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Drought rewires the cores of food webs

SUPPLEMENTARY INFORMATION

Supplementary Table S1 List of species, their label and their trophic category. Their distributions in the core and periphery in the control and drought food webs are indicated by the web ID.

Species	**Label**	**Category**	**Control**		**Drought**	
			Core	Periphery	Core	Periphery
Amorphous detritus	1	detritus	1,2,3,4		1,2,3,4	
Fungal spores	2	detritus	1	2,3,4		1,2,3,4
Hyphomycete fungal hyphae	3	decomposer	1,3,4	2	1,2,4	3
Plant fragments	4	detritus	1,2,3,4		1,2,3,4	
Algal cysts	5	producer		1,2,3,4		2,3,4
Amphora ovalis	6	producer		1,2,3,4		2,3,4
Amphora pediculus	7	producer	1,2,3,4		1,3,4	2
Chrococcus minor	8	producer	1,3,4	2	1,4	2,3
Cocconeis placentula	9	producer	1,2,3,4		1,2,3,4	
Cymatopleura solea	10	producer		1,2,3,4		2,3,4
Cymbella lanceolata	11	producer		4		3
Diatoma vulgare	12	producer	2	1,3,4		2,3,4
Encyonema minutum	13	producer		1,2,3,4		1,2,3,4
Fragilaria vaucheriae	14	producer		1,2,3,4		2,3,4
Gomphonema olivaceum	15	producer	1,2,3,4		1,2,3	4
Gongrosira incrustans	16	producer	1,2,3,4		2	1,3,4
Gyrosigma sp.	17	producer		3,4		1,2,3,4
Melosira varians	18	producer	1,2,3,4		2,3,4	1
Navicula gregaria	19	producer	2,3,4	1	1,3,4	2
Navicula lanceolata	20	producer	2,3,4	1	1	2,3,4
Navicula menisculus	21	producer	2,3,4	1	2	1,3,4
Navicula tripunctata	22	producer	1,2,3,4		1,3,4	2
Nitzschia dissipata	23	producer	1,2,3,4		1,3,4	2
Nitzschia perminuta	24	producer	1,2,3,4		1,2	3,4
Planothidium lanceolatum	25	producer		1,2,3,4		1,2,3,4
Psammothidium lauenburgianum	26	producer		1,2,3,4		1,2,3,4
Rhoicosphenia abbreviata	27	producer	1,2,3,4		1,2,3,4	
Spirulina sp.	28	producer		1,2,3,4		1,2,3,4
Staurosira elliptica	29	producer	1,2,3,4		2,3,4	1
Staurosirella leptostauron	30	producer		2,3		1,3
Surirella brebissonii	31	producer		4		2,3,4
Surirella minuta	32	producer		1,2,3,4		1,2,4
Synedra ulna	33	producer		1,4		1,4

