LINKING CHANGES IN SPECIES COMPOSITION AND BIOMASS IN A GLOBALLY DISTRIBUTED GRASSLAND EXPERIMENT

Table S1: Sites included in this analysis according to site inclusion criteria of this study, based on the Nutrient Network database updated on May 6, 2021. Each site manager has contributed data to this analysis and effort. MAP_v2 is mean annual precipitation (mm), and MAT_v2 is Mean Annual Temperature (Celcius) sourced from WorldClim Version 2. Average response reports the overall effect or quadrant sites fall within Figure S5c -also reported in Figure S9 and the Shiny App (link follows). See expanded version of Table S1 in '.csv' format in the open data repository. To explore and see site-level effect estimates please visit: https://emma-ladouceur.shinyapps.io/nn-cafe-app/

#	Site Code	Site Name	Country	Habitat	Experiment Length	Overall Response	Site Manager(s) / Data Owners	MAP_V2	MAT_v2
1	ahth.is	Audkuluheidi Heath	Iceland	heathland	3	+biomass +rich	Isabel C. Barrio, Ingibjörg Svala Jónsdóttir	615	0.83
2	arch.us	Archbold Biological Station	United States	mixedgrass prairie	5	+biomass -rich	Elizabeth Boughton	1205	22.73
3	azi.cn	Azi	China	alpine grassland	5	+biomass -rich	Zhengwei Ren, Guozhen Du	711	1.36
4	badlau.de	Bad Lauchstaedt	Germany	old field	5	-biomass +rich	Nico Eisenhauer, Sylvia Haider, Julia Siebert	523	9.33
5	barta.us	Barta Brothers	United States	mixedgrass prairie	4	+biomass -rich	David Wedin	581	9.07
6	bayr.de	Bayreuth	Germany	mesic grassland	4	+biomass -rich	Anke Jentsch, Marie Spohn	745	8.51
7	bldr.us	Boulder South Campus	United States	shortgrass prairie	8	-biomass -rich	Kendi Davies, Brett Melbourne	487	9.9
8	bnch.us	Bunchgrass (Andrews LTER)	United States	montane grassland	11	+biomass -rich	Eric Seabloom, Elizabeth Borer	1618	6.77

9	bogong.au	Bogong	Australia	alpine grassland	10	+biomass -rich	John Morgan, Joslin Moore	1678	5.98
10	burrawan.au	Burrawan	Australia	semiarid grassland	11	-biomass -rich	Jennifer Firn	643	18.22
11	burren.ie	Slieve Carran	Ireland	calcareous grassland	3	+biomass -rich	Yvonne Buckley, Ian Donohue	1320	9.77
12	cbgb.us	Chichaqua Bottoms	United States	tallgrass prairie	10	+biomass -rich	W. Stan Harpole, Lori Biederman, Kirsten Hofmockel, Lauren Sullivan	871	9.26
13	cdcr.us	Cedar Creek LTER	United States	tallgrass prairie	13	+biomass -rich	Eric Seabloom, Elizabeth Borer, Adam Kay, W. Stan Harpole	740	6.34
14	cdpt.us	Cedar Point Biological Station	United States	shortgrass prairie	12	+biomass -rich	Johannes Knops	456	9.64
15	chilcas.ar	Las Chilcas	Argentina	mesic grassland	6	+biomass -rich	Laura Yahdjian, Enrique Chaneton, Pedo Tognetti	955	15.09
16	cowi.ca	Cowichan	Canada	old field	11	+biomass -rich	Andrew MacDougall	762	10.45
17	doane.us	Doane College Spring Creek Prairie	United States	tallgrass prairie	8	+biomass -rich	Ramesh Laungani	739	10.65
18	ethass.au	Ethabuka (South Site)	Australia	desert grassland	6	+biomass +rich	Glenda Wardle, Chris Dickman	203	23.95
19	frue.ch	Fruebuel	Switzerland	pasture	7	-biomass -rich	Andy Hector, Yann Hautier, Sabine Güsewell	1546	6.96
20	gilb.za	Mt Gilboa	South Africa	montane grassland	3	+biomass -rich	Peter Wragg	943	14.14

21	hall.us	Hall's Prairie	United States	tallgrass prairie	7	+biomass -rich	Rebecca McCulley, Jim Nelson	1289	13.83
22	hart.us	Hart Mountain	United States	shrub steppe	5	+biomass -rich	David Pyke, Nicole DeCrappeo	259	7.75
23	hnvr.us	Hanover	United States	old field	3	-biomass -rich	Elizabeth Wolkovich, Kathryn Cottingham	1044	6.49
24	hopl.us	Hopland REC	United States	annual grassland	12	+biomass -rich	Eric Seabloom, Elizabeth Borer, W. Stan Harpole	1065	13.24
25	jena.de	JeNut	Germany	grassland	7	+biomass +rich	Anne Ebeling, Christiane Roscher	654	8.57
26	kbs.us	Kellogg Biological Station LTER	United States	old field	7	+biomass -rich	Lars Brudvig	903	8.8
27	kibber.in	Kibber (Spiti)	India	alpine grassland	7	+biomass +rich	Mahesh Sankaran	400	-1.45
28	kilp.fi	Kilpisjärvi.	Finland	tundra grassland	5	+biomass -rich	Anu Eskelinen, Risto Virtanen	569	-3.25
29	kiny.au	Kinypanial	Australia	semiarid grassland	11	-biomass -rich	John Morgan	408	15.59
30	koffler.ca	Koffler Scientific Reserve at Joker's Hill	Canada	pasture	9	-biomass -rich	Arthur Weiss, Marc Cadotte	853	6.28
31	konz.us	Konza LTER	United States	tallgrass prairie	12	+biomass -rich	Melinda Smith, Kimberly Komatsu	889	12.08
32	lake.us	Lakeside Laboratory	United States	tallgrass prairie	4	+biomass -rich	Lori Biederman	726	7.29
33	lancaster.uk	Lancaster	United Kingdom	mesic grassland	9	-biomass +rich	Carly Stevens	1522	8.01

34	look.us	Lookout (Andrews LTER)	United States	montane grassland	11	+biomass -rich	Eric Seabloom, Elizabeth Borer	1877	6.9
35	marc.ar	Mar Chiquita	Argentina	grassland	7	+biomass -rich	Pedro Daleo, Juan Alberti, Jesús Pascual, Oscar Iribarne	907	14.32
36	mcla.us	Mclaughlin UCNRS	United States	annual grassland	12	+biomass +rich	Eric Seabloom, Elizabeth Borer, W. Stan Harpole	936	13.97
37	mtca.au	Mt. Caroline	Australia	savanna	10	+biomass -rich	Suzanne Prober	324	17.75
38	pape.de	Papenburg	Germany	old field	6	+biomass -rich	Helmut Hillebrand	788	9.12
39	ping.au	Pingelly Paddock	Australia	old field	5	+biomass -rich	Jodi Price, Rachel Standish	456	16.28
40	pinj.au	Pinjarra Hills	Australia	pasture	5	-biomass -rich	John Dwyer	1085	19.99
41	potrok.ar	Potrok Aike	Argentina	semiarid grassland	3	+biomass +rich	Pablo Peri, Hector Bahamonde	249	6.62
42	saana.fi	Saana	Finland	montane grassland	5	+biomass -rich	Anu Eskelinen, Risto Virtanen	521	-2.6
43	sage.us	Sagehen Creek UCNRS	United States	montane grassland	6	+biomass -rich	Daniel Gruner, Louie Yang	831	5.83
44	sava.us	Savannah River	United States	savanna	5	+biomass -rich	John Orrock, Ellen Damschen, Lars Brudvig	1184	17.43
45	sedg.us	Sedgwick Reserve UCNRS	United States	annual grassland	10	+biomass -rich	Carla D'Antonio, W. Harpole, Elizabeth Borer, Eric Seabloom	478	15.58

