Oikos

OIK-05867

Grinath, J. B., Larios, L., Prugh, L. R., Brashares, J. S. and Suding, K. N.Environmental gradients determine the potential for ecosystem engineering effects. – Oikos doi: 10.1111/oik.05867

Appendix 1

Table A1. Linear mixed effects model (LMM) results for soil property responses to rainfall, burrowing and rodent presence.

Soil property	Trans-form	Variance structure	N Obs./ Plots-Sites	Main effect*	χ^2	p	Interaction term*	χ^2	p
Ammonium (mg N/ kg dry soil)	LN(x+1)	Power (R)	207/36-18	Rainfall (R)	1.60	0.205	R x B	0.24	0.622
				Burrowing (B)	**4.95**	**0.026**	R x Pr	1.26	0.262
				Presence (Pr)	**8.94**	**0.003**	B x Pr	1.28	0.259
							R x B x Pr	<0.01	0.947
Nitrate (mg N/ kg dry soil)	LN(x+1)	Identity (Pr)	211/36-18	**Rainfall (R)**	**108.31**	**<0.001**	**R x B**	**6.76**	**0.009**
				Burrowing (B)	**98.06**	**<0.001**	R x Pr	0.21	0.645
				Presence (Pr)	1.50	0.221	B x Pr	1.97	0.160
							R x B x Pr	0.56	0.454
Nitrogen mineralization (mg N/ kg dry soil/ day)	NA	None	46/31-18	Rainfall (R)	2.09	0.149	**R x B**	**4.25**	**0.039**
				Burrowing (B)	0.57	0.450	R x Pr	0.06	0.799
				Presence (Pr)	<0.01	0.996	B x Pr	2.40	0.121
							R x B x Pr	0.58	0.446
Volumetric water content (%)	NA	Power (R)	282/36-18	**Rainfall (R)**	**41.11**	**<0.001**	**R x B**	**9.11**	**0.003**
				Burrowing (B)	**59.57**	**<0.001**	R x Pr	0.55	0.458
				Presence (Pr)	1.44	0.231	B x Pr	0.01	0.928
							R x B x Pr	0.17	0.680

*One degree of freedom was used for each explanatory term. Results provided are from Analysis of Deviance tables produced with the 'Anova' function from the 'car' package.

Table A2. Linear mixed effects model (LMM) results for rarefied plant diversity responses to rainfall, burrowing and rodent presence.

Plant diversity	Variance structure	N Obs./ Sites	Main effect*	χ^2	p	Interaction term*	χ^2	p
Alpha (within habitats)	None	69/18	**Rainfall (R)**	**5.31**	**0.021**	R x B	0.18	0.672
			Burrowing (B)	3.01	0.083	R x Pr	0.01	0.911
			Presence (Pr)	3.33	0.068	B x Pr	1.87	0.171
						R x B x Pr	0.04	0.843
Beta (between habitats)	None	34/18	**Rainfall (R)**	**5.97**	**0.015**	R x Pr	<0.01	0.996
			Presence (Pr)	1.85	0.173			
Gamma (across habitats)	None	34/18	Rainfall (R)	0.18	0.674	R x Pr	0.07	0.799
			Presence (Pr)	0.34	0.558			

*One degree of freedom was used for each explanatory term. Results provided are from Analysis of Deviance tables produced with the 'Anova' function from the 'car' package.

Table A3. Linear mixed effects model (LMM) results for quadrat-level plant responses to rainfall, burrowing and rodent presence.

Plant variable	Trans-form	Variance structure	N Obs./ Plots-Sites	Main effect*	χ^2	p	Interaction term*	χ^2	p
Aboveground net primary production (g/m^2/year)	LN(x+1)	Identity (Pr)	268/35-18	**Rainfall (R)**	**154.03**	**<0.001**	**R x B**	**4.67**	**0.031**
				Burrowing (B)	1.30	0.255	R x Pr	1.23	0.267
				Presence (Pr)	**8.35**	**0.004**	B x Pr	2.24	0.134
							R x B x Pr	<0.01	0.965
Shannon evenness (*E*)	NA	Identity (B)	282/36-18	**Rainfall (R)**	**29.06**	**<0.001**	R x B	1.79	0.181
				Burrowing (B)	**6.93**	**0.008**	R x Pr	0.71	0.398
				Presence (Pr)	**8.41**	**0.004**	B x Pr	0.79	0.374
							R x B x Pr	0.35	0.553
Species densities (#/m^2)	NA	Identity (B)	282/36-18	**Rainfall (R)**	**6.59**	**0.010**	R x B	0.03	0.872
				Burrowing (B)	**9.46**	**0.002**	R x Pr	0.30	0.583
				Presence (Pr)	<0.01	0.972	B x Pr	0.12	0.728
							R x B x Pr	0.03	0.859

*One degree of freedom was used for each explanatory term. Results provided are from Analysis of Deviance tables produced with the 'Anova' function from the 'car' package.