Ancylus fluviatilis	34	invertebrate	1,2,3,4			
Asellus aquaticus	35	invertebrate	1,2,3,4		3,4	2
Athripsodes sp.	36	invertebrate	3	1,2,4		
Baetis sp.	37	invertebrate	1,3	4	1	3,4
Brachycentrus subnubilus	38	invertebrate	1,2		3	
Brychius elevatus	39	invertebrate		1,2		
Cricotopus sp.	40	invertebrate	3,4	1,2	1,3,4	
Cryptochironomus sp.	41	invertebrate	4	1,2		1,2,3,4
Eiseniella tetraedra	42	invertebrate			1,3	
Elmis aenea	43	invertebrate		1,2,3,4		
Ephemera danica	44	invertebrate	1,3,4	2	1,2	
Erpobdella octoculata	45	invertebrate	2,3,4	1		
Gammarus pulex	46	invertebrate	1,2,3,4		1,2,3,4	
Haliplus lineatocollis	47	invertebrate		2,3,4		
Heterotrissocladius sp.	48	invertebrate	1,3,4	2	1,3,4	
Hydropsyche sp.	49	invertebrate	2,3,4	1		1,4
Leuctra geniculata	50	invertebrate		1		
Limnius volckmari	51	invertebrate		1,2,3,4		1,2,3,4
Macropelopia sp.	52	invertebrate	4	1,2,3	1	2,3,4
Microtendipes sp.	53	invertebrate	1,2,3,4		1,2,3,4	
Naididae	54	invertebrate	1,2,3,4		1,2,3,4	
Ostracoda	55	invertebrate		1,3,4		
Oulimnius tuberculatus	56	invertebrate		1,2,3,4		1,4
Pentaneura sp.	57	invertebrate		2,3,4		
Pisidium sp.	58	invertebrate	4	1,2,3		1,2,3,4
Platambus maculatus	59	invertebrate		3		
Polycentropus flavomaculatus	60	invertebrate	4	1,2,3		
Polypedilum sp.	61	invertebrate		1,2,4		
Potamopyrgus antipodarum	62	invertebrate	2,3,4	1	1,2,3	4
Procladius sp.	63	invertebrate		2,4		2,4
Prodiamesa olivacea	64	invertebrate	4			4
Radix balthica	65	invertebrate	1,2,3,4		1,2,3,4	
Sericostoma personatum	66	invertebrate	1,2,4			
Sialis lutaria	67	invertebrate	2	3,4		1,3
Simuliidae	68	invertebrate	1,2,3		1	
Synorthocladius sp.	69	invertebrate		2,3,4		1,2,4
Theodoxus fluviatilis	70	invertebrate	4	2		
Tinodes waeneri	71	invertebrate	1,2,3		1,2,3,4	
Tipula montium	72	invertebrate	3		2,4	
Tubificidae	73	invertebrate	1,3,4	2	1,2,3,4	
Valvata piscinalis	74	invertebrate	2,3,4			

Supplementary Table S2 Summary on properties related to the core. The core size, species loss from the core and periphery, and the species re-alignment between the two regions when comparing the four control webs with their respective paired drought webs.

Web pair	**Number of species**		**Core size (% of whole web size)**		**Number of species lost from core**		**Number of species lost from periphery**	
	control	drought	control	drought	extinct	to periphery	extinct	to core
1	59	47	30 (50%)	27 (57%)	4 (13%)	4 (13%)	13 (45%)	4 (14%)
2	63	46	31 (49%)	20 (43%)	8 (26%)	7 (23%)	12 (38%)	3 (9%)
3	61	49	36 (59%)	23 (46%)	8 (22%)	7 (19%)	9 (36%)	0 (0%)
4	65	52	38 (58%)	22 (42%)	7 (18%)	11 (29%)	8 (30%)	0 (0%)

Supplementary Table S3 List of peripheral species that were lost from the food webs under drought. Species were found to be either an *invertebrate* or a *producer*. The number of replicate control webs they were present in and lost from in drought are listed. Species are ordered by the number of times they were lost from the periphery.

Species	Category	Present in control periphery	Lost from periphery
Elmis aenea	**invertebrate**	**4**	**4**
Ostracoda	**invertebrate**	**3**	**3**
***Polypedilum* sp.**	**invertebrate**	**3**	**3**
***Athripsodes* sp.**	**invertebrate**	**3**	**3**
Haliplus lineatocollis	**invertebrate**	**3**	**3**
***Pentaneura* sp.**	**invertebrate**	**3**	**3**
Polycentropus flavomaculatus	**invertebrate**	**3**	**3**
Oulimnius tuberculatus	**invertebrate**	**4**	**2**
Brychius elevatus	**invertebrate**	**2**	**2**
Erpobdella octoculata	invertebrate	1	1
Heterotrissocladius sp.	invertebrate	1	1
Leuctra geniculata	invertebrate	1	1
Cricotopus sp.	invertebrate	2	1
Synorthocladius sp.	invertebrate	4	1
Theodoxus fluviatilis	invertebrate	1	1
Platambus maculatus	invertebrate	1	1
Sialis lutaria	invertebrate	2	1
Algal cysts	producer	4	1
Amphora ovalis	producer	4	1
Cymatopleura solea	producer	4	1
Cymbella lanceolata	producer	2	1
Diatoma vulgare	producer	3	1
Fragilaria vaucheriae	producer	4	1
Staurosirella leptostauron	producer	3	1
Surirella minuta	producer	4	1

Supplementary Table S4 Robustness of control and drought webs under simulated species removal. Proportion of species required in primary removal to generate a total of 50% species loss in each case is shown. In the case of random removal, the average robustness, μ, and the standard deviation, σ, obtained from 100 runs are shown for each empirical web.