46	sereng.tz	Serengeti	Tanzania	savanna	4	-biomass -rich	T. Anderson	827	21.94
47	sevi.us	Sevilleta LTER	United States	desert grassland	11	+biomass -rich	Scott Collins, Laura Ladwig	252	13.06
48	sgs.us	Shortgrass Steppe LTER	United States	shortgrass prairie	11	+biomass -rich	Cynthia Brown, Julia Klein, Dana Blumenthal, Alan Knapp	369	8.95
49	shps.us	Sheep Experimental Station	United States	shrub steppe	9	+biomass -rich	Peter Adler	246	5.32
50	sier.us	Sierra Foothills REC	United States	annual grassland	12	+biomass -rich	Eric Seabloom, Elizabeth Borer, W. Stan Harpole	936	16.31
51	smith.us	Smith Prairie	United States	mesic grassland	12	+biomass -rich	Jonathan Bakker	605	10.18
52	spin.us	Spindletop	United States	pasture	13	+biomass -rich	Rebecca McCulley, Jim Nelson	1152	12.48
53	summ.za	Summerveld	South Africa	mesic grassland	3	+biomass +rich	Peter Wragg	944	18.44
54	temple.us	Temple	United States	tallgrass prairie	13	+biomass -rich	Philip Fay, Jason P. Martina	877	19.4
55	ukul.za	Ukulinga	South Africa	mesic grassland	9	+biomass -rich	Kevin Kirkman, Michelle Tedder, Nicole Hagenah	832	17.65
56	unc.us	Duke Forest	United States	old field	4	+biomass -rich	Charles Mitchell, Justin Wright	1157	14.86
57	valm.ch	Val Mustair	Switzerland	alpine grassland	12	+biomass -rich	Anita Risch, Martin Schuetz	681	0.13

58	veluwe.nl	Veluwe	Netherlands	old field	3	-biomass -rich	Ciska Veen, Judith Sitter, Liesbeth Bakker	851	9.49
59	yarra.au	Yarramundi	Australia	mesic grassland	5	+biomass -rich	Sally Power, Raul Ochoa Hueso	844	17.32

Table S2: The Average total change (Fig.2, Fig. 4a) and the Population level (overall) effect estimates (slope) (Fig. 3, Fig 4b) and 95% credible intervals (CI's) calculated from the posterior distribution for each treatment and univariate model as reported in main results. Each estimate is the absolute average total change or slope / rate of change over time as change/year. To explore and see site-level effect estimates please visit: https://emma-ladouceur.shinyapps.io/nn-cafe-app/

Model	Change Estimate	Treatment	Estimate	Upper CI	Lower CI
	Slope	NPK	-0.47	-0.28	-0.66
Species Richness		Control	-0.08	0.09	-0.27
		NPK	19.99	31.11	7.14
Biomass	Slope	Control	4.97	13.97	-4.37
		NPK	-8.32	-6.73	-9.90
	Average total	Control	-5.74	-4.48	-7.02
		NPK	-0.38	-0.26	-0.51
Species loss (s.loss)	Slope	Control	-0.19	-0.11	-0.28
	Average total	NPK	2.73	3.55	1.91
		Control	4.46	5.54	3.40
	Slope	NPK	-0.01	0.06	-0.08
Species gain (s.gain)		Control	0.12	0.21	0.04
	Average total	NPK	-127	-95.6	-159
		Control	-37.9	27.3	-48.7
	Slope	NPK	-7.44	-4.92	-10.18
Biomass change associated with species loss (SL)		Control	-0.56	-0.26	-0.97
Biomass change associated with species gain (SG)		NPK	106	137	77.3

	Average total	Control	61.8	84.9	41.6
	Slope	NPK	7.36	9.77	5.27
		Control	4.02	5.86	2.6
Biomass change associated with Persistent species (PS)	Average total	NPK	171	241	104
		Control	-30.9	19.8	-81.2
	Slope	NPK	3.05	11.88	-6.14
		Control	-4.47	1.84	-10.76

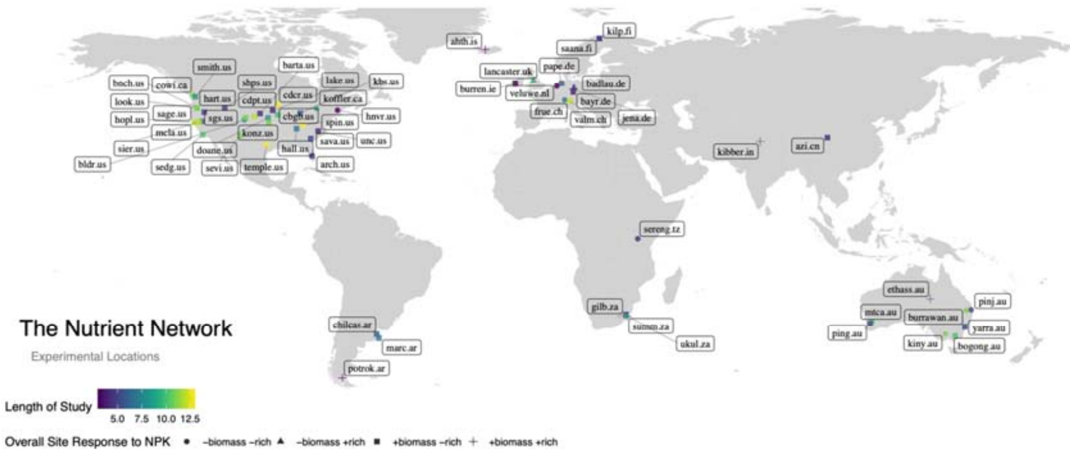

Figure S1: A map of all 59 experimental sites included in this study, colored by the time the experimental site has been running (years). Symbols represent overall site-level response to NPK (Detailed in Figure 2c, TableS1, Figure S5).

