Supporting Information

Sanders et al. 10.1073/pnas.1716825115

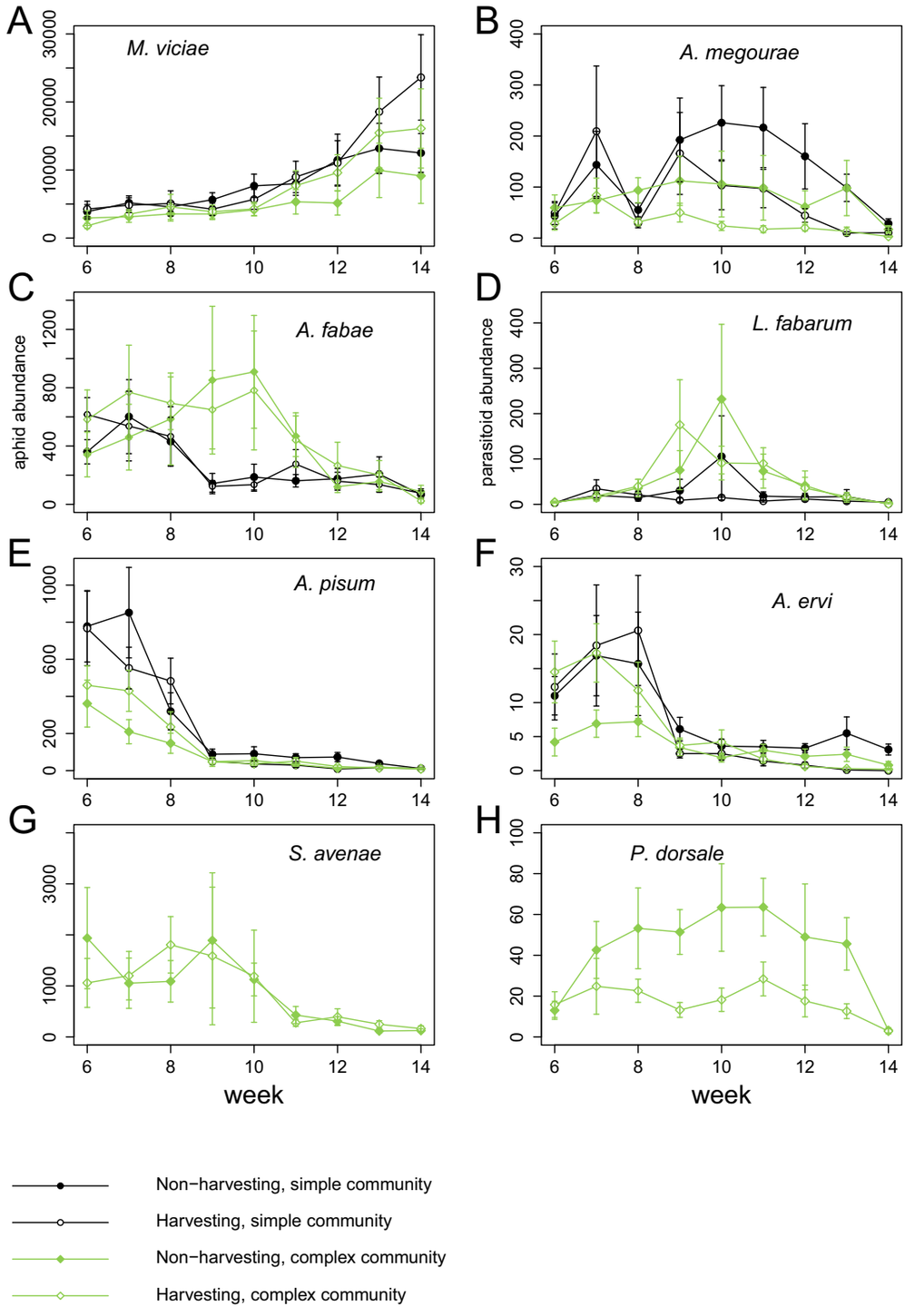

Fig. S1. Population dynamics for the experimental communities. The population dynamics for the aphids *Megoura viciae* (*A*), *Aphis fabae* (*C*), *Acyrthosiphon pisum* (*E*), and *Sitobion avenae* (*G*) and the parasitoids *Aphidius megourae* (*B*), *Lysiphlebus fabarum* (*D*), *Aphidius ervi* (*F*), and *Praon dorsale* (*H*) in simple (black, circle) and complex (green, diamond) communities with *A. megourae* harvested (open symbols) or nonharvested (closed symbols) are shown. Presented are means for species abundance and SEs (from 10 replicates). *A. ervi* densities decreased in harvesting treatments toward the end of the experiment (harvesting × week: $F_{1;317} = 22.72$, $P < 0.0001$) and were stronger in the simpler communities (harvesting × community: $F_{1;27} = 9.07$, $P = 0.0056$). *A. pisum* aphids had lower numbers in the complex community (community: $F_{1;27} = 10.11$, $P = 0.0037$) but were less affected by harvesting in these than in simple communities (harvesting × community: $F_{1;27} = 4.45$, $P = 0.0443$). *L. fabarum* and *A. fabae* population dynamics were unaffected by treatments, and effects on all other species are discussed in the main text. Note the lower densities after fully established foods webs that include top-down control through parasitoids and hyperparasitoids (species persistence is shown in Fig. 2).