	Targeted removal		**Random removal**			
	Control	**Drought**	**Control**		**Drought**	
Web pair			μ	σ	μ	σ
1	0.25	0.32	0.43	0.04	0.46	0.03
2	0.27	0.17	0.45	0.03	0.46	0.05
3	0.31	0.20	0.46	0.02	0.43	0.03
4	0.32	0.23	0.46	0.02	0.44	0.03

Supplementary Table S5 Summary of two independent samples t-tests. In all cases, there was one dependent variable (continuous and proportional data, with a range from 0 to 1) and one independent variable (categorical data) with two levels. Either one-tailed or two-tailed t-test was performed as indicated.

What has been tested?	**Dependent variables***	**Independent variables**	H_0§	**Results**
Has the relative core size changed in response to drought?	Relative core size	Treatment with two levels (control and drought)	$\mu \neq \mu_0$	No ($p > 0.05$)
Is species extinction greater in the periphery than in core?	% of species extinction	Substructure with two levels (core and periphery)	$\mu > \mu_0$	**Yes ($p < 0.05$)**
Do more species move from core to periphery than vice versa?	% of species movement	Substructure with two levels (core and periphery)	$\mu < \mu_0$	**Yes ($p < 0.05$)**
Are control webs more robust than drought ones under random removal?	Robustness	Treatment with two levels (control and drought)	$\mu \neq \mu_0$	No ($p > 0.05$)
Are control webs more robust than drought ones under targeted removal?	Robustness	Treatment with two levels (control and drought)	$\mu \neq \mu_0$	No ($p > 0.05$)

* Data were on proportions and therefore arcsine transformation was applied. Transformed data satisfied the Shapiro-Wilk test for normality.

§The null hypothesis H_0 being $\mu \neq \mu_0$ indicates a two-tailed t-test, while $\mu > \mu_0$ or $\mu < \mu_0$ indicates a one-tailed t-test. μ_0 represents the mean of variables related to the core or the control webs, while μ represents the mean of variables related to the periphery or the drought webs.

Figure S1 Core/periphery structure of control and drought food webs. Comparisons of four pairs of control and drought core profiles (**a-d** for web pair 1-4 respectively). Nodes are ranked by their decreasing order of degree and plotted by the number of links with nodes of a higher rank, k_r^+. The control web is plotted alongside its respective drought web. Species were classified as *Basal* (circles), *Intermediate* (squares) or *Top* (triangles). The maximum of the curve k_{r*}^+, defines the boundary of the core for the control and drought webs.

