Supporting Information

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SI Methods

Cedar Creek Experimental Design. We used 1997, 1998, 1999, 2002, and 2006 data from the Cedar Creek biodiversity experiment in which 168 9 m × 9 m field plots were planted with randomized combinations of 1, 2, 4, 8, and 16 perennial grassland species (1). We included data on eight ecosystem functions: invasion resistance (100% minus percent cover of invasive species), aboveground net primary productivity, belowground biomass (root biomass) (0–30 cm), nitrogen retention in soil (minimizing NO_2 and NO_3–, 0–20 cm), insect species richness and abundance (in August), change in soil C since 1994 (0–20 cm), and plant N (% total N in above-ground biomass). Soil C data were only collected in 2006, while insect richness and abundance data were not collected in 2006. We did not analyze results from 2000, 2001, 2003–2005, or 2007–2010 because data on all functions were not collected in those years. Insect richness and abundance are indices of habitat quality, an important ecosystem function measured previously in this site and others (2–7). While a few other functions were measured in the original experiment, only these eight functions were chosen because they were measured in multiple years (whereas the others were not) and because they have been measured in other large-scale ecosystem function studies (8–10), making our results more easily comparable to other studies.

Diversity Measures. We created 50,000 unique experimental landscapes, each composed of 24 experimental plots. Within each experimental landscape, γ diversity was calculated as the number of unique species, and $\overline{\alpha}$ diversity as the average α of all 24 experimental communities. Several β diversity metrics are appropriate for expressing nondirectional variation in species composition among all communities in a landscape using presence/absence data (11, 12). We chose the one complement of Sørensen's Index as a sensitive measure of β diversity that scales from 0 (all species in common, low β diversity) to 1 (no species in common, high β diversity). We also calculated a coarser measure of β diversity as the number of experimental communities in an experimental landscape that do not share exactly the same species composition, which scales from 1 (identical communities, low β diversity) to 24 (all different communities, high β diversity). Since results from both are similar, we report the coarser measure in the text because we find it easier to interpret.

Landscape Generation. Given the low degree of replication of species composition in the original experiment, and to generate a distribution of experimental landscapes with a full range of β diversity values, we assembled experimental landscapes with a progressively increasing chance of having identical experimental communities drawn to create them. Since there is no spatial component to these experimental landscapes, plots were selected independently of their spatial location in the original biodiversity experiment.

To ensure an even β distribution, we binned these 50,000 experimental landscapes by their β diversity values (from 1 to 24 binned by 1, and from 0.1 to 1 binned by 0.1 for β = 1 – Sørensen's Index) and randomly selected the same number of experimental landscapes from each bin (equal to the number of experimental landscapes in the smallest bin) to create a distribution with perfectly even β diversity. We chose a landscape size of 24 experimental communities because smaller experimental landscapes did not permit full and evenly distributed ranges of $\overline{\alpha}$, β, and γ diversity values, and larger experimental landscapes did not extend the ranges or further even the distributions. After subsampling from the original pool of 50,000 experimental landscapes as described above to create a pool with more even diversity distributions, we were left with 7,512 experimental landscapes (6,489 experimental landscapes when β = 1 – Sørensen's Index).

Analysis. We assessed the ability of experimental landscapes to simultaneously achieve at least a particular quantile (multifunctionality threshold, or T) of each function across all experimental landscapes and functions (2). Results using percent-of-maximum-based thresholds were qualitatively similar and are shown below. For each year and threshold of the 20th, 30th, 40th, 50th, 60th, and 70th quantiles, we calculated the number of functions above T achieved by each experimental landscape. We also calculated the mean number of functions that each experimental landscape achieved at each threshold across all years.

In addition to a threshold-based approach, we also calculated a unique multifunctionality metric (MF) as the mean of all functions minus its SD in each experimental landscape, where each function is scaled to the maximum observed among all experimental landscapes (where 0 is the minimum and 1 is the maximum observed), and individual functions at the landscape scale are the sums of each function among its 24 component experimental communities. Thus, once they are standardized, calculations of individual functions are simply a reduced form of MF, since individual functions do not have among-function variance. MF takes highest values for landscapes that are high performing across functions. We calculated standardized individual function values and MF for all experimental landscapes in each year, and also averaged for each experimental landscape across years. Functions were assigned positive or negative values if responses to diversity treatments were positive or negative (respectively) from an ecosystem services perspective (8).