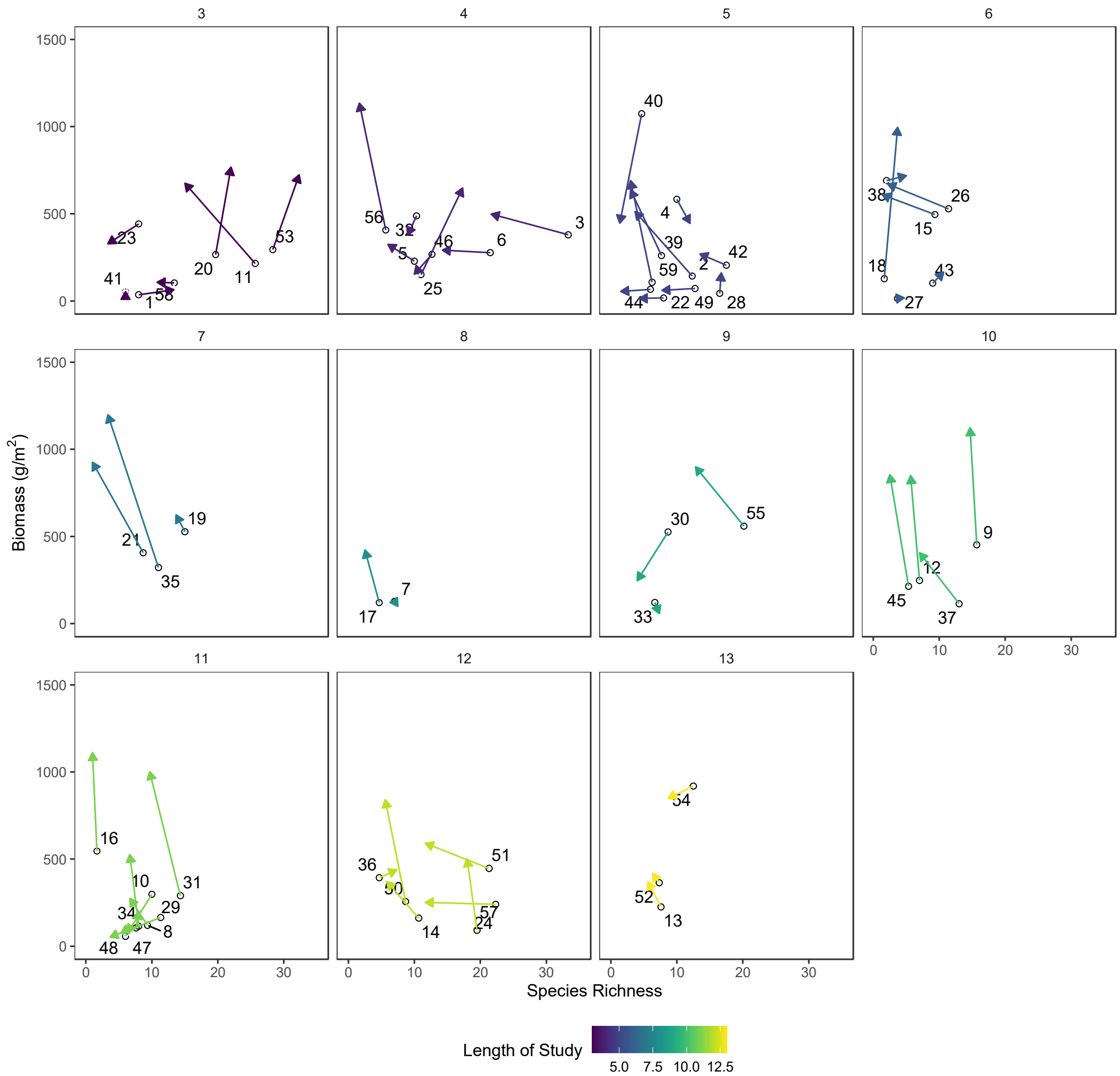

Figure S2: Relationship between the mean plot level species richness and biomass from the starting point of each site before NPK treatment (year 0 - open circle) and in the most recent measurement in time (arrow). The number on top of each plot represents the maximum number of years of measurement for each experimental site included in this study. The number adjacent to the start of each arrow corresponds with the number next to every site code in Table S1.

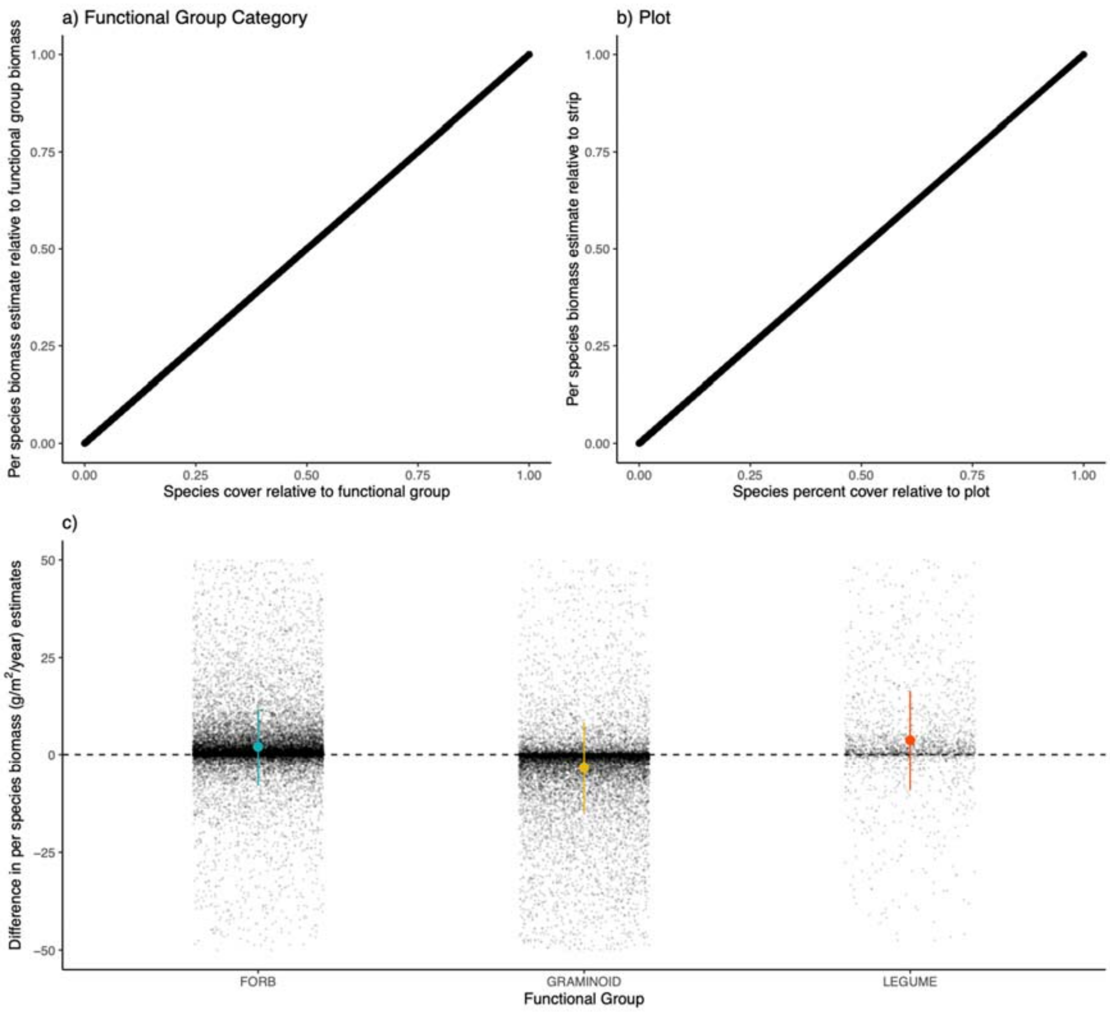

Figure S3: To estimate per species biomass, we related biomass to species percent cover in two ways. The relationship between the relative per species biomass estimate is 1:1 with per species relative percent cover. A) & B) shows the observed relationship between species cover relative to biomass for A) Species cover relative to functional group cover, and per species biomass relative to functional group biomass, and B) species percent cover relative to plot and per species biomass relative to biomass strip samples. C) Each point is the difference in per species' biomass estimates in an individual species biomass estimates when using method visualised in A) or B) as described in the methods.