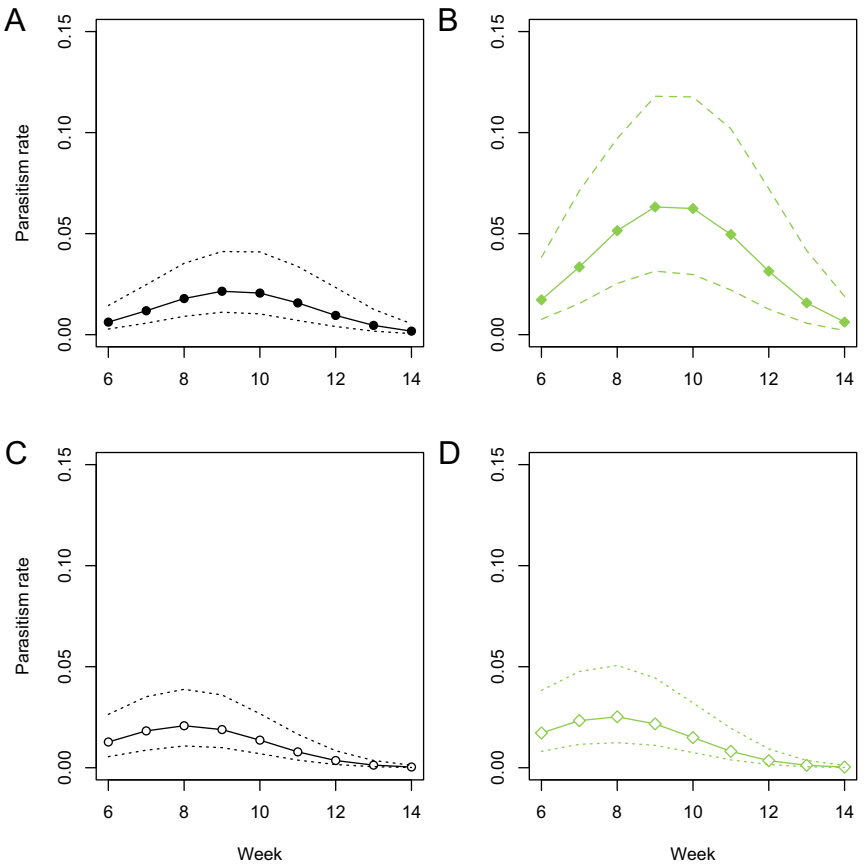

Fig. S2. Parasitism rate for the aphid *M. viciae*. The parasitism rates for *M. viciae* as a result of attacks from the parasitoids *A. megourae* and *P. dorsale* in simple (*A* and *C*, black circles) and complex (*B* and *D*, green diamonds) communities with *A. megourae* either harvested (*C* and *D*, open symbols) or non-harvested (*A* and *B*, closed symbols) are shown. Presented are means for the proportion of parasitoid mummies and 95% confidence intervals (extracted from post hoc distribution). *P. dorsale* was only present in complex communities.

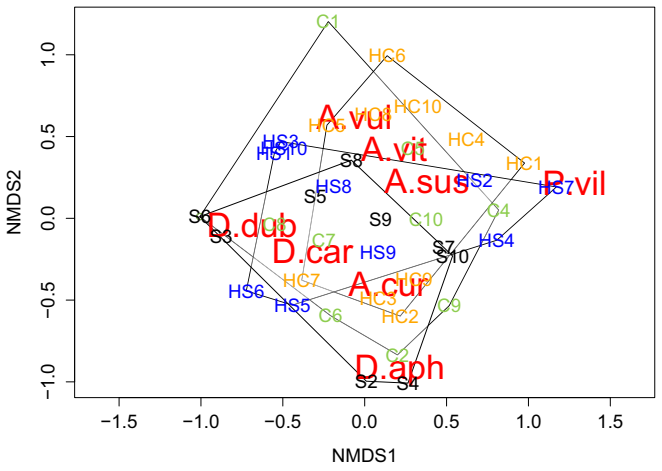

Fig. S3. Hyperparasitoid community composition. The naturally established hyperparasitoid communities in the mesocosms are shown, consisting of eight different species [hyperparasitoid species names are shown in large red letters in the experimental communities in four different treatments (each 10 replicates): simple communities (S, black), complex communities (C, green), simple harvested communities (HS, blue), and complex harvested communities (HC, orange)]. Overall hyperparasitoid community structure and diversity, measured by Simpson's diversity index ($\chi^2 = 2.04$, $P = 0.56$) and species richness ($\chi^2 = 2.43$, $P = 0.48$), were not affected by experimental treatments. A. cur, *A. cursor*; A. sus, *A. suspensus*; A. vit, *A. victrix*; A. vul, *A. vulgaris*; D. aph, *D. aphidum*; D. car, *D. carpenteri*; D. dub, *D. dubiosus*; NMDS, nonmetric multidimensional scaling; P. vil, *P. villosa*.

