Abella, S.R. 2022. Are pre-restoration soil seed banks and vegetation nested and predictive subsets of post-restoration communities? Ecological Restoration.

Supplemental Materials

Supplement S1. Description of soil seed bank assay methods for an experiment examining predictability of understory species composition after forest thinning treatments in *Pinus ponderosa* forests, Arizona.

Freshly collected samples were first assayed without further treatment. The same day samples were collected, 120 cm^3 of soil were placed from each homogenized sample in a layer 1 cm thick on top of 300 cm^3 of sterile potting soil within 700-cm^3 square plastic pots. The pots were randomly arranged on a bench in a greenhouse maintained at 24°C and watered daily. During the next six months, emerging seedlings were counted and taxonomically identified every two weeks. Soil not used in the initial assay was stored for six months at -5°C. After this chilling period, four batches of soil (each 120 cm^3) were extracted from each chilled sample. One batch received no further treatment, while the other three received either heat (100°C for 30 minutes), liquid smoke (Wright's Brand, Roseland New Jersey; applied as 60 mL of a 10% liquid smoke solution via dilution with deionized water and poured on top of seed bank soil), or charred wood. The charred wood treatment involved intermixing the seed bank soil with 30 mL of charred wood prepared by burning *Pinus ponderosa* branches and grinding burned pieces to pass a 4-mm sieve. The chilled and treated samples were then placed in pots and cared for in the greenhouse the same way as for the initial assay, except that a longer, 10-month emergence period was provided. These seed bank treatments were selected because they represented a diversity of potential germination cues and previously promoted emergence in other fire-dependent ecosystems (e.g., Auld 1996). Treatments did not appreciably influence emergence, however, so seedlings were pooled from all seed bank pots including the initial assay (5 pots in total each containing 120 cm^3 of seed bank soil) for each area within sites.

Auld, T.D. 1996. Ecology of the Fabaceae in the Sydney region: fire, ants and the soil seed bank. *Cunninghamia* 4:531-551.

Table S1. Species recorded during an experiment examining predictability of post-restoration species composition in *Pinus ponderosa* forests, Arizona. Data are the number of experimental units (9-m^2 plots combined for areas with or without access by large herbivores) in which a species was present out of the total units listed at the top of columns. Presence (×) of a species in a regional seed bank dataset is also noted.

		– Seed bank (SB) –	——— Vegetation ———				
		2003	2003	2006	2008	2015	
Species[a]	Growth form[b]	n=27	n=54	n=54	n=54	n=32	Regional SB[c]
		——— Seed bank only ———					
Gnaphalium exilifolium	A forb	6					×
Nama dichotomum	A forb	1					×
Oenothera flava ssp. *taraxacoides*	P forb	1					×
		——— Seed bank and vegetation ———					
Achillea millefolium	P forb	1	15	18	18	12	×
Agrostis scabra	P grass	5			1		×
Arenaria lanuginos a ssp. *saxosa*	P forb	1	1		3		×
Carex geophila	P sedge	6	42	44	45	1	×
Chamaesyce serpyllifolia	A forb	5	3	5	1	1	×
Chenopodium graveolens	A forb	1	1	6	5	1	×
Conyza canadensis	A-B forb	11		4	3		×
Cyperus fendlerianus	P sedge	1	1	3	8		×
Drymaria leptophylla	A forb	2		4	1		×
Erigeron divergens	B forb	7	4	20	29		×
Erigeron flagellaris	B forb	7	7	8	9	11	×
Erigeron formosissimus	P forb	1	15	15	15		×
Houstonia wrightii	P forb	1	1	8	12	2	×
Koeleria macrantha	P grass	1	7	8	8		×
Laennecia schiedeana	A forb	1		8	9		×
Lupinus kingii	A forb	1	1		5	3	×
Muhlenbergia minutissima	A grass	2	1	6	7		×
Muhlenbergia montana	P grass	2	10	14	13	4	×
Muhlenbergia ramulosa	A grass	1		10	3		×
Pinus ponderosa	tree	1	8	50	10	15	×
Poa compressa	P grass	1	3	5	3		×
Poa pratensis	P grass	3	11	12	15	4	×
Pseudognaphalium macounii	A-B forb	3		8	11		×
Taraxacum officinale	P forb	2	12	28	21	7	×
Thlaspi montanum	P forb	1		1			×
Trifolium longipes	P forb	1	10	9	9	7	×
Verbena bracteata	A-P forb	3			1		×
Verbascum thapsus	B forb	15		20	18	9	×
		——— Vegetation only ———					
Anaphalis margaritacea	P forb			1			
Antennaria parvifolia	P forb		7	8	10	7	×
Antennaria rosulata	P forb		6	6	5		
Arabis fendleri	P forb			1	2		
Artemisia carruthii	P forb		4	4	5	6	×
Artemisia ludoviciana	P forb		1	1	1		
Astragalus castaneiformis	P forb		1	2			
Astragalus humistratus	P forb		5	6	7	5	
Astragalus rusbyi	P forb				2		
Astragalus troglodytus	P forb		6	4	4		