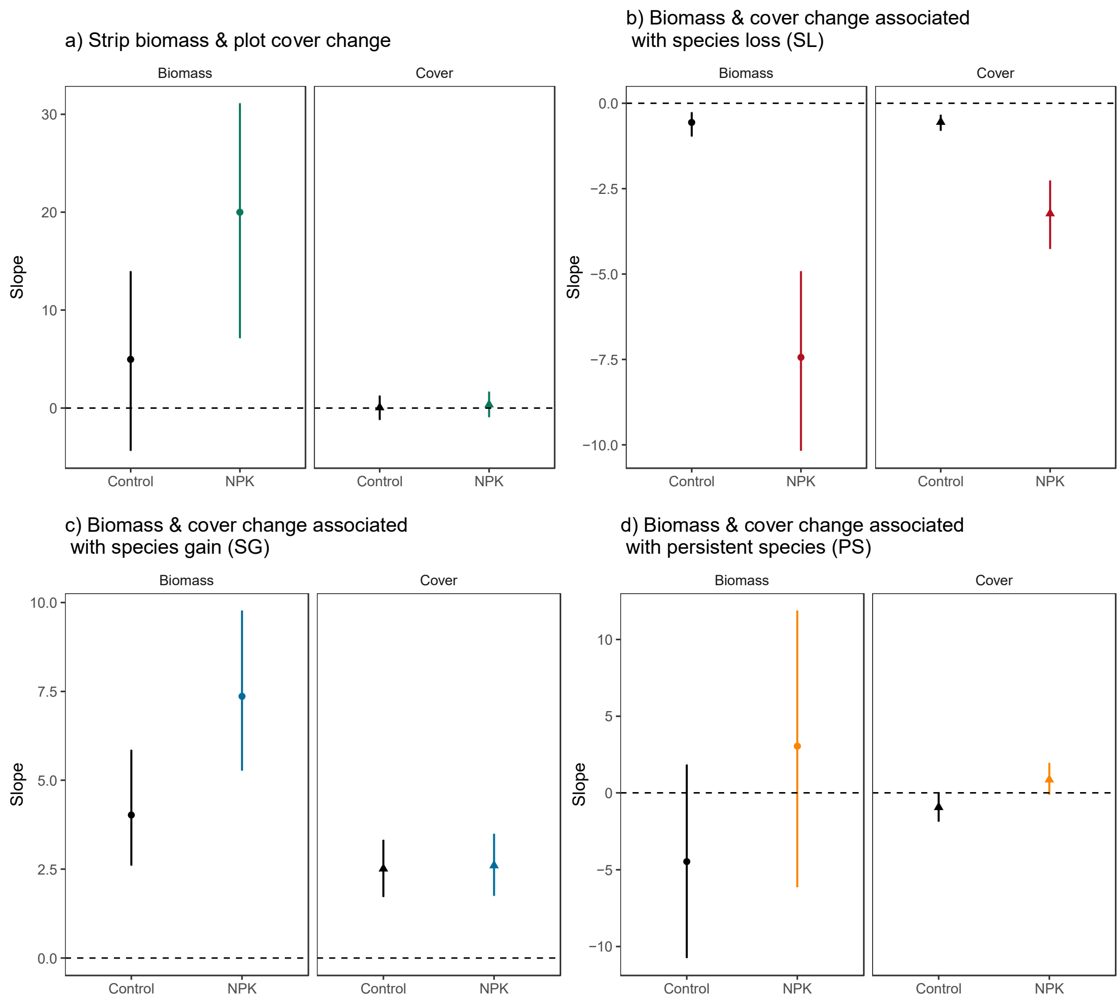

Figure S4: The overall slope (change/year) for each component using biomass estimates or cover estimates for a) strip biomass and plot cover, and biomass or cover change associated with b) species loss (SL), c) species gain (SG), and d) persistent species (PS)

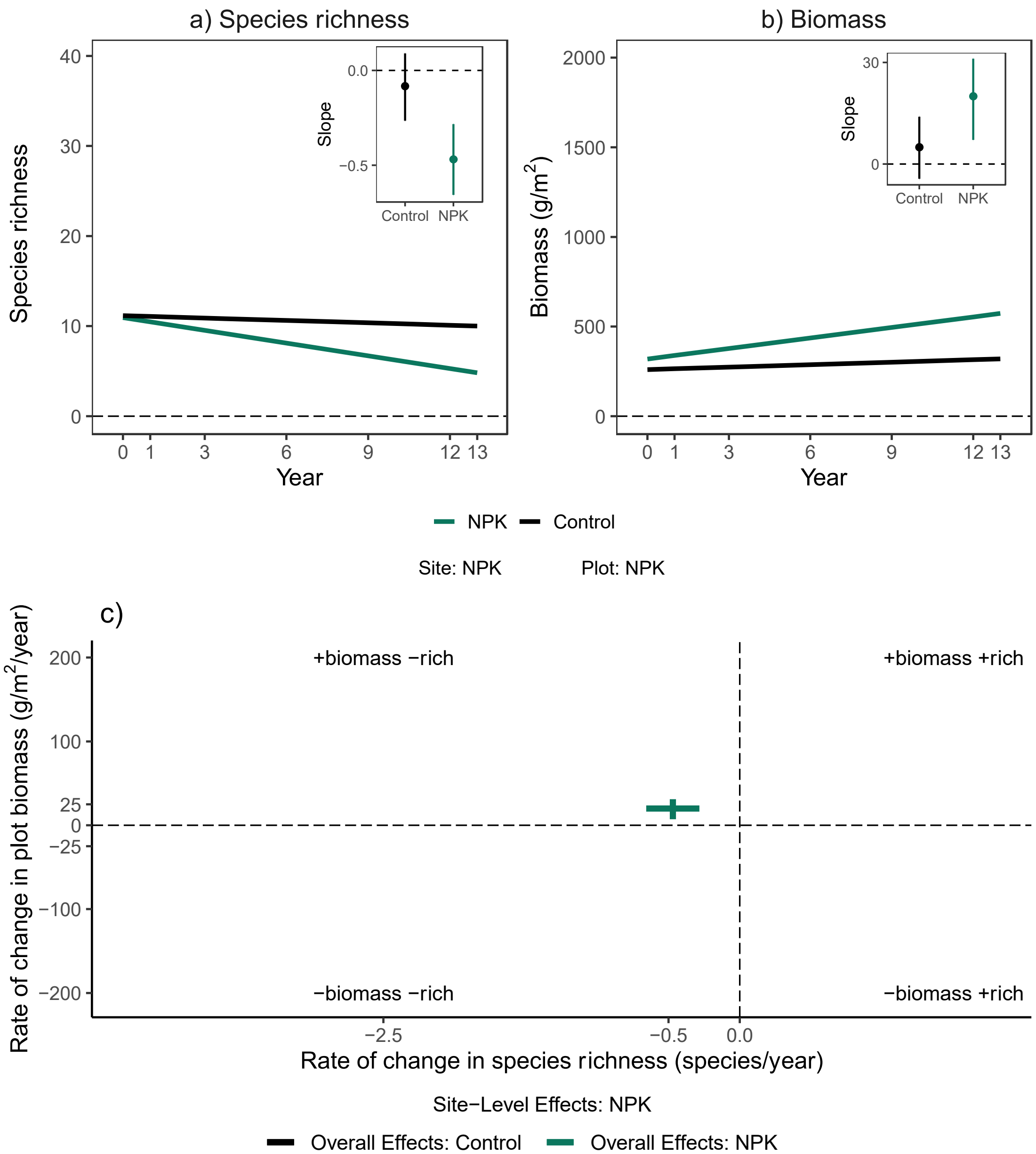

Figure S5: The relationship between the response of species richness and biomass in controls and NPK treatments across time. In a) and b), the thick lines represent the overall effect estimate for NPK (green) and Control plots (black), and the shading around these lines shows the 95% credible interval. Each jittered green point represents a plot treated with NPK. Each green thin line represents the slope of every experimental site treated with NPK as a random effect. The inset plots represent the overall effect estimate (slope) of Control and NPK treatments, error bars represent 95% credible intervals, and the dashed line at 0 represents a reference slope of 0 for each metric.

In c), the large colored point and error bars represent the overall effect estimate of NPK (green) and for Control (black) on species richness and biomass as a rate of change (/year) across studies. Each grey point represents the slope of an experimental site (n=59) treated with NPK, and error bars represent the 95% credible intervals for each site. The dashed reference line at 0 represents a slope of 0 for each metric.

Supplementary Model Details

Table S3: Univariate models
All univariate models were fitted with nutrient addition as a fixed predictor and year as an interacting continuous predictor, and plot nested within block and block nested within site as random effects using the brm function. Model performance was confirmed by the visual inspection of predicted (light grey lines) values vs. observed (black line) (Figures S5 a-g below), and the distribution of residuals across all considered effects in each model for each response listed below. If a model reproduced the data well but did not converge, we increased model sampling incrementally by 1000 iterations until large effective sample sizes, low Rhats and model convergence were achieved. All models used 1000 iterations for warmup.