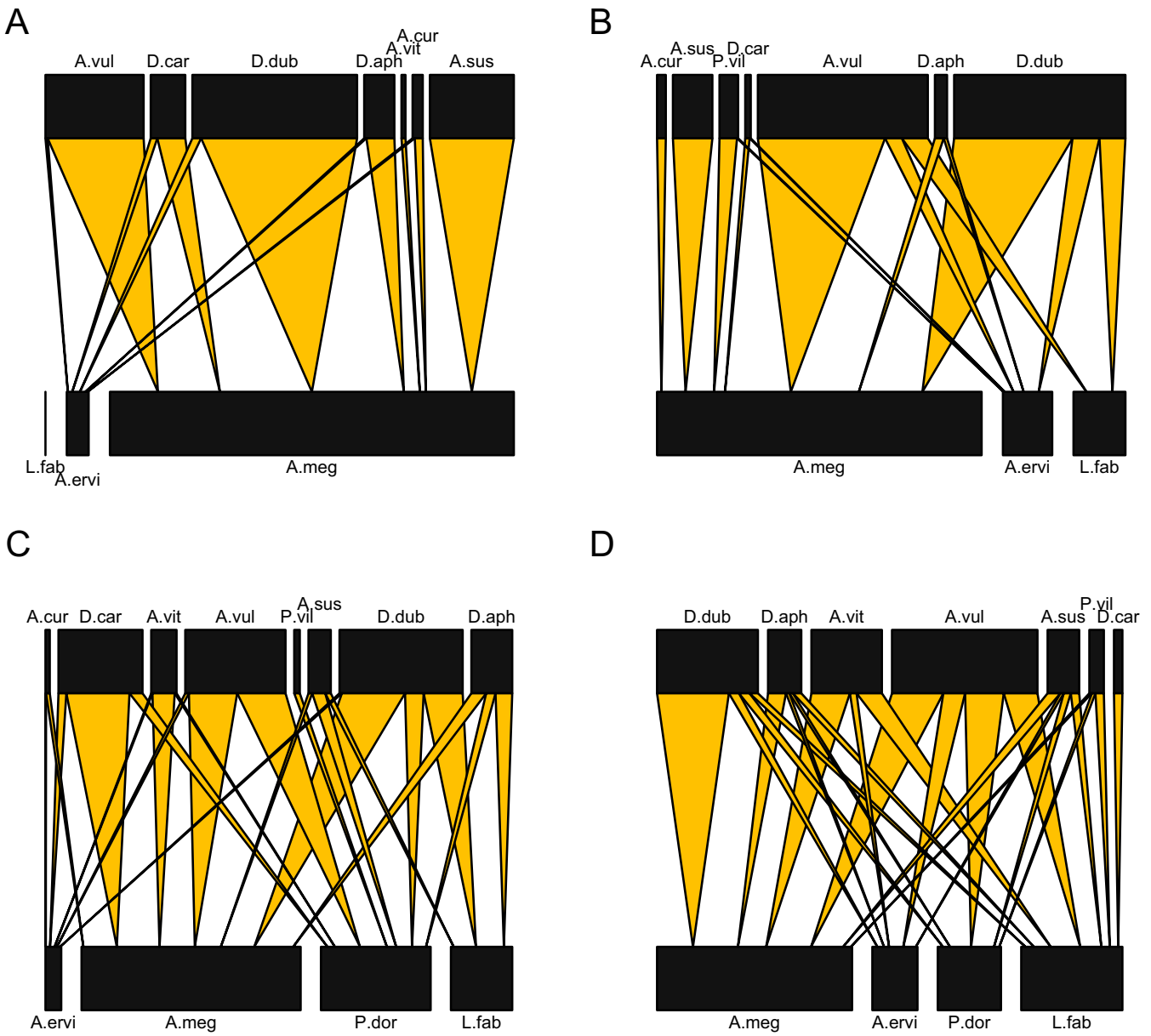

Fig. S4. Quantitative parasitoid-hyperparasitoid networks. Interaction networks are shown for the four different treatments: simple communities nonharvested (*A*, connectance = 0.57), simple communities harvested (*B*, connectance = 0.67), complex communities nonharvested (*C*, connectance = 0.69), and complex communities harvested (*D*, connectance = 0.82). The sums of all interactions sampled over the whole length of the experiment are presented. Full parasitoid and hyperparasitoid (upper levels) species names are provided. A. cur, *A. cursor*; A. ervi, *A. ervi*; A. meg, *A. megourae*; A. sus, *A. suspensus*; A. vit, *A. victrix*; A. vul, *A. vulgaris*; D. aph, *D. aphidum*; D. car, *D. carpenteri*; D. dub, *D. dubiosus*; L. fab, *L. fabarum*; P. dor, *P. dorsale*; P. vil, *P. villosa*.