Table A4. Permutational multivariate analysis of variance (PERMANOVA) results of plant community composition responses to rainfall, burrowing and rodent presence.

Dependent variable	d.f.	Predictor variable	F	p	R^2
Bray-Curtis dissimilarities	1	**Burrowing (B)**	**6.53**	**0.001**	**0.044**
	2	**Rainfall (R)**	**4.29**	**0.002**	**0.058**
	1	**Presence (Pr)**	**5.69**	**0.001**	**0.038**
N Obs.: 68	16	**Site**	**5.10**	**0.001**	**0.548**
N Sites: 18	2	R x B	1.10	0.401	0.015
	1	B x Pr	0.86	0.504	0.006
Permutations: 999	1	R x Pr	1.24	0.204	0.008
	2	R x B x Pr	0.61	0.863	0.008
residuals =	41				0.275

Table A5. Permutational multivariate analysis of dispersion (PERMDISP) results of plant community composition responses to rainfall, burrowing and rodent presence.

Dependent variable	N Obs.	Permutations	d.f.	Predictor variable	F	p
Bray-Curtis dissimilarities	68	999	2	**Rainfall**	**4.92**	**0.012**
Bray-Curtis dissimilarities	68	999	1	Burrowing	0.11	0.751
Bray-Curtis dissimilarities	68	999	1	Presence	0.02	0.898

Table A6. Environmental fit of soil properties to the NMDS ordination of plant community composition.

N Obs.	Permutations	Transform	Soil property	p	R^2
68	999	NA	Water content	0.159	0.055
		LN(x +1)	**Ammonium**	**0.016**	**0.120**
		LN(x +1)	Nitrate	0.242	0.043
45	999	NA	**N mineralization**	**0.003**	**0.235**

Table A7. Plant species indicator values across rainfall levels on and off burrows. Indicator values are based on each species' fidelity and relative cover across the experimental groups. Significant indicator species ($p \leq 0.05$) are shown with '*' and the score in bold for the experimental condition they indicate.

		Growing season rainfall:	6.4 cm		12.8 cm		19.2 cm	
Plant ID		Scientific name Burrow:	Off	On	Off	On	Off	On
Forbs	F3	*Amsinckia tessellata*	0.2733	0.3512	0.1935	0.4731	0.2233	0.4478
	F4	*Calandrinia menziesii*	0.4322	0.2387	0.2537	0.2050	0.2023	0.1816
	F6	*Capsella bursa-pastoris*	0.0000	0.0000	0.1894	0.3081	0.0000	0.0000
	F8	*Caulanthus lasiophyllus*	0.3055	0.3547	0.3147	0.3612	0.2115	0.4440
	F9	*Chorizanthe uniaristata*	0.2205	0.0771	0.1543	0.0000	0.4480	0.0000
	F12	*Dichelostemma capitatum*	0.4193	0.2011	0.1901	0.0570	0.2684	0.0563
	F13	*Eriogonum gracillimum*	0.1856	0.2730	0.1203	0.1273	0.1820	0.3308
	F14	*Erodium cicutarium*	0.4075	0.4247	0.4150	0.4404	0.3930	0.3647
	F15	*Herniaria hirsuta* ssp. *cineria*	0.3154	0.0980	0.3102	0.1486	0.3295	0.2818
	F16	*Hollisteria lanata*	0.0000	0.0000	0.3653	0.2213	0.2852	0.1016
	F17	*Lasthenia californica*	0.2434	0.1712	0.3258	0.1784	0.3386	0.0946
	F18	*Lasthenia minor*	0.2118	0.1840	0.2581	0.3080	0.3518	0.1503
	F19	*Lepidium dictyotum*	0.1882	0.2893	0.0461	0.0000	0.2737	0.3153
	F20	*Lepidium nitidum*	0.4839	0.3787	0.4503	0.3409	0.3770	0.2368
	F21	***Leptosiphon liniflorus***	0.0000	0.0000	0.0939	0.0000	**0.5460***	0.0000
	F22	*Malacothrix coulteri*	0.3164	0.0000	0.0000	0.0000	0.1604	0.1695
	F24	*Microseris elegans*	0.1923	0.1467	0.0000	0.0000	0.0817	0.2363
	F25	*Monolopia lanceolata*	0.2535	0.4166	0.0000	0.0000	0.0000	0.1292
	F26	*Pectocarya penicillata*	0.4152	0.2488	0.2035	0.0801	0.1740	0.0561
	F29	*Salsola tragus*	0.0000	0.1677	0.0925	0.1144	0.0795	0.1787
	F31	*Sisymbrium irio*	0.0000	0.0000	0.2268	0.0572	0.2691	0.2458
	F32	***Trichostema lanceolatum***	0.0000	0.0000	0.0744	0.0000	**0.4831***	0.0000
	F33	*Tropidocarpum gracile*	0.3646	0.2881	0.1676	0.2550	0.4122	0.1622
Grasses	G1	*Bromus madritensis* ssp. *rubens*	0.2769	0.1555	0.2600	0.2338	0.3288	0.5144
	G2	*Festuca bromoides*	0.0000	0.0000	0.2789	0.2585	0.1660	0.0430
	G3	***Festuca microstachys* v. *pauciflora***	0.0000	0.0000	**0.5615***	0.5219	0.3483	0.3322
	G4	*Festuca myuros* v. *hirsuta*	0.0000	0.0000	0.1635	0.0645	0.2867	0.2223
	G5	***Hordeum murinum***	0.1429	0.3700	0.2062	0.4418	0.3068	**0.5757***
	G7	*Schismus arabicus*	0.3317	0.3981	0.4272	0.3385	0.4677	0.4390
Legumes	L1	***Acmispon wrangelianus***	0.2685	**0.4750***	0.0334	0.0000	0.0739	0.0698
	L2	*Astragalus* sp.	0.3391	0.1235	0.0000	0.0000	0.2612	0.0000
	L3	*Lupinus microcarpus* v. *microcarpus*	0.0000	0.1886	0.0000	0.0000	0.3277	0.0000
	L4	*Trifolium gracilentum*	0.3614	0.3395	0.0871	0.0525	0.1201	0.0355