Univariate Model	Distribution	Iterations	Effective Sample Sizes	Rhat
Species richness	Gaussian	5,000	427-5,430	≤ 1.01
Biomass	Student	6,000	1,216-9,887	≤ 1.00
Species loss (s.loss)	Student	5,000	2,442-7,931	≤ 1.00
Species gains (s.gain)	Student	5,000	2,192-7,137	≤ 1.00
Biomass change associated with species loss (SL)	Student	5,000	1,482-1,978	≤ 1.01
Biomass changed associated with species gain (SG)	Student	5,000	1,226-3,636	≤ 1.00
Biomass change associated with persistent species (PS)	Student	5,000	6,368-13,348	≤ 1.00

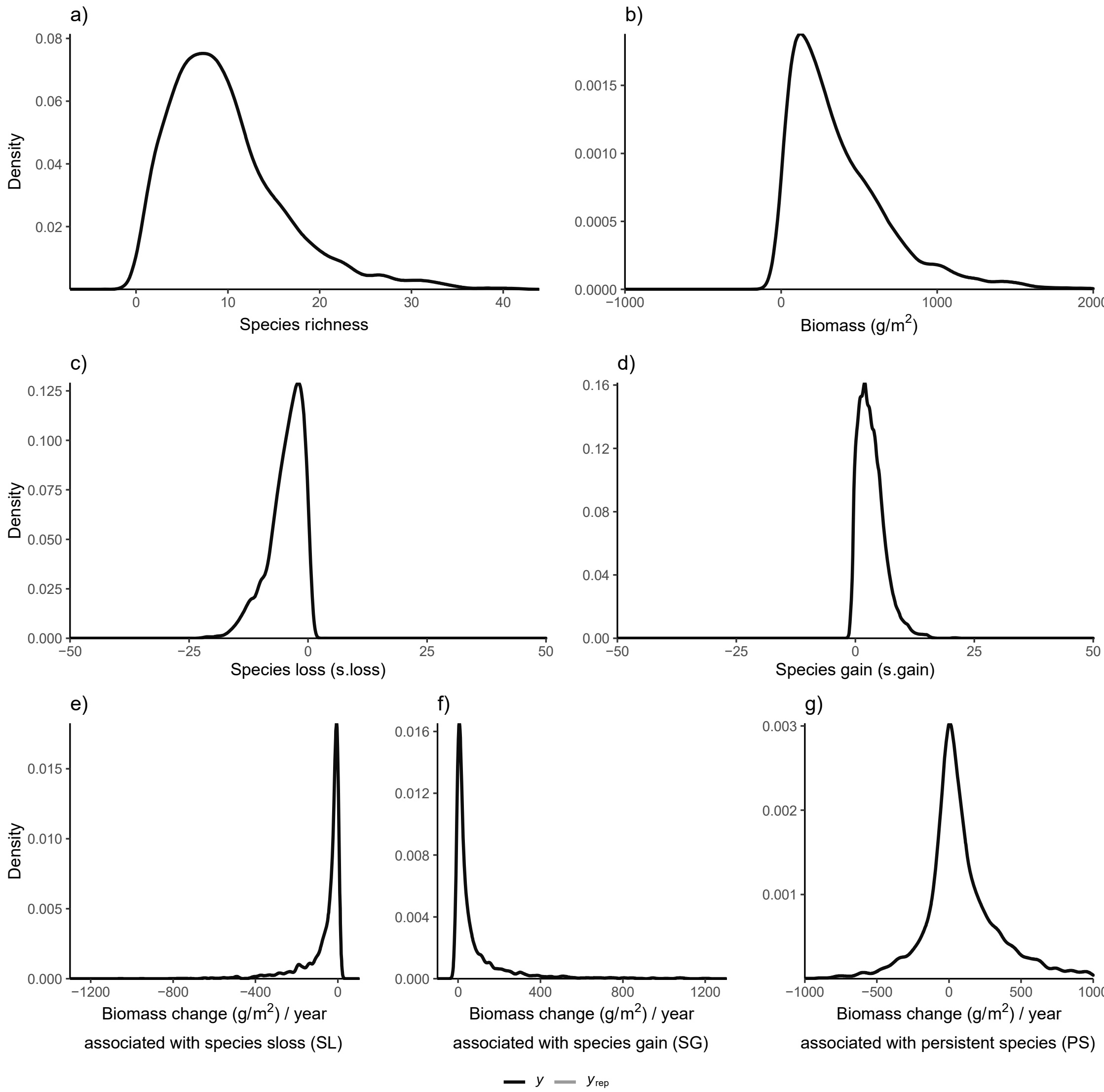

Figure S6a-g: Predicted values for each univariate model indicated by the grey lines and observed values of the data indicated by the black line for a) Species richness, b) Biomass (g/m2), c) Species loss d) Species gain e) Biomass change (g/m^2) associated with species loss, f) Biomass change (g/m2) associated with species gain g) Biomass change (g/m^2) associated with persistent species.

Table S4: Multivariate Models

Two multivariate models were fit to understand the correlation between responses to NPK over time using the brm function. In the first, richness and biomass were fit together in a multivariate model. In the second, Species losses (s.loss), species gains (s.gains), and Biomass change associated with species loss (SL), species gains (SG) and persistent species (PS) were fit together in a multivariate model. In both models, nutrient addition as a fixed predictor and year as an interacting continuous predictor using the brm function. Site was used as a random effect.

Multivariate Model	Distribution	Iterations	Effective Sample Sizes	Rhat

Richness & Biomass	Student	6,000 for each response	1,631-16,902	≤ 1.0
Price partition components (s.loss, s.gain, SL, SG, PS)	Student	6,000 for each response	1,167-10,367	≤ 1.0

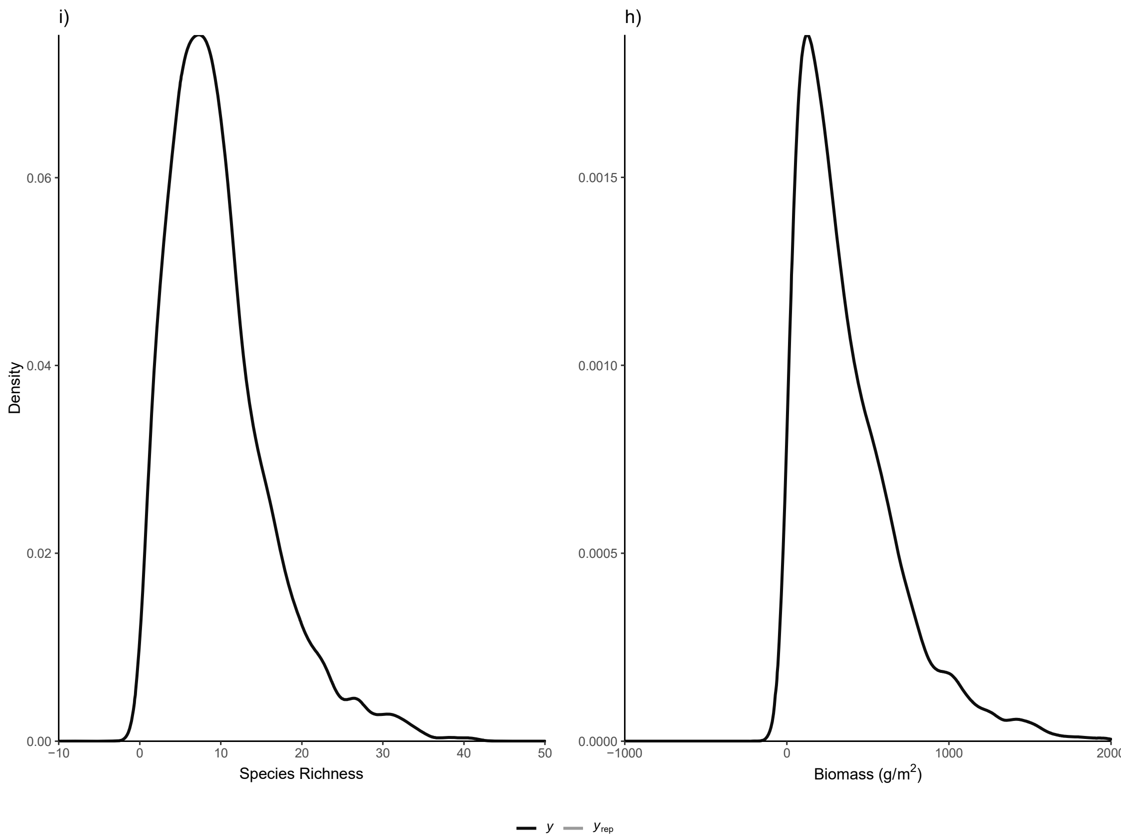

Fig S6i -h: Multivariate Model : Species Richness & Biomass. Species richness and strip biomass predicted values of the multivariate model indicated by the grey lines and observed values of the data indicated by the black line.