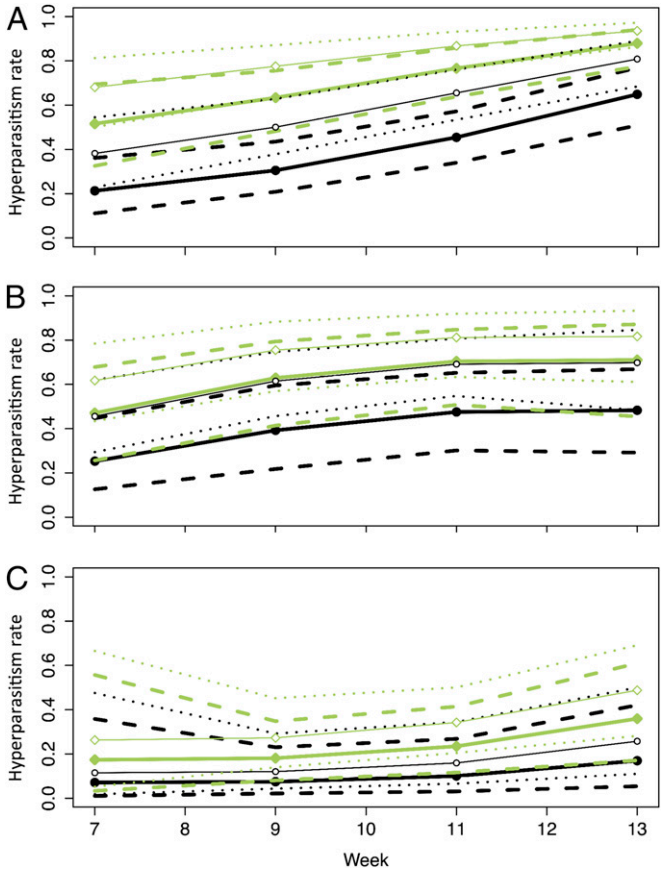

Fig. S5. Hyperparasitism rate for primary parasitoids. The hyperparasitism rates for *A. megourae* (*A*), *A. ervi* (*B*), and *L. fabarum* (*C*) as a result of attacks from the hyperparasitoid community (species are identified in legends for Figs. S3 and S4) in simple (black, circles) and complex (green, diamonds) communities with *A. megourae* either harvested (open symbols) or nonharvested (closed symbols) are shown. Presented are means for the proportion of parasitoid mummies that have been hyperparasitized and 95% confidence intervals (extracted from post hoc distribution).

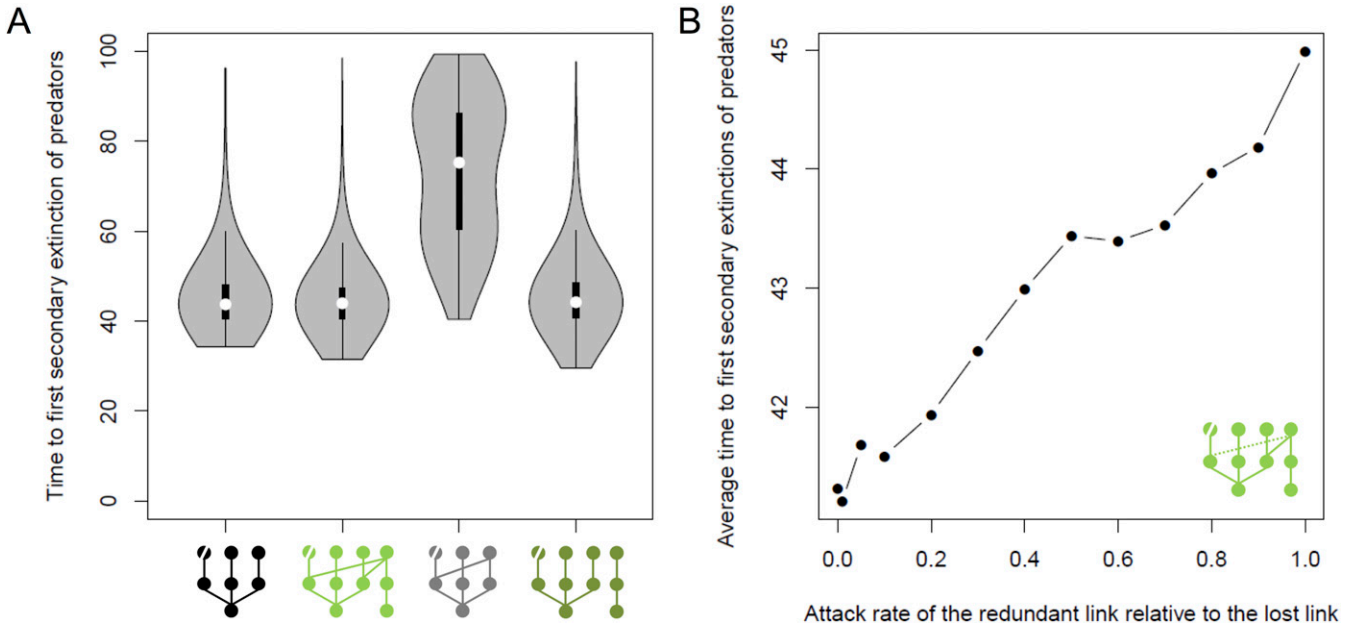

Fig. S6. Time to first secondary extinctions of predators in the modeled food web scenarios. The time to first predator secondary extinctions in four different food web structures (*A*) and as a function of the predator attack rate in the redundant link relatively to other predator attack rates (*B*) are shown. Each food web scenario was replicated 1,000 times with varying model parameter values. The food web structure modeled in each scenario is represented below the panels, with the removed species indicated by a diagonal line through its node. The dotted line in *B* indicates the position of the redundant link in the food web.