We used ordinary least squares regression to determine how the independent variables of $\overline{\alpha}$, β, and γ diversity influenced the dependent variables of each individual function, the number of functions achieved above thresholds, and MF. To compare the strength of effects and explanatory power of each independent variable, we also calculated standardized regression weights and partial coefficients of determination (partial r^2) for each diversity metric in multivariate models of each dependent variable. We also performed an analysis of residual variance on the three bivariate regressions between MF and $\overline{\alpha}$, β, and γ diversity to examine changes in MF variance as a function of diversity.

Standard transformations of independent variables did not improve regression diagnostics or significantly improve model fit. Multicollinearity tolerance always exceeded 0.2, and slope parameter estimates of each independent variable changed less than 2% during both stepwise forward parameter additions and backward deletions, indicating that multicollinearity did not bias interpretations (13, 14). All three biodiversity metrics are included in all regressions reported and displayed in the main text, and are the best models as chosen by Akaike Information Criterion (AIC). All three diversity metrics are also included in either the best model or are within $\Delta AIC \leq 1$ of the best model of the other regressions reported below, with a few exceptions indicated in Tables S1 and S2. We tested for experimental landscape independence and correlation structure by regressing model residuals against each diversity metric. No correlation structure was detected for any regression and *P* values approached 1. Including diversity interaction terms in multiple regressions on multifunctionality increased overall model R^2s by less than 10% relative to regressions with no interaction terms. Given the difficulties of interpreting interactions between continuous variables (15) and their limited explanatory power in this case, we do not report them. We performed all analyses using the R software package (16).

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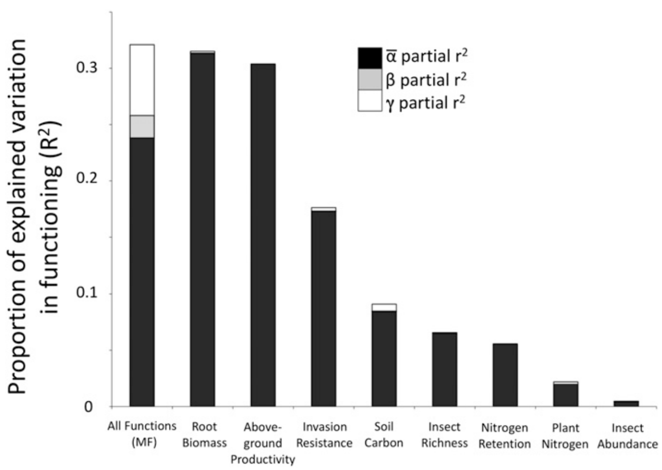

Fig. S1. Biodiversity coefficients of determination. Partial coefficients of determination for $\bar{\alpha}$, β and γ diversities in nine multiple regressions explaining cross-year averages of multifunctionality and each single function (soil carbon data from 2006 only). The r^2s reflect the proportion of variance explained by each scale of diversity in each regression ($P < 0.001$ for all coefficients) and sum to the total variance explained (R^2). β diversity is calculated as the number of experimental communities in an experimental landscape that do not share exactly the same species composition. Results with β calculated as 1 – Sorensen's Index are qualitatively similar.

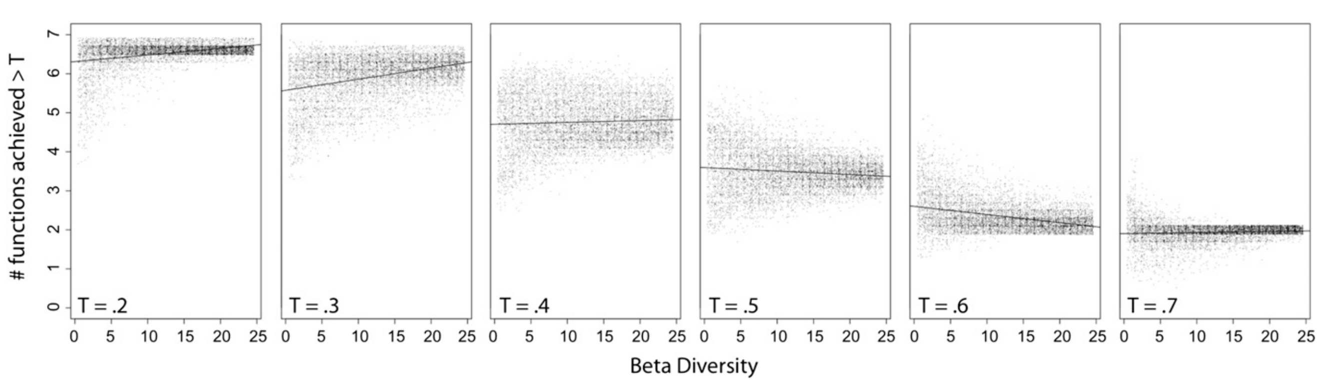

Fig. S2. Effect of β diversity on the average number of functions achieved by each experimental landscape above thresholds (T) across all years, where T is the percent-of-maximum observed functioning of each function across all experimental landscapes. β diversity is calculated as the number of experimental communities in an experimental landscape that do not share exactly the same species composition. n = 7,512 experimental landscapes. $P < 0.001$ for all.

