--	78.93	11.83	3	5	N	414	-7	13	2
GB	Northern Great Basin Experimental Range:--	43.48	-119.72	6	3	W	269	7	18	407
GCE	Jasper Ridge Biological Station:--	37.38	-122.23	13	15	C, N, T, W	675	13	25	400

Experiment	**Site:Community Type**	**Lat.**	**Long.**	**years**	**# trt**	**manipulation**	**MAP**	**MAT**	**gamma diversity**	**ANPP**
GFP	Konza LTER:20 year burn	39.08	-96.58	3	3	M, W	866	12	36	490
GFP	Konza LTER:4 year burn	39.08	-96.58	3	3	M, W	866	12	35	368
GFP	Konza LTER:annual burn	39.08	-96.58	3	3	M, W	866	12	35	469
GFP	Kruger National Park:--	-24.40	31.78	3	3	M, W	573	22	25	567
GrazePrecip	SFREC:G2	39.25	-121.28	3	2	H, W	1019	15	18	323
GrazePrecip	SFREC:G4	39.25	-121.28	3	2	H, W	1019	15	19	323
HerbDiv	Wichita State Ninnescah Reserve:--	37.53	-97.67	6	8	H, N	752	13	49	721
HerbWood	Langi Ghiran State Park:--	-37.30	143.08	3	3	N, W	666	12	51	15
Imagine	Clermont Climate Change Experiment:--	45.71	-3.02	4	3	C, T, W	780	9	12	489
Interaction	Rio Mayo Experimental Station:--	-45.68	-70.27	4	5	N, W	183	9	9	57
IRG	Konza LTER:lowland	39.08	-96.58	19	1	W	866	12	37	498
IRG	Konza LTER:upland	39.08	-96.58	19	1	W	866	12	39	491
KGFert	Kluane Lake:--	61.07	-138.38	7	3	N	369	-4	7	139
LIND	Lindenhof Environmental Station:--	49.92	11.58	3	9	P, W	674	8	30	648
Lovegrass	Trattin:--	-27.74	151.14	3	11	H, M, N, P	678	18	29	750
Lucero	San Claudio:--	-35.88	-61.08	6	1	N	978	15	49	904
MAT2	Arctic LTER:--	68.63	-149.60	14	1	N	229	-12	20	185
MEGARICH	Center for Ecology & Hydrology, Bangor:--	53.28	-4.57	4	3	C, M, N, T	873	9	20	780
MNT	Arctic LTER:--	68.63	-149.60	11	1	N	229	-12	52	150
NDE	Inner Mongolia Grassland Research Station:--	43.43	116.07	6	17	M, N	331	0	18	214
NFert	Sevilleta LTER:--	34.40	-106.67	18	1	N	231	12	48	70
NitAdd	Yunwu Mountain National Natural Reserve:--	36.25	106.41	3	5	N	447	6	27	242

Experiment	Site:Community Type	Lat.	Long.	years	# trt	manipulation	MAP	MAT	gamma diversity	ANPP
NitPhos	Azi Branch Research Station:--	33.67	101.85	4	6	N	681	1	55	420
Nitrogen	Sedgwick Reserve:annual	34.70	-120.04	5	3	N	537	14	22	285
Nitrogen	Sedgwick Reserve:perennial	34.70	-120.04	5	3	N	537	14	20	193
NSFC	Restoration Ecological Research Station:--	42.03	116.28	8	3	N, W	386	1	32	165
PME	Lefthand Canyon:--	40.12	-105.30	4	4	W	409	9	24	200
PPlots	Konza LTER:--	39.08	-96.58	12	7	N	866	12	41	472
PQ	Buxton Health and Safety Laboratory:--	53.23	-1.92	16	5	T, W	1146	8	37	380
RaMPs	Konza LTER:--	39.08	-96.58	16	3	T, W	866	12	48	773
RHPs	Konza LTER:--	39.08	-96.58	9	3	N	866	12	36	640
RMAPC	Teberda Biosphere Reserve:alpine lichen heath	43.45	41.68	9	5	N, W	934	2	34	149
RMAPC	Teberda Biosphere Reserve:Festuca grassland	43.45	41.68	9	5	N, W	934	2	29	240
RMAPC	Teberda Biosphere Reserve:Geranium meadow	43.45	41.68	9	5	N, W	934	2	24	301
RMAPC	Teberda Biosphere Reserve:snowbed	43.45	41.68	9	5	N, W	934	2	21	121
Salt Marsh	Carpenteria Salt Marsh Reserve:high marsh zone MA	34.40	-119.53	7	1	N	574	14	5	1415
Salt Marsh	Carpenteria Salt Marsh Reserve:high marsh zone S	34.40	-119.53	7	1	N	574	14	5	1415
Salt Marsh	Carpenteria Salt Marsh Reserve:low marsh zone DS	34.40	-119.53	7	1	N	574	14	5	1415
Salt Marsh	Carpenteria Salt Marsh Reserve:low marsh zone JS	34.40	-119.53	7	1	N	574	14	3	1415
Salt Marsh	Carpenteria Salt Marsh Reserve:low marsh zone S	34.40	-119.53	7	1	N	574	14	5	1415
Salt Marsh	Carpenteria Salt Marsh Reserve:mid-high marsh zone AS	34.40	-119.53	7	1	N	574	14	4	1415