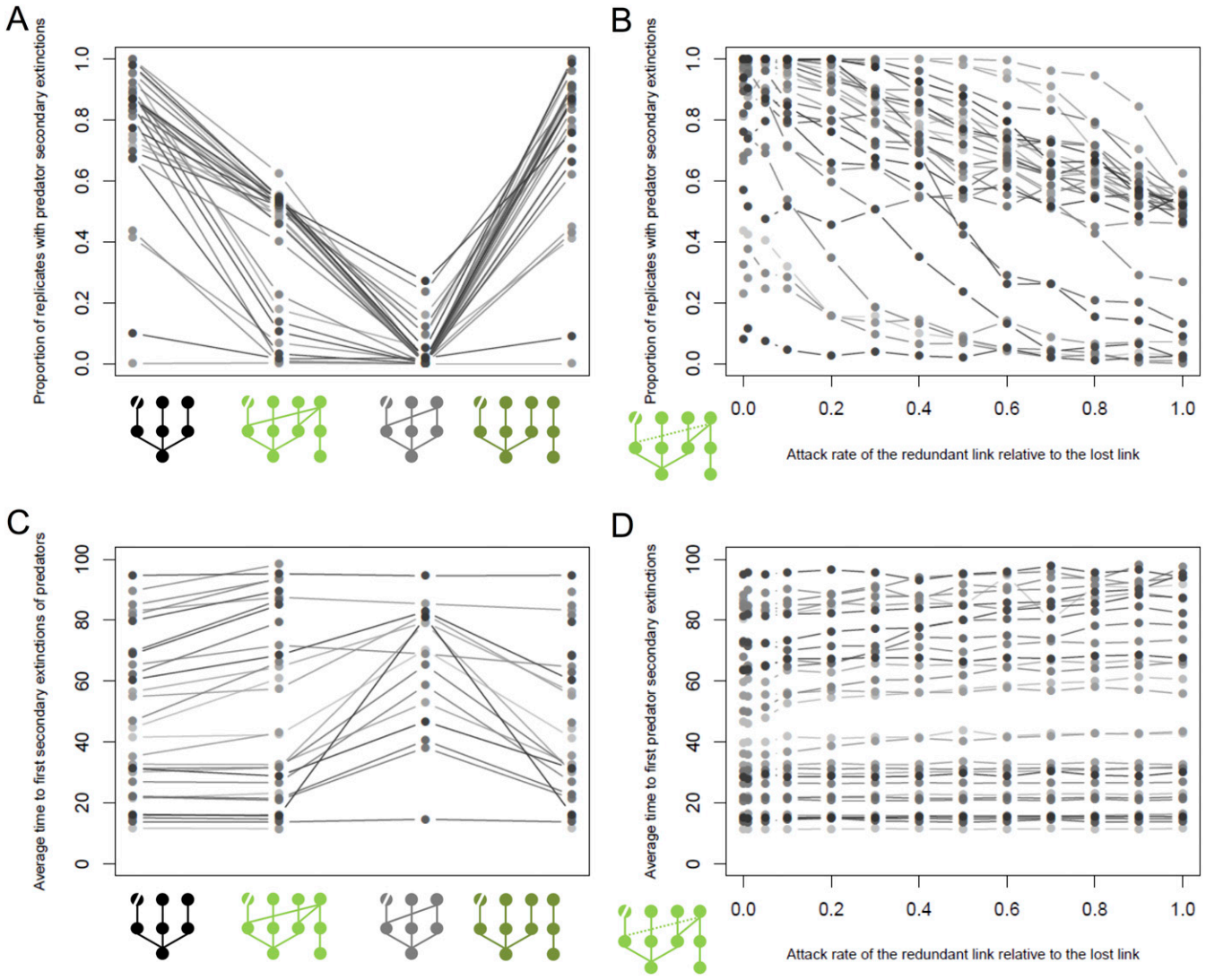

Fig. S7. Sensitivity analysis for predator secondary extinctions in the modeled food web scenarios. The proportion of replicates with predator secondary extinctions (*A* and *B*) and average time to first secondary extinctions of predators (*C* and *D*) in the four food web scenarios (*A* and *C*) and as a function of the predator attack rate in the redundant link relative to other predator attack rates (*B* and *D*) are shown. Results from each set of simulations (Table S3) are represented by points of a different gray shade connected by a line. The food web structures modeled in each scenario are represented in the panels, with the removed species indicated by a diagonal line through its node. The dotted line in *B* and *D* indicates the position of the redundant link in the food webs. The results show that while the parameter ranges affect the probability of secondary extinctions, the effect of trophic redundancy is consistent across most of the sets of simulations.

Table S1. Survival analysis for nonharvested parasitoids

Factor	Exp(coefficient)	Lower 95% CI	Upper 95% CI	z	*P*
Harvesting (Ha)	55.13	6.00	506.99	3.54	0.0004
Community (Com)	2.62	0.25	27.00	0.81	0.4176
Species identity (Si)	0.78	0.09	6.73	−0.26	0.8219
Ha × Com	0.09	0.01	0.95	−2.01	0.0448
Ha × Si	0.53	0.07	4.14	−0.61	0.5433
Com × Si	2.65	0.61	11.60	1.30	0.1945

Parasitoid species identity: only nonharvested species *L. fabarum* and *A. ervi*. Parameter estimates of the Cox proportional hazard model with exp(coefficient), lower and upper 95% confidence intervals (CIs), z values, and *P* values. Negative coefficient values [exp(coefficient) <1] indicate a negative effect on the hazard, and thus a positive effect on survival. Positive coefficient values [exp(coefficient) >1] indicate a positive effect on hazard, and thus a negative effect on survival.

Table S2. Hyperparasitism rate for primary parasitoids

	Harvesting		Community		Week	
Species	z	*P*	z	*P*	z	*P*
A. megourae	2.81	0.0049	4.24	<0.0001	4.62	<0.0001
L. fabarum	1.20	0.2302	1.843	0.0653	1.15	0.6057
A. ervi	2.09	0.0370	2.04	0.0069	2.70	0.0069

Presented are the results from generalized linear mixed effects models (binomial error structure) with a combined variable (hyperparasitized and nonhyperparasitized aphid mummies) as a response variable and harvesting, community complexity, and week as fixed factors. Block and mesocosm were included as random factors.