Table S1. Standardized regression coefficients for the effects of $\overline{\alpha}$, β, and γ diversity on single and multiple functions

Threshold	Year	Function	$\overline{\alpha}$	β	γ	R^2
multifunctionality (not threshold-based)	All	All	0.46	0.11	0.16	0.32
multifunctionality (not threshold-based)	1997	All	0.12	0.08	0.17	0.08
multifunctionality (not threshold-based)	1998	All	0.29	0.08	0.11	0.14
multifunctionality (not threshold-based)	1999	All	0.36	0.11	0.14	0.22
multifunctionality (not threshold-based)	2002	All	0.43	0.12	0.15	0.30
multifunctionality (not threshold-based)	2006	All	0.57	0.06	0.10	0.39
20	All	All	0.36	0.53	0.16	0.57
20	1997	All	0.21	0.42	0.14	0.33
20	1998	All	0.34	0.44	0.12	0.41
20	1999	All	0.26	0.44	0.13	0.37
20	2002	All	0.30	0.44	0.14	0.41
20	2006	All	0.41	0.44	0.10	0.45
30	All	All	0.49	0.52	−0.02	0.49
30	1997	All	0.27	0.39	0.01*	0.23
30	1998	All	0.41	0.41	−0.03	0.31
30	1999	All	0.35	0.43	−0.01*	0.30
30	2002	All	0.40	0.43	−0.01	0.33
30	2006	All	0.51	0.40	−0.04	0.38
40	All	All	0.58	0.35	−0.10	0.38
40	1997	All	0.31	0.25	−0.04	0.14
40	1998	All	0.43	0.27	−0.08	0.21
40	1999	All	0.40	0.29	−0.07	0.20
40	2002	All	0.46	0.28	−0.08	0.24
40	2006	All	0.59	0.23	−0.12	0.32
50	All	All	0.61	0.08	−0.14	0.31
50	1997	All	0.32	0.06	−0.07	0.09
50	1998	All	0.42	0.07	−0.10	0.15
50	1999	All	0.42	0.09	−0.10	0.15
50	2002	All	0.48	0.05	−0.11	0.19
50	2006	All	0.61	0.02	−0.15	0.32
60	All	All	0.56	−0.22	−0.14	0.35
60	1997	All	0.30	−0.16	−0.07	0.12
60	1998	All	0.40	−0.15	−0.10	0.18
60	1999	All	0.40	−0.15	−0.09	0.18
60	2002	All	0.44	−0.18	−0.11	0.22
60	2006	All	0.57	−0.20	−0.15	0.35
70	All	All	0.47	−0.45	−0.13	0.46
70	1997	All	0.26	−0.35	−0.07	0.21
70	1998	All	0.33	−0.34	−0.09	0.24
70	1999	All	0.36	−0.33	−0.11	0.26
70	2002	All	0.38	−0.37	−0.11	0.31
70	2006	All	0.51	−0.38	−0.15	0.43
NA	All	Nitrogen retention	0.24	0.00	−0.01	0.06
NA	All	Above-ground productivity	0.55	0.01	−0.02	0.30
NA	All	Insect abundance	0.07	0.00	0.00	0.01
NA	All	Insect richness	0.26	0.01	−0.01	0.07
NA	All	Invasion resistance	0.41	−0.02	0.02	0.18
NA	All	Plant nitrogen	−0.14	0.00	−0.03	0.07
NA	All	Root biomass	0.56	0.01	0.01	0.32
NA	1997	Nitrogen retention	0.26	0.00	−0.02	0.06
NA	1997	Above-ground productivity	0.26	0.00	0.00	0.07
NA	1997	Insect richness	0.29	0.01	−0.03	0.00
NA	1997	Insect abundance	0.01*	0.00*	−0.01*	0.08
NA	1997	Invasion resistance	0.36	−0.02	0.02	0.14
NA	1997	Plant nitrogen	−0.25	0.00*	−0.01*	0.07
NA	1997	Root biomass	0.14	−0.02*	0.05	0.03
NA	1998	Nitrogen retention	0.27	0.01	−0.02	0.07
NA	1998	Above-ground productivity	0.36	0.01	−0.03	0.12
NA	1998	Insect abundance	−0.04	0.01	0.00	0.00
NA	1998	Insect richness	0.22	0.01	0.00	0.05
NA	1998	Invasion resistance	0.41	0.00	−0.01	0.16
NA	1998	Plant nitrogen	−0.02	−0.01	−0.01	0.00
NA	1998	Root biomass	0.38	0.00	0.00	0.14