Experiment	Site:Community Type	Lat.	Long.	years	# trt	manipulation	MAP	MAT	gamma diversity	ANPP
Snow	Niwot Ridge LTER:--	40.05	-105.58	6	7	N, T, W	705	-1	26	240
Study 119	Jornada LTER:Bajada shrubland	32.53	-106.72	5	1	N	256	14	50	104
Study 119	Jornada LTER:basin slopes	32.53	-106.72	5	1	N	256	14	64	113
Study 119	Jornada LTER:piedmont	32.53	-106.72	5	1	N	256	14	66	79
Study 119	Jornada LTER:playa	32.53	-106.72	5	1	N	256	14	22	199
Study 278	Jornada LTER:--	32.53	-106.72	3	9	N, W	256	14	15	173
T7	Kellogg Biological Station:--	42.40	-85.37	24	3	N, L	912	8	54	438
TER	San Claudio:--	-35.88	-61.08	4	3	M, N	978	15	70	676
TIDE	Plum Island Estuary LTER:--	42.75	-70.87	8	1	N	1151	9	8	1002
TMECE	Smithsonian Environmental Research Center:mixed	38.87	-76.55	27	1	C	1072	13	4	611
TMECE	Smithsonian Environmental Research Center:Spartina	38.87	-76.55	27	1	C	1072	13	5	629
TMECE	Smithsonian Environmental Research Center:Scirpus	38.87	-76.55	27	1	C	1072	13	5	758
UK	Spindletop Research Farm:--	38.17	-84.82	5	3	T, W	1156	12	24	253
WAPAClip	Kessler Atmospheric and Ecological Field Station:--	34.98	-97.52	3	11	M, T, W	899	16	33	403
WarmNut	Finse:--	60.00	7.00	8	3	N, T	1030	0	79	95
Water	Sedgewick Reserve:annual	34.70	-120.04	5	7	H, P, W	537	14	21	306
Water	Sedgewick Reserve:perennial	34.70	-120.04	5	7	H, P, W	537	14	19	254
watering	Angelo Coast Range Reserve:--	39.74	-123.63	13	2	W	1526	10	32	176
watfer	McLaughlin Natural Reserve:--	38.85	-123.83	5	3	N, W	1049	11	32	25
WENNDEx	Sevilleta LTER:--	34.40	-106.67	7	7	N, W	231	12	32	89
Wet	Nanticoke River Watershed:BRC marsh	38.55	-75.73	4	3	N	1110	13	16	166
Wet	Nanticoke River Watershed:BRC swamp	38.55	-75.73	4	3	N	1110	13	13	23
Wet	Nanticoke River Watershed:BSA marsh	38.55	-75.73	4	3	N	1110	13	20	283

Experiment	Site:Community Type	Lat.	Long.	years	# trt	manipulation	MAP	MAT	gamma diversity	ANPP
Wet	Nanticoke River Watershed:BSA swamp	38.55	-75.73	4	3	N	1110	13	40	37
Wet	Nanticoke River Watershed:TNC marsh	38.55	-75.73	3	3	N	1110	13	30	256
Wet	Nanticoke River Watershed:TNC swamp	38.55	-75.73	4	3	N	1110	13	46	83
Yu	Inner Mongolia Grassland Research Station:--	43.43	116.07	8	6	N	331	0	17	147