Blepharoneuron tricholepis	P grass	12	11	11	1	×
Bromus ciliatus	P grass		1			
Bromus tectorum	A grass		3	6	2	×
Carex occidentalis	P sedge	2	2	2		
Castilleja spp.	P forb	2	3	3		
Ceanothus fendleri	shrub	5	8	8	4	×
Chenopodium leptophyllum	A forb			1		×
Cirsium vulgare	B forb		3	3	4	
Cirsium wheeleri	P forb	9	14	16	10	
Cologania angustifolia	P forb	2	2	3	1	
Dracocephalum parviflorum	A-P forb		1	1		
Elymus elymoides	P grass	53	52	52	20	×
Elymus trachycaulus	P grass				22	
Epilobium brachycarpum	A forb	2	2	6	1	
Erigeron colomexicanus	B forb		1	1		
Eriogonum racemosum	P forb	1	2	1		
Erigeron speciosus	P forb			1		
Festuca arizonica	P grass	16	16	17	7	×
Gayophytum diffusum	A forb			1		×
Geranium caespitosum	P forb	4	6	6	2	
Heliomeris multiflora	P forb	5	8	8		×
Helianthella quinquenervis	P forb	1	1	1		
Hieracium fendleri	P forb	5	10	7	4	×
Hordeum jubatum	P grass			1		
Hymenoxys bigelovii	P forb	4	4	4		×
Ipomoea plummerae	P forb		3	1		×
Iris missouriensis	P forb	1	2	2	1	
Lactuca serriola	A forb		5	4	2	×
Lathyrus laetivirens	P forb	7	7	6		
Lepidium densiflorum	A-B forb				1	×
Linaria dalmatica	P forb	1	4	3	13	×
Lotus plebeius	P forb	1	2	1		
Lotus wrightii	P forb	11	20	21	13	×
Lupinus argenteus	P forb	9	12	10	8	
Machaeranthera canescens	B-P forb		1	2		×
Muhlenbergia wrightii	P grass			1		×
Noccaea montana	P forb			1		
Oxalis alpina	P forb	3	5	4	1	
Packera multilobata	A-P forb	17	30	25	4	×
Panicum bulbosum	P grass	1	1	1		
Pascopyrum smithii	P grass				14	×
Pedicularis centranthera	P forb	1	1			
Pennellia longifolia	B-P forb		2	2		×
Penstemon virgatus	P forb	5	7	6		
Phlox gracilis	A forb		1			
Phlox speciosa	P forb	14	13	12		
Poa fendleriana	P grass	25	29	28	7	×
Polygonum douglasii	A-P forb	19	15	26	2	
Portulaca oleracea	A forb		1	1		×
Potentilla crinita	P forb	9	6	6	1	
Potentilla hippiana	P forb	1	2	2	1	
Potentilla plattensis	P forb	2	2	2	3	
Potentilla subviscosa	P forb	3	6	6	1	×