Table S3. Sets of parameter values used in the sensitivity analysis

Parameter ranges	b_{min}	b_{max}	K_{min}	K_{max}	b_{Hmin}	b_{Hmax}	a_{Hmin}	a_{Hmax}	b_{Pmin}	b_{Pmax}	a_{Pmin}	a_{Pmax}
Simulation 1	0.06	1.65	14.75	30.38	−1.94	−1.60	0.19	0.49	−0.37	−0.09	1.23	1.63
Simulation 2	2.61	3.94	15.38	31.25	−1.83	−1.55	1.46	1.72	−1.61	−1.27	0.06	0.54
Simulation 3	1.89	2.86	31.42	48.21	−0.65	−0.33	1.11	1.59	−1.20	−1.05	0.39	1.17
Simulation 4	1.77	2.86	16.42	34.71	−1.04	−0.73	0.51	1.08	−1.27	−1.03	0.51	1.15
Simulation 5	1.56	3.52	0.77	18.11	−1.44	−1.19	0.47	0.98	−2.43	−2.08	0.87	1.36
Simulation 6	2.24	3.85	2.33	14.29	−0.55	−0.17	0.99	1.51	−1.04	−0.72	0.02	0.76
Simulation 7	3.54	5.48	0.00	10.98	−0.42	−0.07	1.27	1.57	−0.81	−0.51	0.10	0.66
Simulation 8	1.73	2.68	14.68	29.70	−1.97	−1.79	1.28	1.66	−1.71	−1.40	0.40	0.99
Simulation 9	0.76	2.64	28.24	43.14	−1.79	−1.44	1.33	1.71	−2.25	−1.99	0.90	1.57
Simulation 10	2.28	4.04	16.73	29.15	−0.59	−0.35	0.36	0.89	−1.24	−0.89	0.82	1.11
Simulation 11	0.43	2.28	0.70	14.42	−0.72	−0.34	1.21	1.80	−2.50	−2.28	0.75	1.00
Simulation 12	4.45	6.03	14.49	29.13	−1.34	−0.96	0.12	0.60	−2.38	−2.09	0.60	1.39
Simulation 13	2.79	3.87	8.63	21.50	−1.09	−0.83	0.90	1.37	−2.41	−2.18	0.03	0.43
Simulation 14	0.94	1.67	21.50	39.37	−1.87	−1.70	0.46	0.83	−2.01	−1.64	1.06	1.38
Simulation 15	4.48	5.33	3.18	18.69	−0.61	−0.30	0.90	1.06	−1.88	−1.55	0.79	1.23
Simulation 16	0.74	1.75	22.69	41.18	−0.24	−0.03	0.28	0.50	−0.73	−0.36	0.65	0.95
Simulation 17	1.20	1.85	12.49	23.64	−2.02	−1.70	1.20	1.37	−0.97	−0.75	1.17	1.72
Simulation 18	0.52	1.75	24.45	42.43	−1.92	−1.69	0.74	1.12	−0.76	−0.46	0.00	0.60
Simulation 19	4.60	6.56	7.43	21.94	−0.89	−0.51	0.73	1.30	−2.07	−1.67	0.50	1.12
Simulation 20	3.56	4.45	25.30	33.32	−1.68	−1.51	1.46	1.79	−1.08	−0.73	0.11	0.76
Simulation 21	4.74	6.30	0.31	13.32	−1.73	−1.35	0.00	0.30	−1.36	−0.98	0.69	1.35
Simulation 22	0.79	2.49	0.00	9.61	−1.54	−1.28	1.13	1.47	−2.33	−2.04	0.46	0.99
Simulation 23	3.59	5.32	24.62	40.01	−1.93	−1.75	0.98	1.32	−2.15	−2.04	0.50	1.19
Simulation 24	1.85	3.00	14.75	34.13	−2.13	−1.74	0.03	0.55	−1.37	−1.07	0.82	1.35
Simulation 25	0.00	1.40	18.68	30.95	−1.61	−1.50	1.57	1.81	−1.65	−1.29	1.21	1.97
Simulation 26	1.26	2.25	3.96	23.91	−0.56	−0.20	1.18	1.63	−1.88	−1.64	0.92	1.57
Simulation 27	0.00	0.97	6.32	14.80	−0.60	−0.41	0.04	0.44	−0.80	−0.46	0.01	0.62
Simulation 28	4.66	5.93	24.02	42.10	−1.64	−1.26	1.02	1.42	−1.56	−1.28	0.26	1.00
Simulation 29	0.56	2.38	30.38	39.50	−2.14	−1.81	1.33	1.75	−1.45	−1.12	0.70	1.11
Simulation 30	4.52	6.30	29.49	47.88	−0.84	−0.44	0.00	0.31	−1.50	−1.16	0.37	1.04