Table S1. Cont.

Threshold	Year	Function	$\bar{\alpha}$	β	γ	R^2
NA	1999	Nitrogen retention	0.04	0.01*	−0.02	0.00
NA	1999	Above-ground productivity	0.55	0.01	−0.02	0.29
NA	1999	Insect abundance	0.17	0.00*	0.01	0.03
NA	1999	Insect richness	0.05	0.01	0.00*	0.00
NA	1999	Invasion resistance	0.39	−0.01	0.02	0.16
NA	1999	Plant nitrogen	−0.16	0.01	−0.03	0.03
NA	1999	Root biomass	0.44	0.02	0.00	0.19
NA	2002	Nitrogen retention	−0.06	−0.03	0.01*	0.00
NA	2002	Above-ground productivity	0.59	0.01*	−0.01	0.34
NA	2002	Insect abundance	0.03	0.01	0.00*	0.00
NA	2002	Insect richness	0.24	0.01	0.00	0.06
NA	2002	Invasion resistance	0.36	−0.02	0.01	0.13
NA	2002	Plant nitrogen	−0.09	0.01	−0.03	0.01
NA	2002	Root biomass	0.54	0.01	0.00	0.30
NA	2006	Nitrogen retention	0.22	0.01	0.00*	0.05
NA	2006	Above-ground productivity	0.65	0.01*	−0.01	0.42
NA	2006	Invasion resistance	0.18	−0.02	0.03	0.04
NA	2006	Plant nitrogen	−0.08	0.01	−0.03	0.01
NA	2006	Root biomass	0.68	0.01	0.00*	0.45
NA	2006	Soil carbon	0.28	0.00	0.04	0.09

β diversity is calculated as the number of communities in a landscape that do not share exactly the same species composition. n = 7,512 landscapes for each regression. NA indicates not applicable because regressions measure single functions. $P < 0.05$ for all regressions.

*Parameter should not be included in best model as selected by AIC.

Table S2. Standardized regression coefficients for the effects of $\overline{\alpha}$, β, and γ diversity on single and multiple functions