Pseudocymopterus montanus	P forb	9	9	8			
Quercus gambelii	tree	15	15	14	8		
Ribes cereum	shrub		1				
Senecio actinella	P forb	2	2	2	5		
Senecio spartioides	P forb				2		
Solidago velutina	P forb	3	5	5			
Sonchus oleraceus	A forb		2				×
Sporobolus interruptus	P grass	5	5	6			
Symphyotrichum falcatum	P forb	1	1	1			
Thalictrum fendleri	P forb	1	1	1	1		
Tragopogon dubius	A-B forb		2	1			×
Vicia americana	P forb	20	18	17	13		
Vicia pulchella	P forb			1			

[a] Species in bold are non-native in the United States.

[b] A, annual; B, biennial; P, perennial.

[c] Abella, S.R., J.D. Springer and W.W. Covington. 2007. Seed banks of an Arizona *Pinus ponderosa* landscape: responses to environmental gradients and fire cues. *Canadian Journal of Forest Research* 37:552-567.

Table S2. Statistical results at the site scale for generalized linear mixed models associated with Figure 4 and Figure S5 for an experiment examining predictability of understory species composition after forest thinning treatments with or without access by large ungulates in *Pinus ponderosa* forests, Arizona. The restoration statistical factor includes no treatment (control) or forest thinning (thinning set 1 areas). Note that statistics at the site scale shown here were essentially equivalent (with rounding) for presence-absence and quantitative datasets for vegetation, as the Simpson similarity index emphasizes shared abundance between samples with richness differences factored out. Species presence-absence and relative cover data returned nearly equivalent Simpson similarities.

	Factors		
	Restoration (1, 48)[a]	Year (3, 48)	Disturbance × year (3, 48)
Figure 4 herbivore access	F-statistic (*p* value)		
a) Seed bank presence absence	2.8 (0.099)	6.6 (<0.001)	4.3 (0.009)
b) Seed bank quantitative	3.1 (0.087)	6.1 (0.001)	3.8 (0.016)
c) Vegetation presence absence	0.7 (0.419)	50.3 (<0.001)	1.2 (0.328)
d) Vegetation quantitative	0.7 (0.419)	50.3 (<0.001)	1.2 (0.328)
Figure S5 no access			
a) Seed bank presence absence	3.0 (0.089)	2.5 (0.075)	3.4 (0.025)
b) Seed bank quantitative	2.9 (0.093)	4.3 (0.009)	5.3 (0.003)
c) Vegetation presence absence	2.6 (0.118)	32.8 (<0.001)	0.1 (0.904)
d) Vegetation quantitative	2.6 (0.118)	32.8 (<0.001)	0.1 (0.904)

[a] Between- and within-group degrees of freedom.