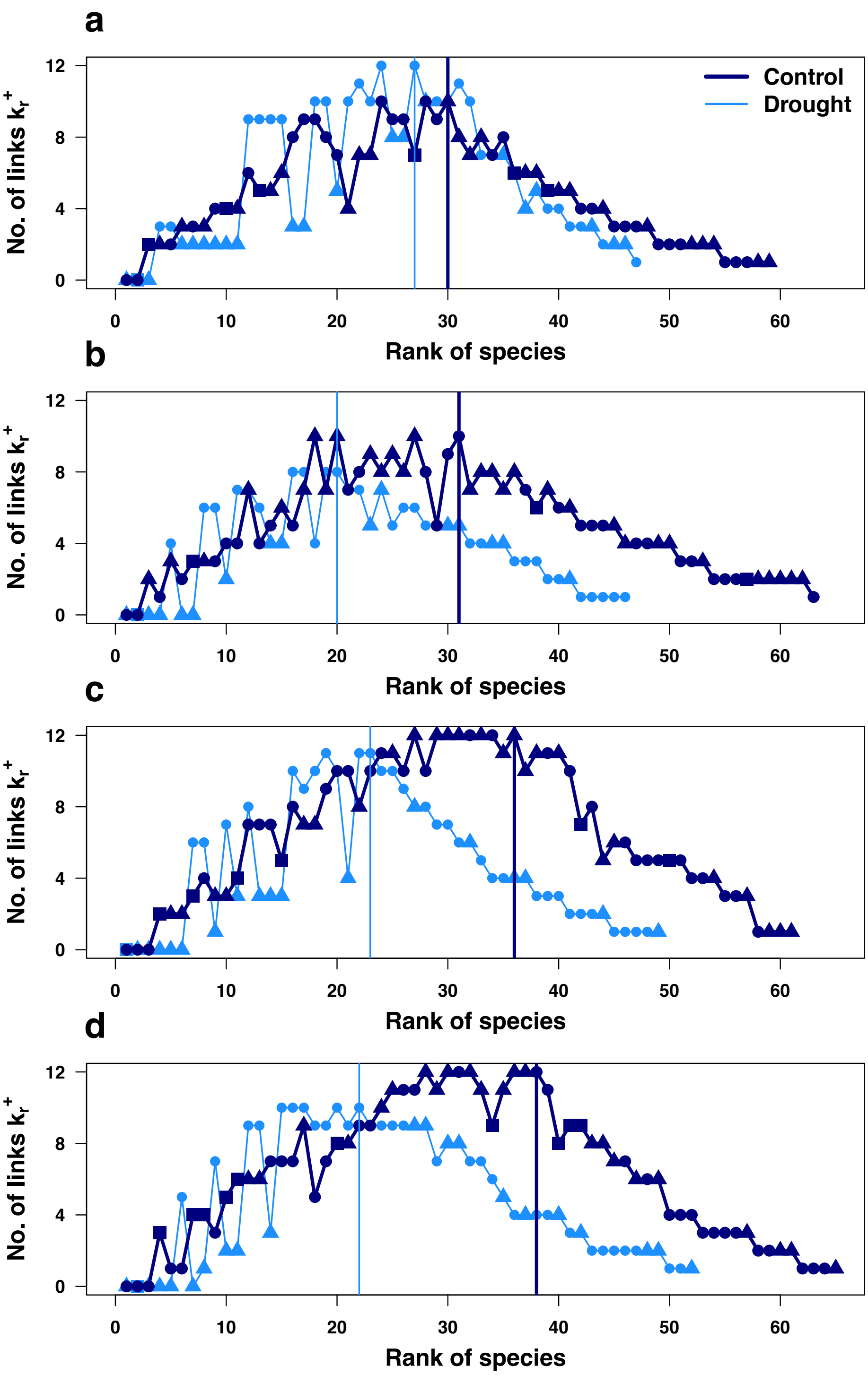

Figure S2 Drought caused species re-alignment in substructures. Comparisons of four pairs of control and drought food web structures (**a-d** for web pair 1-4 respectively). Core species in the inner ring are surrounded by peripheral species in the outer ring. Re-alignments of species were mainly originated from the core, and this is particularly evident in (**c**) and (**d**) in which all species movement originated from the core.