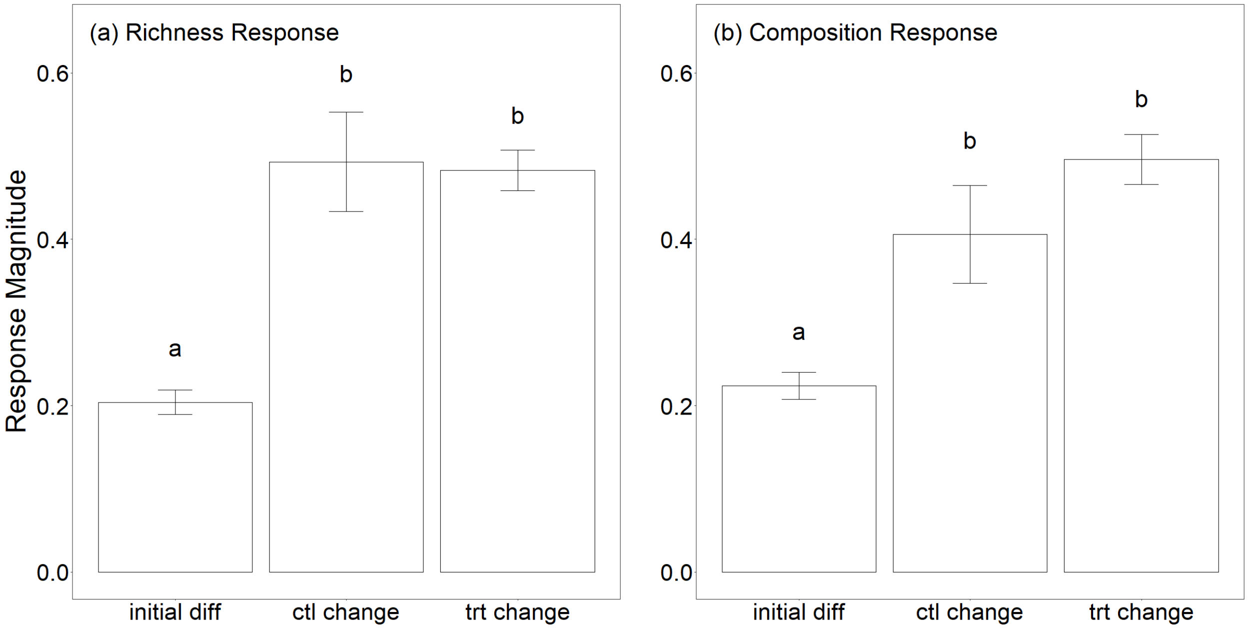


Appendix 3. Map of the 52 sites with experiments included in these analyses, with points colored by gamma diversity (averaged across all experiments at the site if more than one experiment is present).

Appendix 4: Standardized parameter estimates for the effects of global change manipulations on temporal trends of community differences (lnRR richness, composition difference), and the effects of site-level (gamma) diversity and aboveground net primary productivity (ANPP). Linear slopes are indicative of the linear component of the temporal trends, and quadratic slopes are indicative of the quadratic component of the temporal trends. Shown are median posterior estimates and standard deviations (std dev). Parameters with 95% confidence intervals not encompassing zero are considered significant and are indicated by bold text.

Response Variable	Explanatory Variable	Parameter	Estimate	Std Dev
lnRR Richness	Gamma Diversity	linear slope	0.0086	0.0228
lnRR Richness	Gamma Diversity	quadratic slope	0.0366	0.0247
lnRR Richness	**ANPP**	**linear slope**	**0.0481**	**0.0228**
lnRR Richness	ANPP	quadratic slope	0.0001	0.0238
Composition Difference	Gamma Diversity	linear slope	-0.0067	0.0169
Composition Difference	Gamma Diversity	quadratic slope	-0.0038	0.0184
Composition Difference	ANPP	linear slope	-0.0119	0.0207
Composition Difference	ANPP	quadratic slope	0.0032	0.0213

Appendix 5: For treatments that exhibited parabolic treatment responses (10.5% of richness and 10.1% of composition responses), changes in (a) lnRR richness and (b) composition in control and treatment plots through time were higher than differences between the control and treatment plots in the first year of an experiment, indicating that control and treatment plots are converging in composition because control plots are diverging from their initial state to become more similar to the treatment plots through time. Initial diff: difference between treatment and control communities in the first year of the experiment; ctl change: comparison of community change in controls plots between first and last year of the experiment; trt change: comparison of community change in treatment plots between first and last year of the experiment. Shown are means±SE of the magnitude of response, with significant differences among means indicated by different letters.



Appendix 6: Table of regression coefficients to examine the effects of nitrogen, drought, and irrigation treatment magnitudes on richness and compositional responses. Bold text indicates significant effects (*i.e.*, confidence interval for the effect size does not overlap 0).