Variable correlation

Correlation between the two response variables (biomass and species richness) in the multivariate model had a correlation coefficient of -0.26 with high uncertainty (95% CI: -0.60 to 0.14).

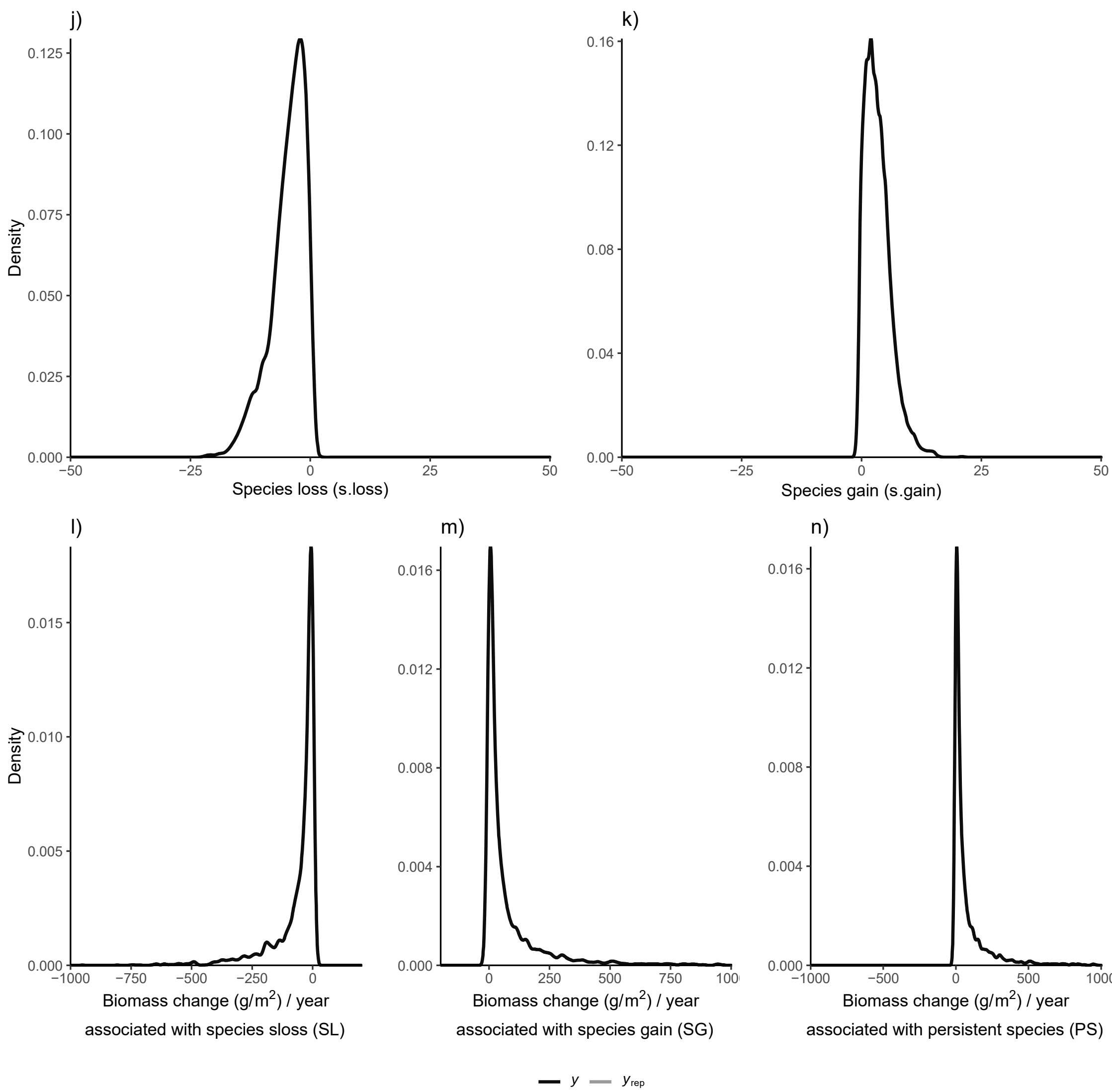

Fig S6j-n: Multivariate Model: Price partition components. Species losses (s.loss), species gains (s.gain), and biomass change associated with species loss (SL), species gains (SG) and persistent species (PS) predicted values of the multivariate model indicated by the grey lines and observed values of the data indicated by the black line.

Table S5: Variable correlation
Correlation between site-level responses to NPK across time for Price partition components. CI represents the 95% credible interval of the correlation coefficient.

Response variables	Correlation coefficient	Lower CI	Upper CI
SL & SG	-0.07	-0.38	0.23
SL & PS	-0.24	-0.55	0.09

SG & PS	-0.06	-0.39	0.29
SL & s.loss	0.26	-0.04	0.54
SL & s.gain	0.03	-0.27	0.34
SG & s.loss	-0.19	-0.49	0.13
SG & s.gain	-0.1	-0.42	0.23
PS & s.loss	-0.21	-0.5	0.11
PS & s.gain	-0.12	-0.43	0.2
s.loss & s.gain	0.29	-0.03	0.58

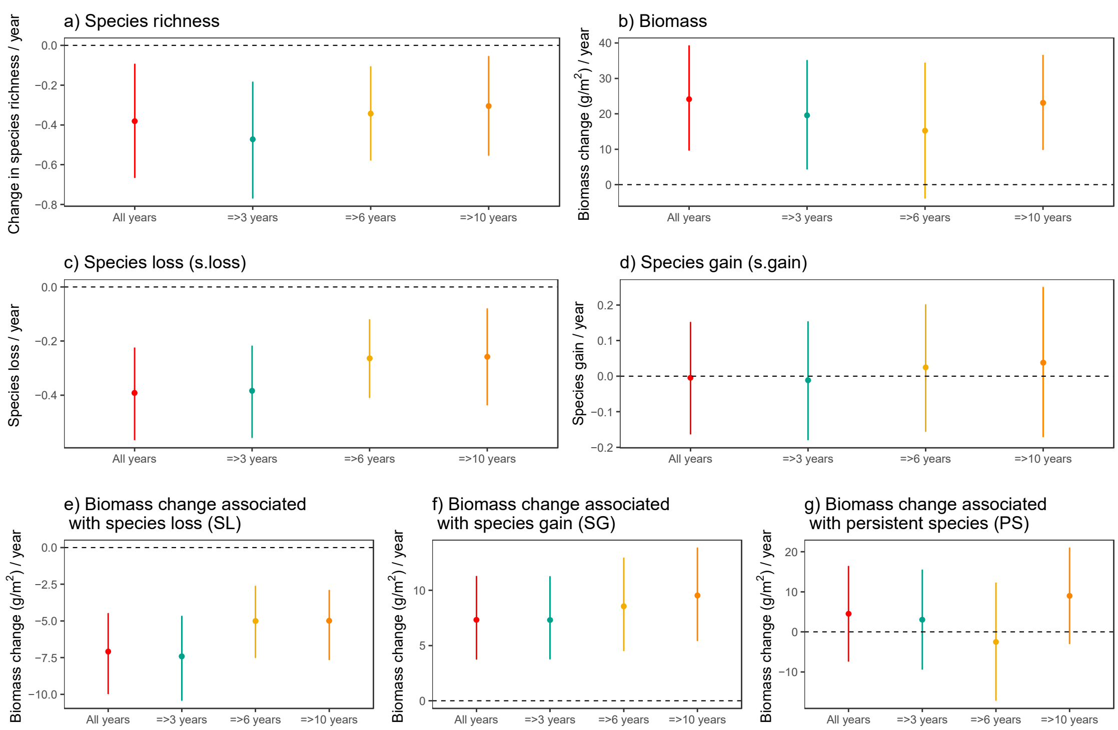

Fig S7: The overall effect estimate (Slope) for NPK over time for each response variable. Along the x-axis of each plot is the estimate of each response according to varying inclusion criteria for experimental sites that have been running for different lengths of time. For all models used in this study, sites that have been measured for ≥3 years were included in the main presented analyses for this work. The dashed line at 0 represents a slope of 0.