Simulation 31	0.00	1.36	1.80	7.33	−0.29	−0.01	0.88	1.22	−0.78	−0.57	0.70	1.20
Simulation 32	0.19	1.40	0.00	13.16	−1.62	−1.42	0.30	0.65	−0.91	−0.54	0.00	0.44
Simulation 33	3.27	4.63	30.06	44.31	−1.30	−1.07	0.84	1.29	−1.67	−1.35	0.08	0.47
Simulation 34	1.23	2.83	20.52	39.61	−1.42	−1.06	1.09	1.55	−0.65	−0.30	0.20	0.94
Simulation 35	0.34	1.71	2.09	21.28	−1.15	−0.80	0.34	0.54	−1.22	−0.95	0.08	0.58
Simulation 36	3.58	5.21	21.17	40.45	−1.29	−1.15	0.25	0.77	−1.92	−1.69	1.26	1.86
Simulation 37	0.93	2.69	9.15	21.72	−1.80	−1.50	0.77	1.05	−0.96	−0.71	0.73	1.52
Simulation 38	0.16	1.32	11.15	20.47	−0.89	−0.69	1.60	1.81	−1.69	−1.37	0.82	1.50
Simulation 39	0.45	2.38	5.70	22.93	−0.45	−0.16	1.14	1.63	−2.41	−2.15	1.04	1.55
Simulation 40	1.54	3.43	12.42	19.96	−2.05	−1.78	0.46	1.03	−0.87	−0.67	0.15	0.88
Simulation 41	2.62	4.15	20.78	32.59	−1.13	−0.86	0.91	1.32	−1.13	−0.95	1.09	1.56
Simulation 42	3.86	5.84	27.10	32.28	−0.99	−0.63	1.56	2.03	−0.97	−0.61	0.00	0.46
Simulation 43	2.80	4.20	9.35	15.52	−1.24	−1.01	0.05	0.49	−0.54	−0.37	0.10	0.48
Simulation 44	3.58	4.20	0.00	11.62	−0.43	−0.14	1.41	1.70	−2.11	−2.00	1.19	1.73
Simulation 45	5.16	6.78	1.97	15.41	−1.11	−0.95	0.98	1.22	−0.86	−0.55	1.18	1.98
Simulation 46	5.49	6.01	12.61	24.26	−1.45	−1.06	0.41	0.81	−2.54	−2.19	0.30	1.00
Simulation 47	1.19	2.99	27.14	43.48	−1.49	−1.18	1.10	1.27	−0.38	0.00	0.17	0.79
Simulation 48	1.30	3.22	10.36	23.52	−2.09	−1.70	0.41	0.91	−1.94	−1.75	0.00	0.50
Simulation 49	3.14	4.08	13.79	21.58	−0.96	−0.70	0.03	0.48	−1.74	−1.46	0.69	1.39
Simulation 50	2.87	4.58	0.83	10.54	−1.91	−1.58	0.32	0.73	−2.27	−2.02	0.37	0.80
Simulation 51	0.17	0.75	20.42	27.71	−0.93	−0.53	0.39	0.97	−1.17	−1.04	0.00	0.52
Simulation 52	3.93	5.42	0.00	14.14	−0.65	−0.44	0.74	0.96	−1.56	−1.24	1.15	1.94
Simulation 53	4.10	5.94	28.15	47.72	−1.46	−1.14	1.37	1.97	−0.64	−0.50	1.00	1.77
Simulation 54	5.37	6.24	0.30	15.57	−1.75	−1.40	0.43	0.99	−0.47	−0.31	0.96	1.32
Simulation 55	3.71	4.74	15.92	26.20	−1.88	−1.54	0.76	1.24	−2.15	−1.77	0.32	0.77
Simulation 56	2.59	3.84	4.13	16.25	−1.10	−0.78	0.59	1.14	−0.32	−0.09	1.03	1.67
Simulation 57	3.69	5.55	9.20	25.42	−0.39	−0.25	1.04	1.36	−2.40	−2.02	0.00	0.35
Simulation 58	1.39	2.57	1.71	10.41	−2.16	−1.82	0.00	0.40	−0.52	−0.21	0.16	0.77
Simulation 59	1.52	2.32	21.19	35.18	−1.30	−0.92	1.06	1.61	−1.93	−1.63	1.18	1.86
Simulation 60	4.57	5.69	26.18	45.94	−0.79	−0.64	1.54	1.74	−1.56	−1.42	0.70	1.25
Simulation 61	3.45	5.23	0.42	19.21	−1.49	−1.29	0.10	0.65	−0.70	−0.34	0.69	1.03
Simulation 62	1.98	3.33	24.24	41.14	−0.66	−0.51	0.72	1.21	−0.36	−0.23	0.54	0.96
Simulation 63	3.33	4.00	0.00	18.36	−0.39	−0.07	0.29	0.83	−0.36	−0.19	0.93	1.21