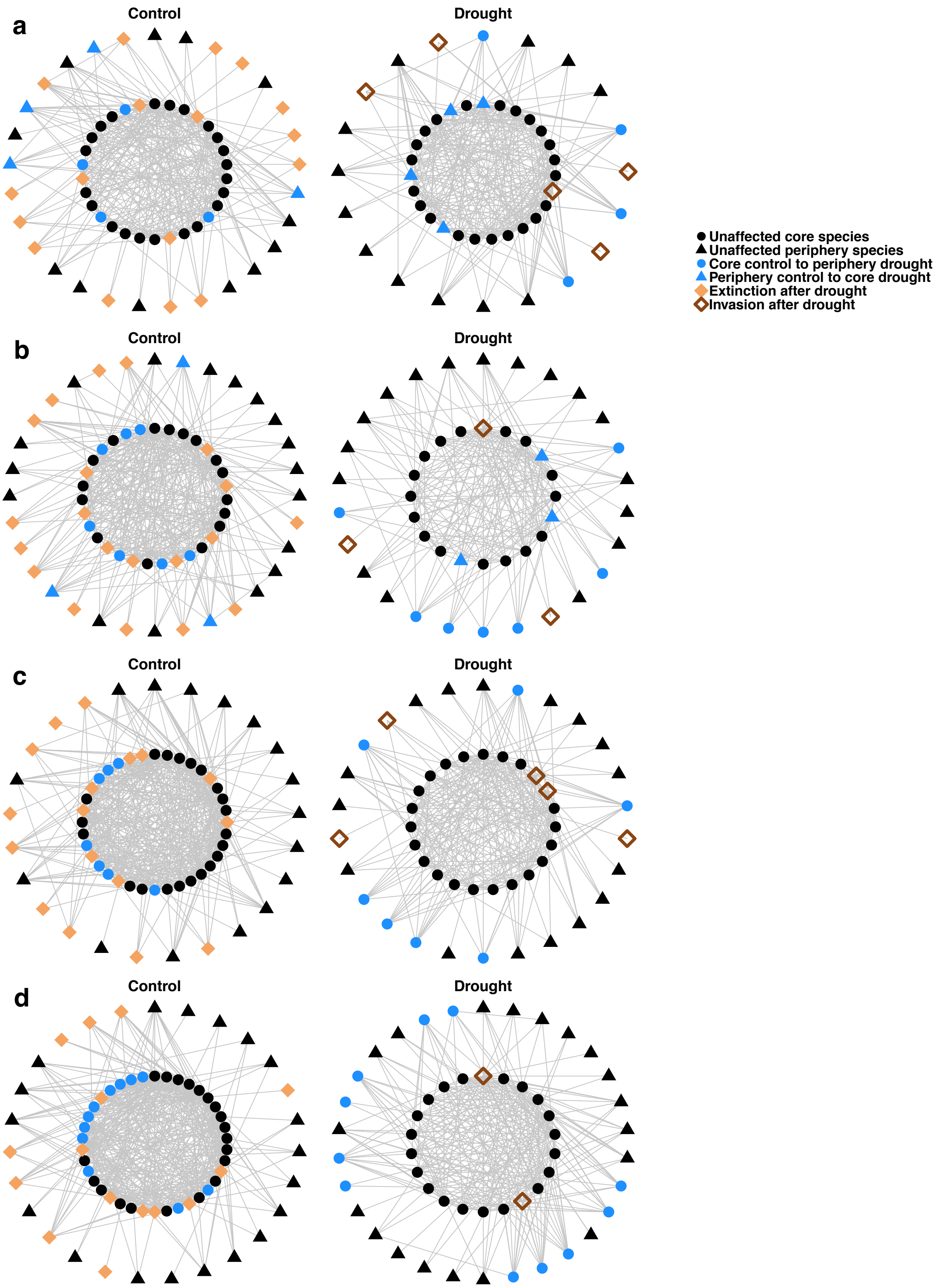

Figure S3 Drought reduced link density in the core and caused further restructuring in the core. The density of connections across the network measured by the rich-club coefficient, ϕ_r, is shown for four pairs of control and drought-disturbed mesocosms (**a-d** for web pair 1-4 respectively). Nodes were ordered by degree which were then *normalised* by the size of the network. Boundaries of the cores are marked by vertical lines as in Fig. S1. Comparisons of the web pair's deviance in connection density from their respective null models and more negative z-scores indicate greater deviance from the null model.