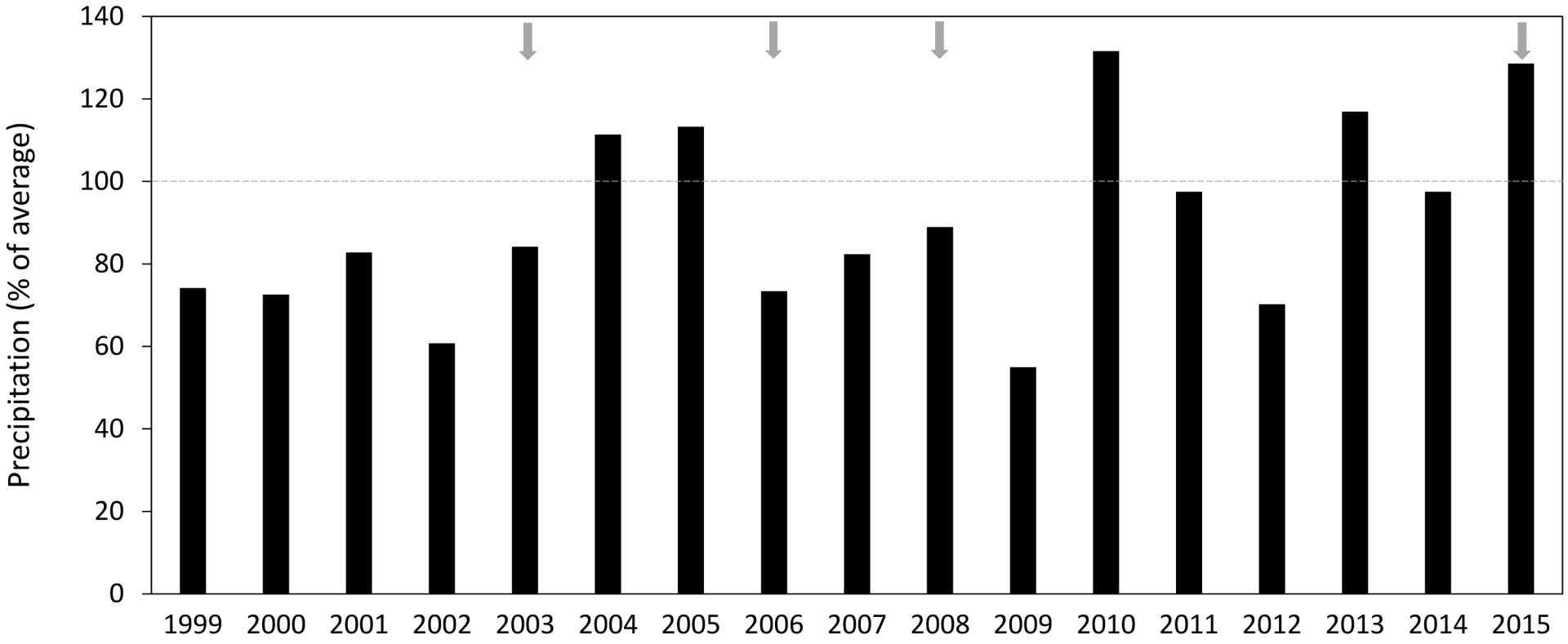

Figure S1. Precipitation as a percentage of the 54-cm long-term average (1950 through 2018) reported at the Flagstaff Airport weather station (elevation 2134 m), Arizona, (Western Regional Climate Center, Reno, Nevada). Arrows note pre-treatment seed bank and vegetation (2003) and post-treatment measurement years for the experiment.