	Mean Effect	**Lower CI**	**Upper CI**
(a) Nitrogen – richness			
Intercept	-0.144	-0.382	0.094
N	**-0.479**	**-0.803**	**-0.154**
MAP	-0.146	-0.384	0.091
N*MAP	**0.378**	**0.115**	**0.640**
(b) Nitrogen – composition			
Intercept	0.073	-0.167	0.312
N	0.313	-0.010	0.636
MAP	**0.270**	**0.029**	**0.511**
N*MAP	-0.190	-0.453	0.074
(c) Drought – richness			
Intercept	0.017	-0.371	0.404
Drought	-0.234	-0.657	0.189
MAP	-0.390	-0791	0.011
Drought*MAP	-0.069	-0.449	0.310
(d) Drought – composition			
Intercept	-0.021	-0.467	0.426
Drought	-0.170	-0.660	0.321
MAP	-0.073	-0.531	0.384
Drought*MAP	0.092	-0.344	0.528
(e) Irrigation – richness			
Intercept	0.023	-0.362	0.409
Irrigation	-0.069	-0.453	0.315
MAP	**-0.431**	**-0.833**	**-0.029**
Irrigation*MAP	0.069	-0.405	0.543
(f) Irrigation – composition			
Intercept	-0.030	-0.445	0.385
Irrigation	-0.145	-0.562	0.273
MAP	0.136	-0.293	0.565
Irrigation*MAP	-0.093	-0.602	0.416

Appendix 7. Experiment and Site Acknowledgements.

Experiment	**Site**	**Funding Source**
	Arctic LTER	U.S. National Science Foundation DEB 0423385 and 1026843
	Cedar Creek LTER	U.S. National Science Foundation 1234162
	Konza Prairie LTER	U.S. National Science Foundation
	Jornada Basin LTER	U.S. National Science Foundation DEB-1235828, DEB 1354732, DEB 1754106
	Niwot Ridge LTER	U.S. National Science Foundation DEB-1027341
	San Claudio	UBACyT 20020100100615BA, 20020120300076BA, G024, and G046
	Sevilleta LTER	U.S. National Science Foundation
	SFREC	U.S. National Science Foundation 20121208, U.S. Department of Agriculture 2006-01350
	Smithsonian Environmental Research Center	U.S. National Science Foundation DEB-0950080, DEB-1457100, DEB-1557009; U.S. Department of Energy DE-SC0008339; U.S. Geological Survey G10AC00675; Smithsonian Institution
BFFert/KGFert	Kluane Lake	NSERC Discovery Grant
BioCON	Cedar Creek LTER	U.S. National Science Foundation DEB-1234162, DEB-0716587, DEB-1242531, DEB- 1120064
Culardoch	Culardoch Experimental Site	Rural and Environment Science and Analytical Services Division of the Scottish Government
CCD	Gap Prairie Farm Rehabilitation Administration, Kinsella Research Ranch, Riding Mountain National Park	Natural Sciences and Engineering Research Council Discovery and Strategic Grant
CLIP	Latnjajaure Field Station	Carl Tryggers stiftelse för vetenskaplig forskning and Qatar Petroleum
E6	Kansas University Field Station	U.S. National Science Foundation DEB 1655500 and DEB 950100
Fireplots	Macarthur Agro-Ecological Research Center	Archbold Biological Station
GANE	Svalbard	UK Natural Environment Research Council Global Atmospheric Nitrogen Enrichment Program

Imagine	Clermont Climate Change Experiment	IFB-GICC IMAGINE; ANR QDIV, VALIDATE
FACE	Oak Ridge National Laboratory	U.S. Department of Energy DE-AC05-00-OR22725
FACE	Pontville Small Arms Range Complex:--	Australian Research Council Discovery Projects Scheme Grants DP0451686, DP0772319, DP0984779
NDE	Inner Mongolia Grassland Research Station	International Postdoctoral Exchange Fellowship Program 20170070; National Key R&D program of China 2016YFC0500700
MEGARICH	Center for Ecology & Hydrology, Bangor	UK Natural Environment Research Council; UK Department for Environment, Food and Rural Affairs Project CC0359; European Union EV5V-CT-93-5213
RaMPs	Konza LTER	U.S. National Science Foundation DEB-1257174
RHPs	Konza LTER	U.S. National Science Foundation DEB-1147439
RMAPC	Teberda Biosphere Reserve	Governmental Contract AAAA-A16-116021660037-7 of MSU
TIDE	Plum Island Estuary LTER	U.S. National Science Foundation DEB 0213767, DEB 0816963, DEB 1354494, DEB 1719621, OCE 0423565, OCE 1058747, OCE 1238212, OCE 1637630
UK	Spindletop Research Farm	U.S. Department of Energy 08-SC-NICCR-1073; USDA-ARS Forage Animal Production Research Unit 58-6440-7-135; Kentucky Agricultural Experiment Station; University of Kentucky's College of Agriculture, Food, and the Environment
WarmNut	Finse	Norwegian Research Council
watfer	McLaughlin Natural Reserve	Academy of Finland 253385 and 297191
NitAdd	Yunwu Mountain National Natural Reserve	Natural Science Foundation of China 41601586, 41671289; State's Key Project of Research and Development Plan 2016YFC0500700