Table S3. Cont.

Parameter ranges	b_{min}	b_{max}	K_{min}	K_{max}	b_{Hmin}	b_{Hmax}	a_{Hmin}	a_{Hmax}	b_{Pmin}	b_{Pmax}	a_{Pmin}	a_{Pmax}
Simulation 64	5.19	6.64	13.25	27.37	−1.83	−1.44	0.92	1.42	−1.07	−0.87	0.20	0.92
Simulation 65	0.00	1.46	4.10	22.28	−0.96	−0.58	0.70	0.96	−2.08	−1.71	1.02	1.65
Simulation 66	0.89	2.28	27.18	41.95	−0.73	−0.63	0.80	1.36	−0.99	−0.86	1.17	1.39
Simulation 67	4.30	5.84	11.31	27.06	−0.80	−0.44	1.50	2.01	−2.10	−1.91	0.88	1.64
Simulation 68	3.20	4.92	31.26	37.12	−1.64	−1.37	0.41	0.78	−1.35	−1.13	0.00	0.57
Simulation 69	0.00	1.86	0.00	13.74	−1.03	−0.66	0.72	1.07	−0.67	−0.33	0.00	0.57
Simulation 70	4.19	6.18	29.05	38.57	−1.25	−0.86	1.54	2.01	−2.10	−1.78	0.68	1.16
Simulation 71	2.60	4.51	10.90	22.22	−1.63	−1.34	0.67	1.23	−0.92	−0.71	0.38	1.10
Simulation 72	0.00	1.39	13.58	26.30	−1.04	−0.76	0.00	0.46	−2.27	−1.88	0.20	0.71
Simulation 73	2.50	3.70	17.17	24.20	−1.51	−1.20	0.16	0.75	−1.51	−1.24	0.77	1.00
Simulation 74	1.40	2.90	6.91	20.21	−1.39	−1.02	0.21	0.64	−1.75	−1.50	1.04	1.58
Simulation 75	4.58	6.13	16.30	34.07	−1.55	−1.38	0.59	1.17	−0.55	−0.26	0.48	1.06
Simulation 76	3.05	3.83	18.36	33.51	−0.35	−0.07	0.00	0.46	−1.35	−1.04	0.08	0.77
Simulation 77	3.47	4.76	28.12	47.01	−1.83	−1.63	0.57	1.06	−1.55	−1.16	0.24	0.57
Simulation 78	2.12	3.86	13.41	24.22	−0.32	−0.06	1.17	1.70	−1.46	−1.07	0.42	0.78
Simulation 79	0.47	1.91	0.00	14.43	−0.40	−0.28	0.51	1.05	−1.82	−1.47	1.06	1.32
Simulation 80	3.91	5.22	19.38	35.49	−0.37	−0.16	1.10	1.64	−0.52	−0.16	1.08	1.66
Simulation 81	3.29	5.28	19.07	38.06	−0.57	−0.22	1.54	1.90	−1.74	−1.41	0.13	0.86
Simulation 82	3.76	4.58	24.37	38.75	−1.89	−1.76	0.00	0.26	−2.12	−1.72	0.18	0.55
Simulation 83	5.01	5.92	11.06	28.07	−0.83	−0.49	0.07	0.38	−1.87	−1.60	0.30	1.06
Simulation 84	2.11	3.42	29.97	46.65	−1.52	−1.22	0.90	1.17	−2.16	−1.80	0.34	0.90
Simulation 85	0.43	1.50	35.31	43.56	−0.55	−0.32	0.02	0.60	−2.15	−1.91	1.37	1.58
Simulation 86	4.46	5.01	7.11	17.02	−1.55	−1.31	0.97	1.56	−2.45	−2.19	0.00	0.73
Simulation 87	2.86	4.69	33.57	44.55	−1.22	−0.93	0.44	0.95	−2.48	−2.21	0.82	1.29
Simulation 88	4.90	6.37	18.29	35.84	−1.39	−1.17	1.32	1.59	−0.42	−0.09	1.03	1.38
Simulation 89	5.34	6.04	2.59	20.04	−1.05	−0.68	1.42	1.89	−0.51	−0.13	1.35	1.62
Simulation 90	3.10	4.57	24.58	31.05	−0.24	−0.10	1.45	2.03	−0.30	−0.02	0.00	0.44
Simulation 91	1.75	3.44	11.70	31.18	−0.81	−0.69	0.96	1.51	−0.80	−0.69	0.84	1.50
Simulation 92	2.19	3.23	25.56	32.31	−0.54	−0.29	1.29	1.68	−0.55	−0.31	0.19	0.87
Simulation 93	1.86	3.79	0.00	9.18	−0.72	−0.49	0.37	0.61	−1.07	−0.83	0.00	0.63
Simulation 94	0.45	1.71	28.16	44.72	−0.72	−0.41	0.49	1.03	−2.25	−2.08	0.71	1.16
Simulation 95	4.08	5.50	3.47	22.16	−1.00	−0.84	0.33	0.76	−1.86	−1.47	0.37	0.96
Simulation 96	2.00	3.87	13.85	33.52	−2.08	−1.82	1.37	1.78	−0.67	−0.51	1.14	1.66
Simulation 97	1.98	3.78	25.96	36.42	−1.32	−1.01	1.51	1.70	−1.18	−0.80	0.74	1.45
Simulation 98	5.10	6.62	21.27	31.36	−1.27	−0.91	0.36	0.79	−1.89	−1.49	1.20	1.63
Simulation 99	1.49	2.24	2.73	11.64	−1.18	−0.85	0.18	0.63	−1.40	−1.22	1.16	1.91
Simulation 100	4.13	5.79	31.49	42.13	−1.80	−1.54	0.14	0.51	−1.11	−0.92	1.35	1.66

For each of 100 simulations, model parameters were drawn from the following uniform distributions: b_i from [b_{min}; b_{max}], [b_{Hmin}; b_{Hmax}], and [b_{Pmin}; b_{Pmax}] for plants, herbivores, and predators/parasitoids, respectively; a_{ij} from [a_{Hmin}; a_{Hmax}] and [a_{Pmin}; a_{Pmax}] for the per capita effects of herbivores and predators/parasitoids, respectively; and K_i from [K_{min}; K_{max}]. Rows in gray correspond to simulations where parameter values do not allow species coexistence in all food web scenarios. Such simulations are thus not included in Fig. S7. Minimum (*min*) and maximum (*max*) parameter values of b = intrinsic growth rate, and a = per capita effect of one species on the per capita growth rate of another species. K is plant species carrying capacity. Values are for plants, herbivores (*H*), and predators/parasitoids (*P*).

Other Supporting Information Files

Dataset S1 (XLS)
Dataset S2 (XLS)
Dataset S3 (XLS)