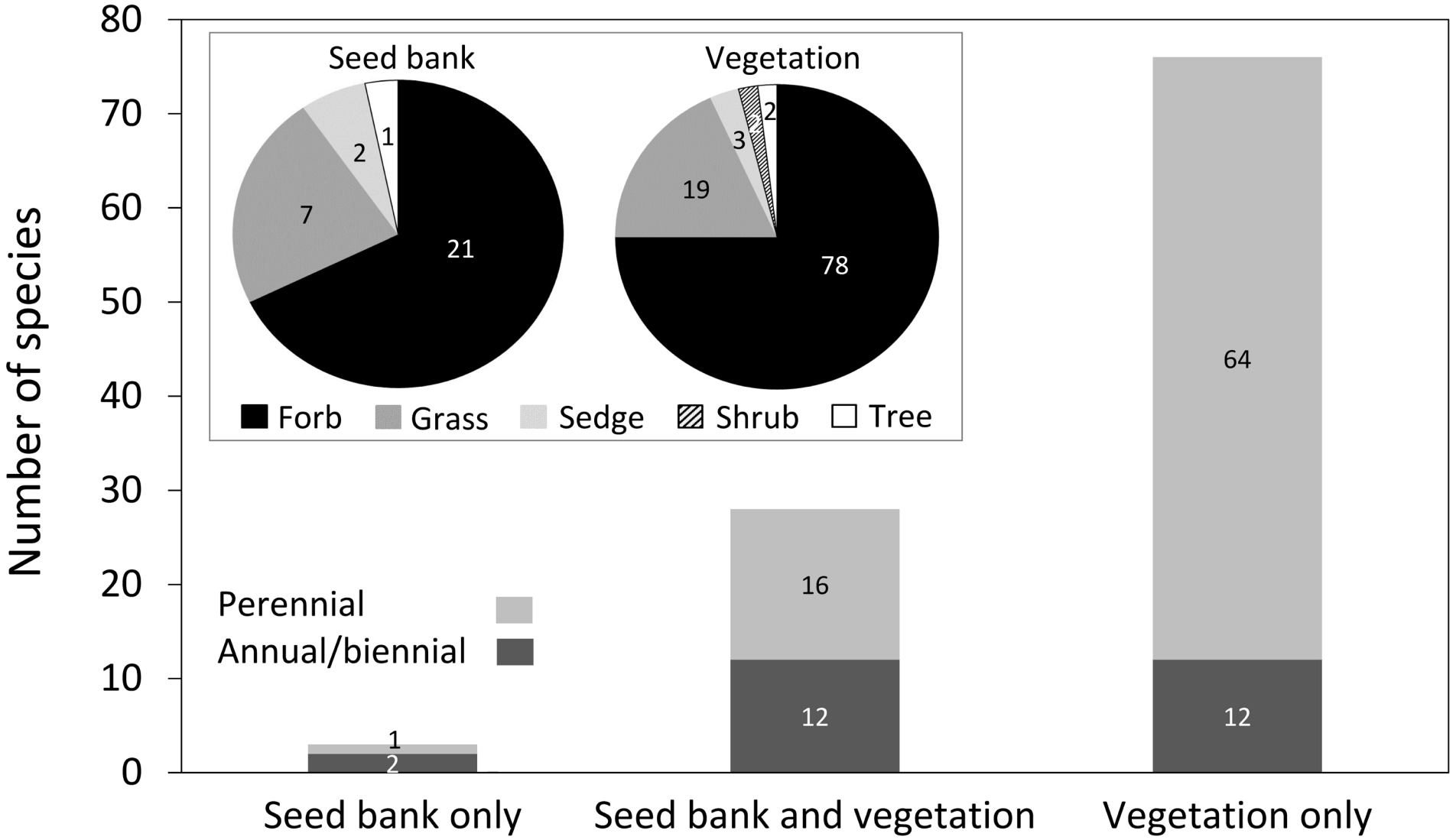

Figure S2. Summary of species detected in pre-treatment soil seed banks and pre- and post-treatment vegetation during an experiment evaluating if pre-treatment components are predictive of post-treatment changes after restoration forest thinning and large-herbivore exclusion in *Pinus ponderosa* forests, Arizona. The main graph displays species detection according to potential longevity of species individuals and whether species occurred in only the pre-treatment seed bank, the seed bank and vegetation (pre- or post-treatment), or only in the vegetation (pre- or post-treatment). Numbers on bars list numbers of species. The inset pie charts show the number of species in the seed bank and vegetation by species growth form, with numbers listing the number of species. Table S1 provides species identities.