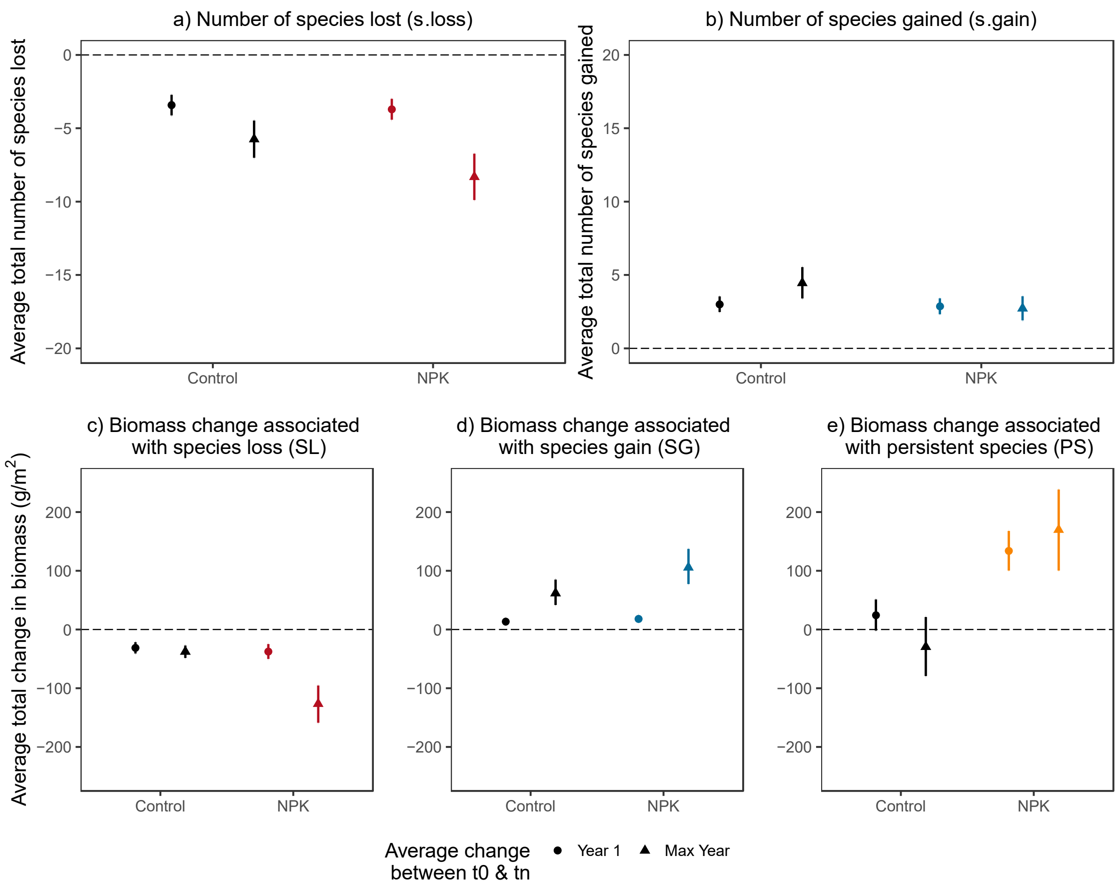

Fig S8: The absolute average total change in species (a, b) and biomass (c, d, e) at the start of experimental treatments (average change between year 0 and year 1) and across time (maximum year measured). Small grey jittered points show the data models were fit to at every site between year 0 and 1, and the most recently recorded experimental year (maximum- also shown in Figure 2); large colored points are the fitted overall effects (average total) of treatment at 1 (circles) and13 years (triangles, maximum year of experimental measurements across all sites) and colored lines show the 95% credible intervals.

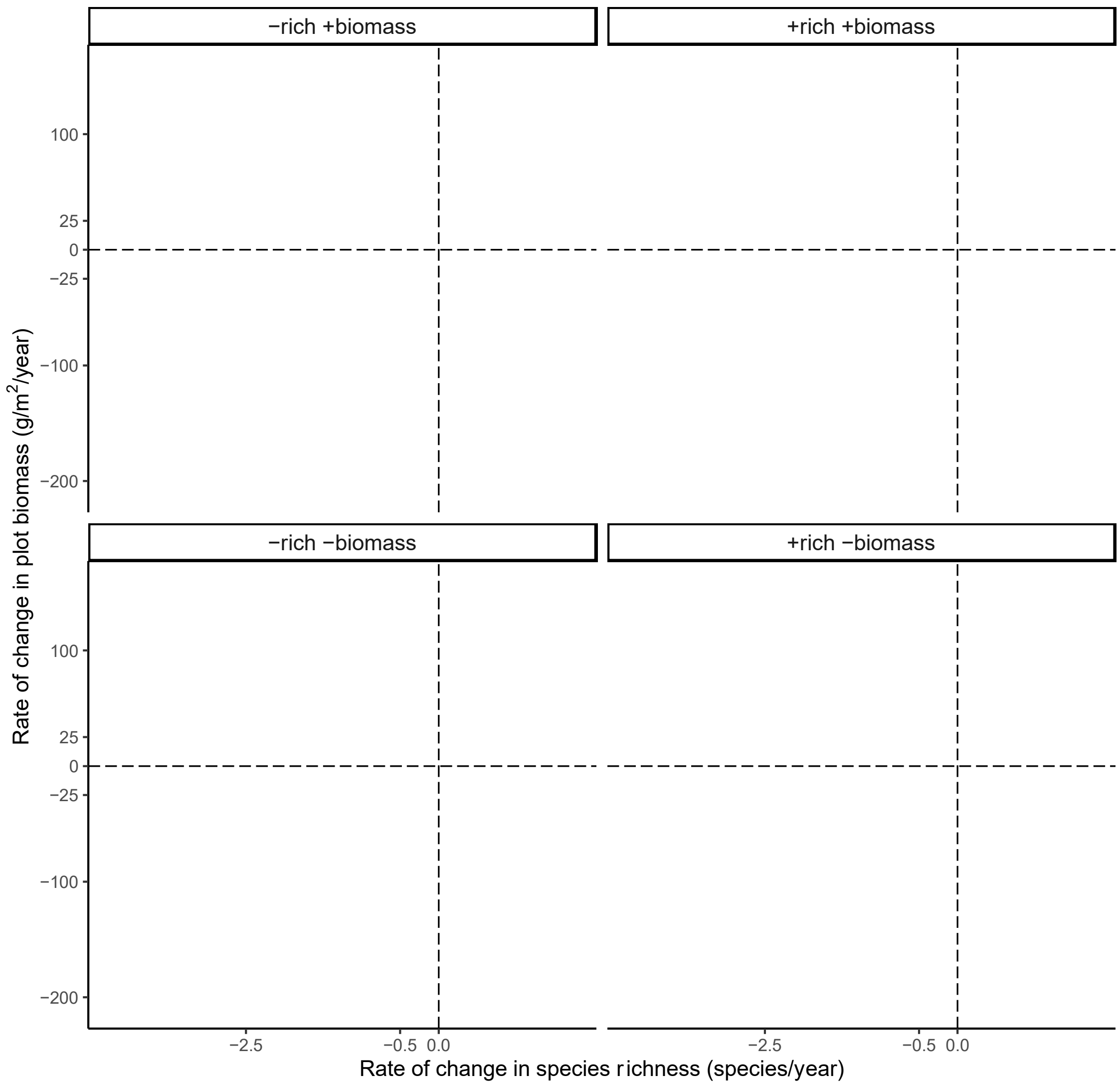

Fig S9: Site-level response of species richness (x-axis) and biomass (y-axis) to NPK at each site. Points are site-level estimates, error bars represent 95% Credible Intervals of site-level estimates. This Figure is analogous to Figure 2c, but is divided by the quadrants each site lands in to tell us each site's response to NPK in terms of richness and biomass. We use these categories (+ - richness, + - biomass) to look at partition components in Figure 5. The site-level response categories defined here are also reported in Table S1, and in the supplementary shiny app: https://emma-ladouceur.shinyapps.io/nn-cafe-app/