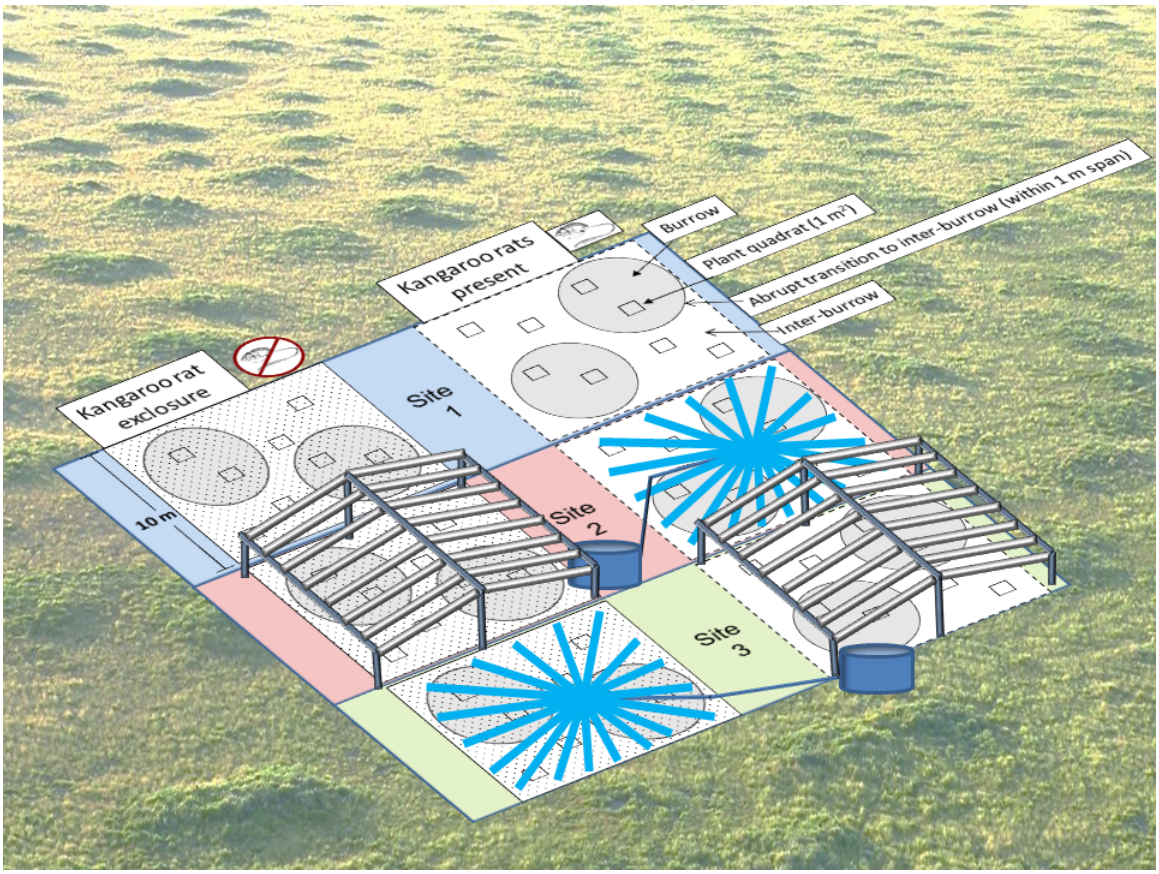

Figure A1. Diagram of the experimental setup. All 18 sites consisted of two plots (100 m²) spanning kangaroo rat burrow and inter-burrow habitats, which were sampled using eight 1 m² quadrats/plot. At each site, plots were located in a rodent exclosure and a control area with rodents present. Using a stratified design, we randomly assigned three rainfall treatments within groups of three neighboring sites. Rainfall was not manipulated in the first treatment and these plots received ambient precipitation. In the second treatment, we removed 50% of rainfall with shelters over plots in the rodent exclosures and added this rainwater to plots with rodents present. The third treatment removed 50% of rainwater from plots where rodents were present and added this precipitation to plots within rodent exclosures. The Carrizo Plain is shown in the background photo (credit: Don Johnson); giant kangaroo rat burrows are evidenced by mounded topography.