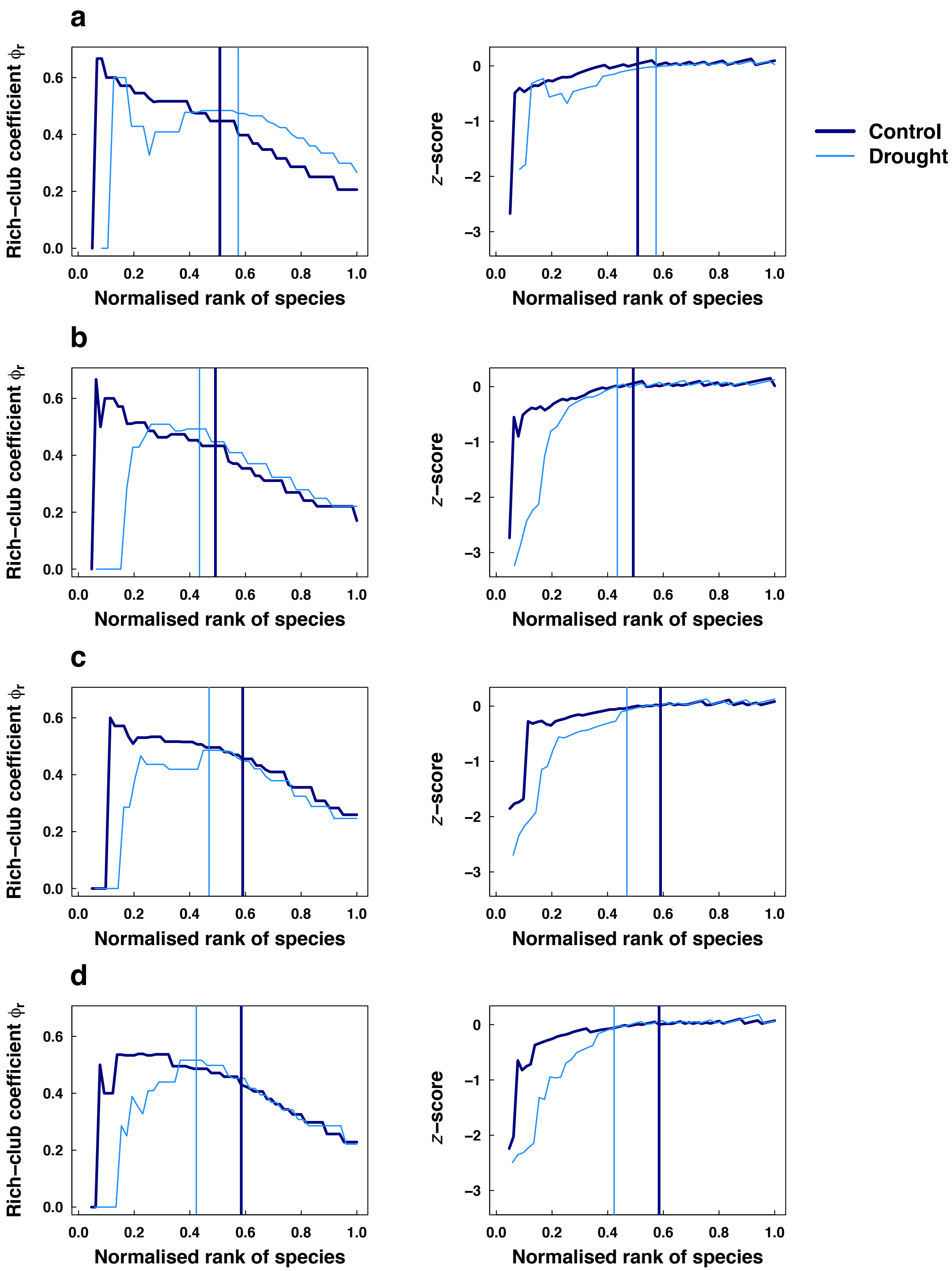

Figure S4 Rewiring in food webs. Core species in the inner ring are surrounded by peripheral species in the outer ring. Focal species highlighted by circles. (**a**) The snail *Radix balthica* is tolerant of drought conditions and was present in the core in both control and drought webs. (**b**) The isopod *Asellus aquaticus* moved from core to periphery as degree declined markedly after drought. The reduced number of resources likely reflects changes in the biotic habitat and encounter rate caused by drying. (**c**) The midge *Cricotopus sp*, shifted from periphery to core as its diet diversified under drought, reflecting redistribution and likely altered encounter rate.