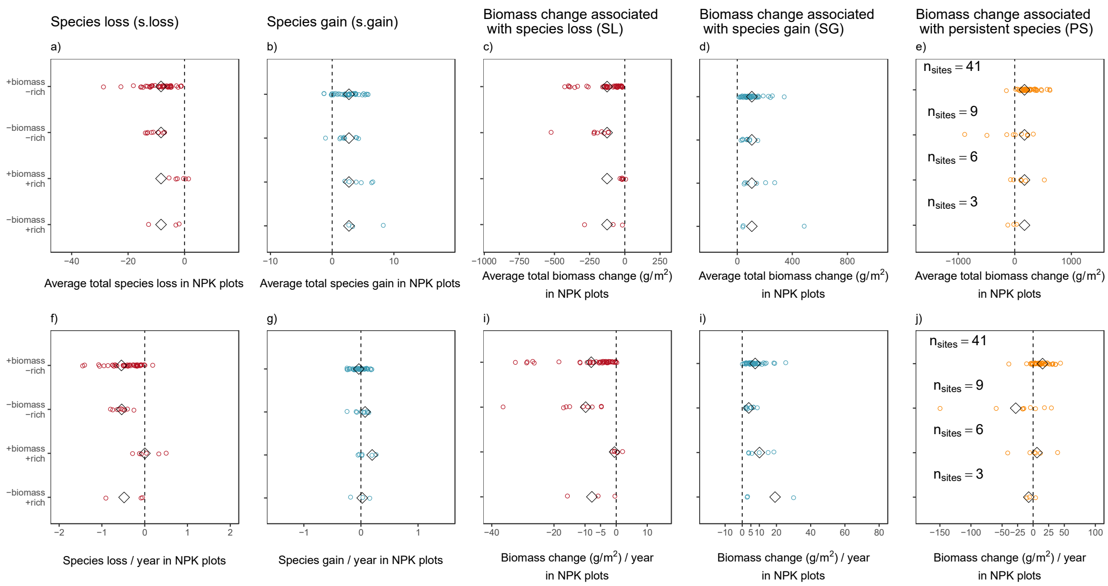

Figure S10: Posterior distributions of components of biodiversity and associated biomass change for each component model. Density plots of the site-level average total (a-e) and slope (f-j) coefficients within a given site-level response to NPK over time in terms of components of change in species richness and total aboveground biomass. The y-axis groups show the quadrant from Fig. S5c & Fig S8 that each site-level NPK slope estimate fell within (e.g., -biomass, -rich shows the posterior density slope estimates for sites where both biomass and the number of species decreased through time). Circles represent the mean each site; diamonds represent the overall/population mean of each y-axis grouping for each metric. X-axes vary for clarity.

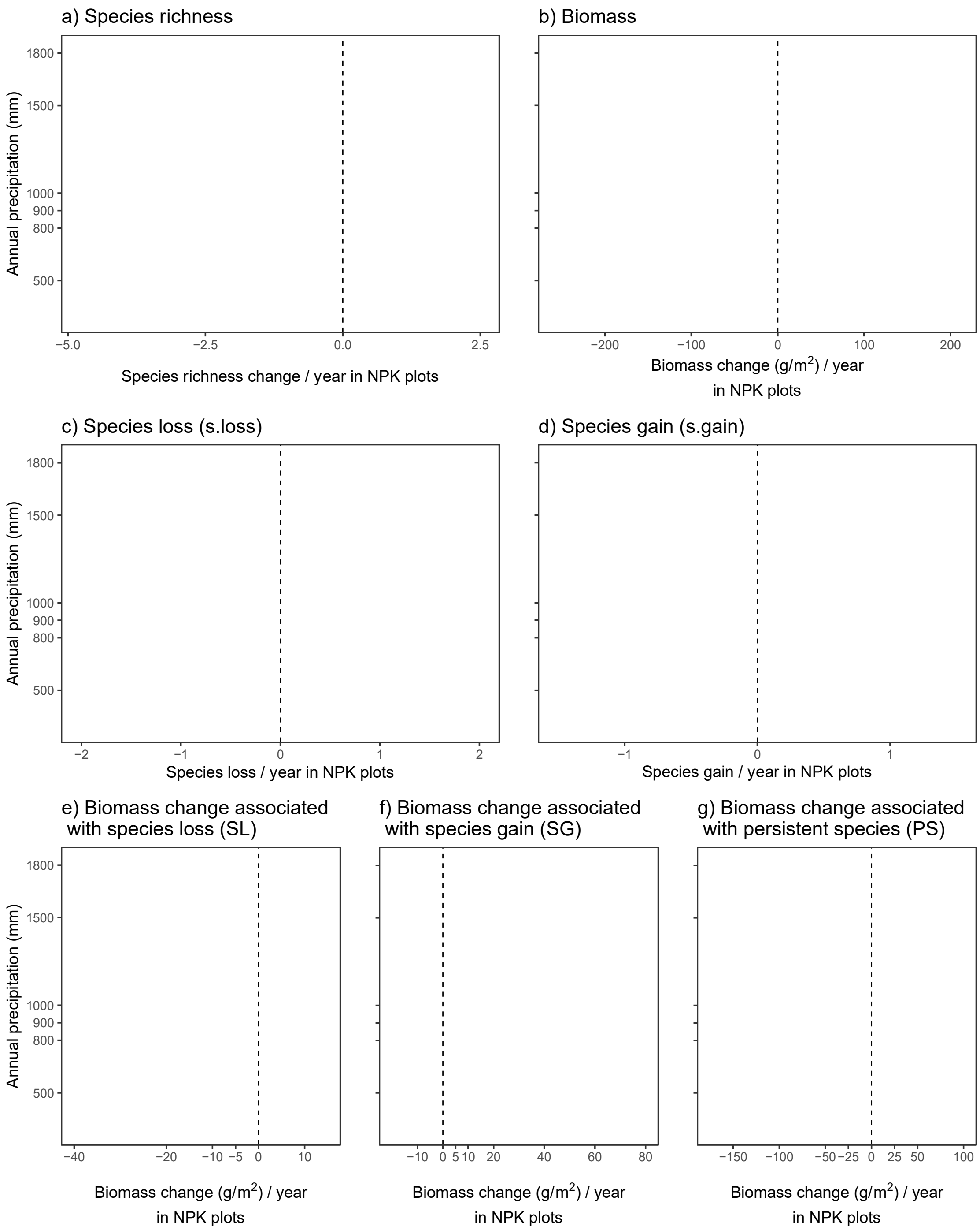

Fig S11: Posterior distributions for each component model against annual precipitation in mm. Density ridges of the site-level slope coefficients within a given site-level response to NPK over time in relation to annual precipitation in mm along the y-axis.

Supplementary results

Results Associated with Figure S5

In control plots, there was no change over time in species richness (mean slope -0.08 species/year, -0.27 to 0.09 95% CI) or aboveground biomass (4.97, 95% CI: -4.37 to 13.97, biomass g/m2/year) (Table S2, Fig. S5).

In plots treated with NPK, species richness declined (-0.47, 95% CI: -0.66 to -0.22, species/year, Fig. S5a) and biomass increased (19.99, 95% CI: 7.14 to 31.11 g/m2/ year, fig. S5b) over time (see Fig. S2 for site level means between year 0 and the most recent year of measurement). The response to NPK addition of species richness change over time and biomass change over time were not correlated (-0.29, 95% CI: -0.63 to 0.19; Fig. S5c, Table S5).