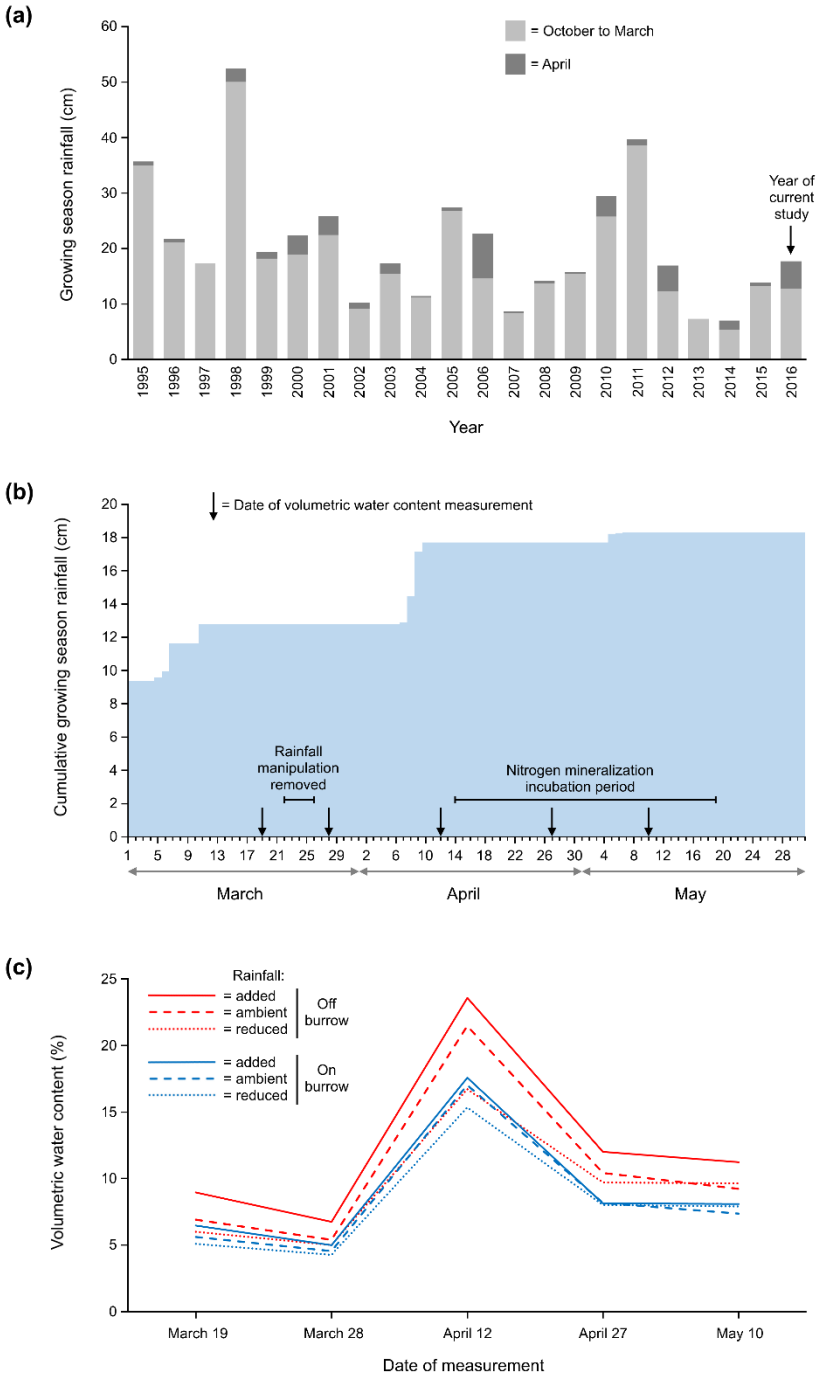

Figure A2. Growing season precipitation (a) preceding and (b) during the study, and (c) average soil water content across the experimental conditions before and after the removal of the rainfall manipulation.

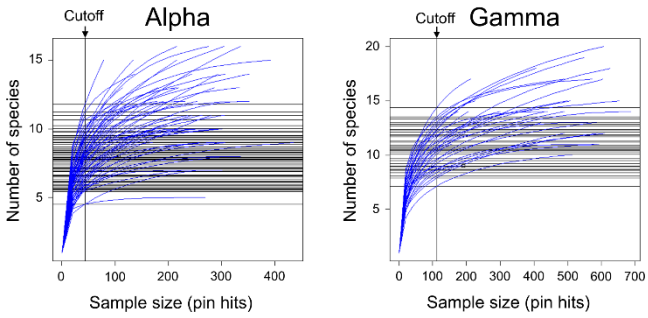

Figure A3. Rarefaction curves for cover-corrected measures of alpha and gamma diversity. Summing raw pinframe observations across quadrats within each experimental treatment, we used the 'rarefy' function from the 'vegan' package in R to estimate alpha diversity as species richness from the first 44 observations (from bootstrapped random samples) within burrow and inter-burrow habitats in each plot (cutoff point determined by the sample with the fewest number of observations). Prior to rarefaction, one plot was withheld because of a lack of quadrats off burrow; another community was withheld because too few individuals were observed