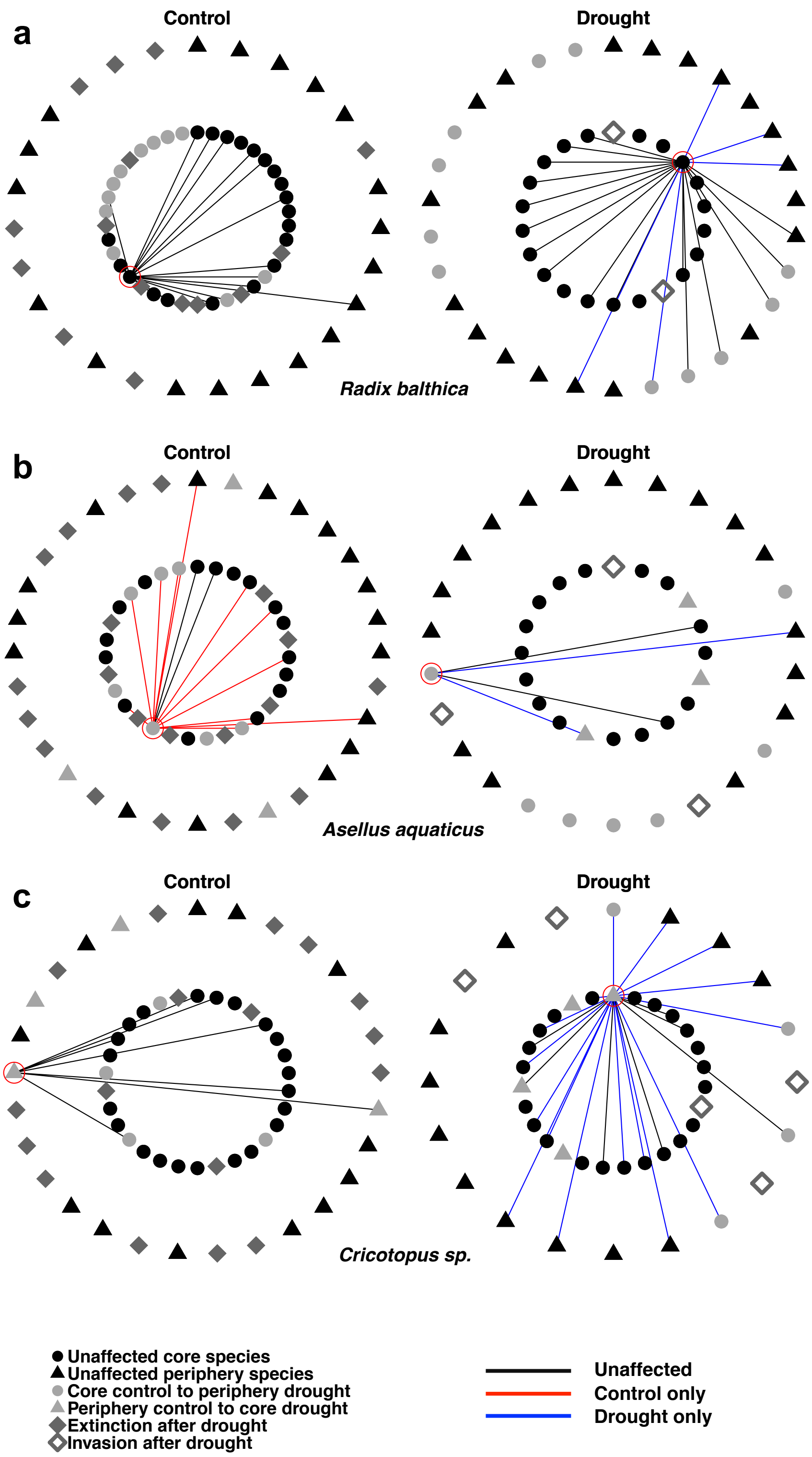

Figure S5 Network robustness against random and targeted species removal. Cumulative secondary extinction against simulated random species removal and targeted generalist removal for four pairs of control and drought-disturbed mesocosms (**a-d**). The solid diagonal line represents a total loss of 100% of species and the dashed diagonal line represents a total loss of 50% of species.