Threshold	Year	Function	$\overline{\alpha}$	β	γ	R^2
multifunctionality (not threshold-based)	All	All	0.59	0.18	0.05	0.34
multifunctionality (not threshold-based)	1997	All	0.21	0.17	0.05	0.07
multifunctionality (not threshold-based)	1998	All	0.34	0.11	0.05	0.13
multifunctionality (not threshold-based)	1999	All	0.47	0.16	0.06	0.23
multifunctionality (not threshold-based)	2002	All	0.59	0.20	0.03	0.33
multifunctionality (not threshold-based)	2006	All	0.67	0.09	0.01	0.43
20	All	All	0.59	0.49	0.10	0.49
20	1997	All	0.34	0.39	0.09	0.25
20	1998	All	0.49	0.39	0.09	0.34
20	1999	All	0.42	0.39	0.10	0.30
20	2002	All	0.54	0.44	0.06	0.38
20	2006	All	0.61	0.37	0.06	0.41
30	All	All	0.60	0.34	0.07	0.40
30	1997	All	0.36	0.30	0.05	0.18
30	1998	All	0.46	0.25	0.08	0.25
30	1999	All	0.40	0.25	0.10	0.23
30	2002	All	0.54	0.31	0.02	0.29
30	2006	All	0.64	0.25	0.00	0.36
40	All	All	0.62	0.14	0.02	0.36
40	1997	All	0.35	0.15	0.02	0.12
40	1998	All	0.43	0.09	0.04	0.19
40	1999	All	0.42	0.11	0.06	0.19
40	2002	All	0.54	0.12	−0.02	0.25
40	2006	All	0.65	0.07	−0.04	0.37
50	All	All	0.58	−0.10	−0.01*	0.38
50	1997	All	0.31	−0.04	0.02*	0.11
50	1998	All	0.37	−0.09	0.03	0.18
50	1999	All	0.40	−0.08	0.03	0.20
50	2002	All	0.50	−0.07	−0.04	0.26
50	2006	All	0.63	−0.09	−0.07	0.40
60	All	All	0.50	−0.31	−0.02	0.44
60	1997	All	0.23	−0.23	0.03	0.15
60	1998	All	0.30	−0.26	0.03	0.22
60	1999	All	0.36	−0.24	0.00*	0.25
60	2002	All	0.45	−0.23	−0.06	0.32
60	2006	All	0.58	−0.22	−0.08	0.46
70	All	All	0.40	−0.47	−0.03	0.52
70	1997	All	0.18	−0.38	0.01	0.22
70	1998	All	0.24	−0.38	0.01	0.27
70	1999	All	0.30	−0.39	0.00	0.32
70	2002	All	0.38	−0.36	−0.06	0.38
70	2006	All	0.50	−0.36	−0.09	0.50
NA	All	Nitrogen retention	0.20	−0.04	0.03	0.05
NA	All	Above-ground productivity	0.52	−0.05	0.03	0.31
NA	All	Insect abundance	0.06	−0.01	0.01	0.02
NA	All	Insect richness	0.21	−0.04	0.03	0.06
NA	All	Invasion resistance	0.44	−0.04	0.02	0.22
NA	All	Plant nitrogen	−0.13	0.04	−0.04	0.02
NA	All	Root biomass	0.54	−0.05	0.05	0.32
NA	1997	Nitrogen retention	0.17	−0.08	0.06	0.06
NA	1997	Above-ground productivity	0.19	−0.07	0.06	0.07
NA	1997	Insect abundance	−0.03	0.00	0.00	0.00
NA	1997	Insect richness	0.24	−0.03	0.03	0.07
NA	1997	Invasion resistance	0.39	−0.03	0.02	0.17
NA	1997	Plant nitrogen	−0.22	0.07	−0.06	0.08
NA	1997	Root biomass	0.12	−0.04	0.04	0.03
NA	1998	Nitrogen retention	0.23	−0.05	0.04	0.07
NA	1998	Above-ground productivity	0.29	−0.07	0.05	0.12
NA	1998	Insect abundance	−0.08	−0.02	0.02	0.00
NA	1998	Insect richness	0.18	−0.03	0.04	0.04
NA	1998	Invasion resistance	0.42	−0.08	0.03	0.22
NA	1998	Plant nitrogen	0.00	0.04	−0.03	0.00
NA	1998	Root biomass	0.33	−0.05	0.04	0.14

Table S2. Cont.

Threshold	Year	Function	$\bar{\alpha}$	β	γ	R^2
NA	1999	Nitrogen retention	0.00	−0.04	0.04	0.00
NA	1999	Above-ground productivity	0.52	−0.03	0.01	0.28
NA	1999	Insect abundance	0.18	0.00	0.02	0.04
NA	1999	Insect richness	0.01	−0.04	0.04	0.00
NA	1999	Invasion resistance	0.39	−0.09	0.07	0.21
NA	1999	Plant nitrogen	−0.15	0.04	−0.05	0.04
NA	1999	Root biomass	0.42	−0.05	0.06	0.22
NA	2002	Nitrogen retention	0.00	0.05	−0.06	0.00
NA	2002	Above-ground productivity	0.56	−0.04	0.03	0.35
NA	2002	Insect abundance	0.05	0.01	−0.01	0.00
NA	2002	insect richness	0.24	−0.02	0.00	0.06
NA	2002	Invasion resistance	0.39	−0.03	0.00	0.16
NA	2002	Plant nitrogen	−0.13	0.00	0.00	0.02
NA	2002	Root biomass	0.53	−0.06	0.05	0.34
NA	2006	Nitrogen retention	0.25	0.00	0.00	0.06
NA	2006	Above-ground productivity	0.68	−0.01	−0.01	0.46
NA	2006	Invasion resistance	0.27	0.05	−0.05	0.05
NA	2006	Plant nitrogen	−0.07	0.02	−0.03	0.01
NA	2006	Root biomass	0.69	−0.02	0.00	0.49
NA	2006	Soil carbon	0.29	−0.01	0.01	0.09

β is measured as 1 – Sørensen's index. n = 6,489 landscapes for each regression. NA indicates not applicable because regressions measure single functions. $P < 0.05$ for all regressions.

*Parameter should not be included in best model as selected by AIC.