to obtain rarefied estimates (n = 69 communities total). Similarly, we summed observations across all quadrats within each plot to estimate gamma diversity as species richness over the first 112 observations per plot (using bootstrapped random samples). Horizontal lines depict the rarefied number of species calculated for each sample.

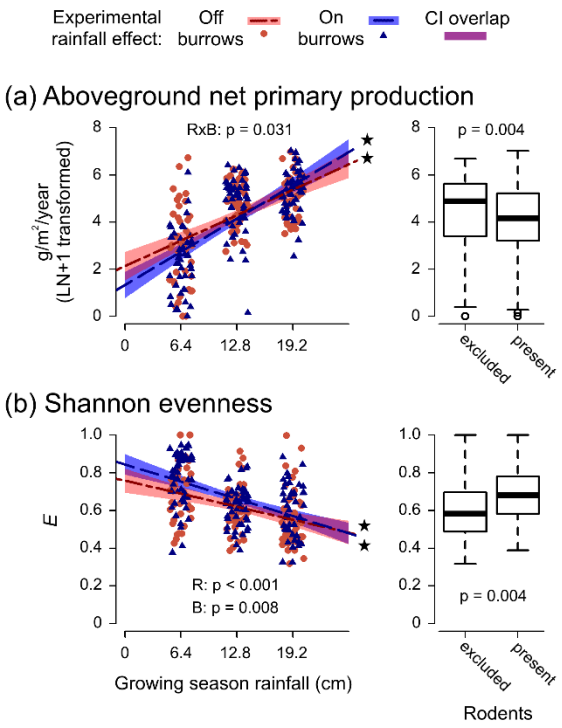

Figure A4. Quadrat-level plant (a) production and (b) species evenness responses to experimental rainfall, rodent burrowing, and rodent presence. The p-values shown (R: rainfall, B: burrowing, RxB: interaction) are from linear mixed effects models. Rainfall and burrowing effects are visualized with post hoc regressions with 95% confidence intervals; effects of rodent presence are shown as boxplots. Significant post hoc regressions (slope: $p \leq 0.05$) are indicated by stars. Points are jittered at each rainfall level to show y-axis variability.