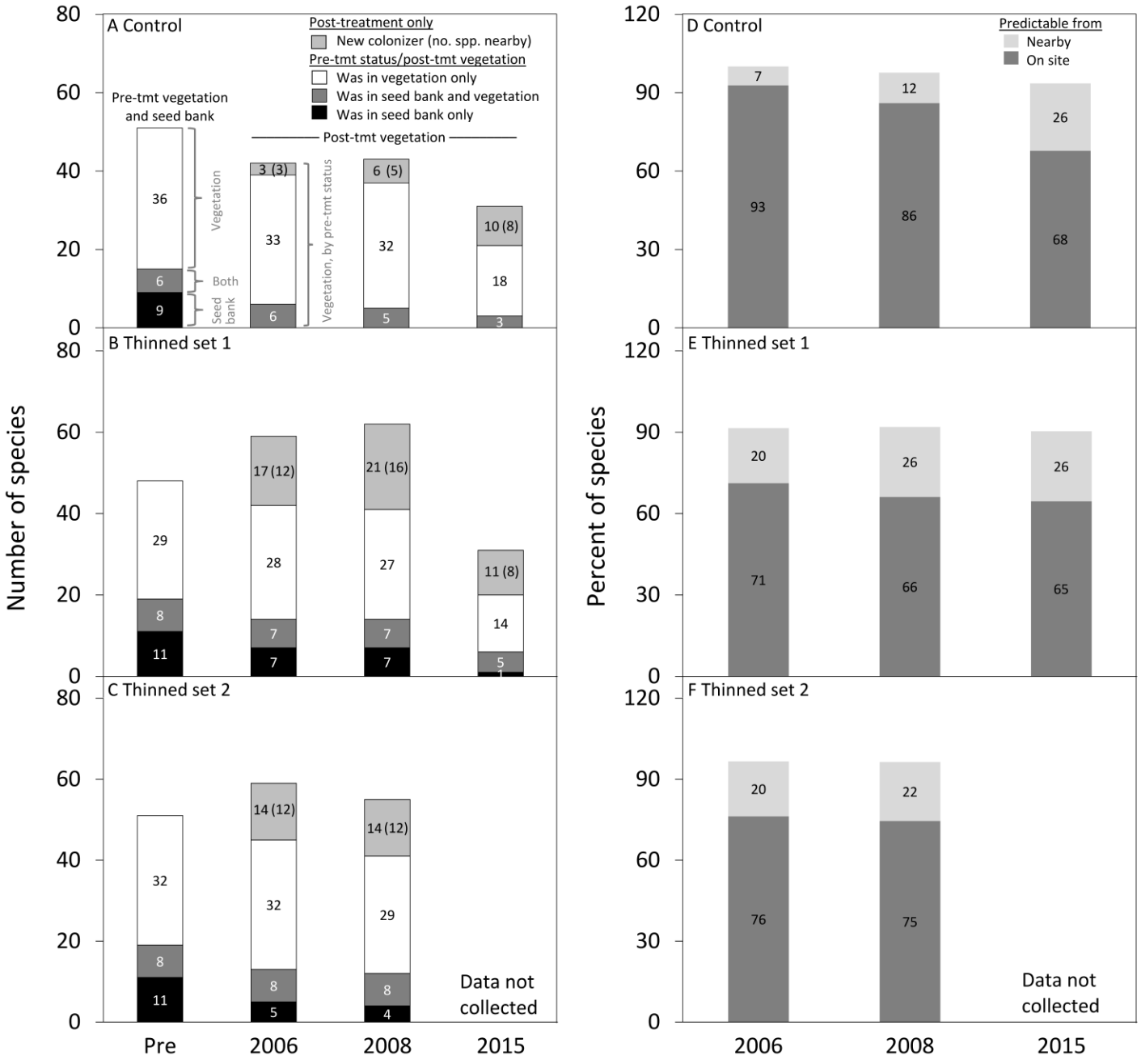

Figure S3. Status and transitions of species in understory plant communities before and up to 12 years after restoration treatments (forest thinning) where large herbivores were excluded in *Pinus ponderosa* forests, Arizona. Disturbance treatments include a control (no restoration) and two sets of forest thinning treatments. For panels A-C, numbers of species are totals for nine (pre-treatment in 2003 and post-treatment in 2006 and 2008) and eight (post-treatment in 2015) sites within treatments. Numbers on bars list numbers of species. Post-treatment vegetation is classified according to whether species, in 2003 before treatment, had occurred only in the seed bank, seed bank and vegetation, or only in the vegetation, along with new colonizers not detected before treatment in the on-site seed bank or vegetation. Numbers in parentheses for the new colonizer category represent the number of new colonizers (of the total) recorded before treatment in off-site but nearby vegetation of remnant canopy openings. As an example, in (B) for 2006 three years after treatment, of 11 species detected only in the seed bank before treatment, 7 occurred in vegetation in 2006; 7 of 8 species in both seed banks and vegetation before treatment remained in vegetation; 28 of 29 species only in vegetation before treatment remained in vegetation; and of 17 new colonizers not detected in on-site seed banks or vegetation before treatment, 12 occurred in vegetation of nearby remnant openings. Panels D-F display percentages of species in post-treatment vegetation that had occurred before treatment on site (seed bank or vegetation) or in nearby vegetation in remnant canopy openings. Percentages are listed on bars.

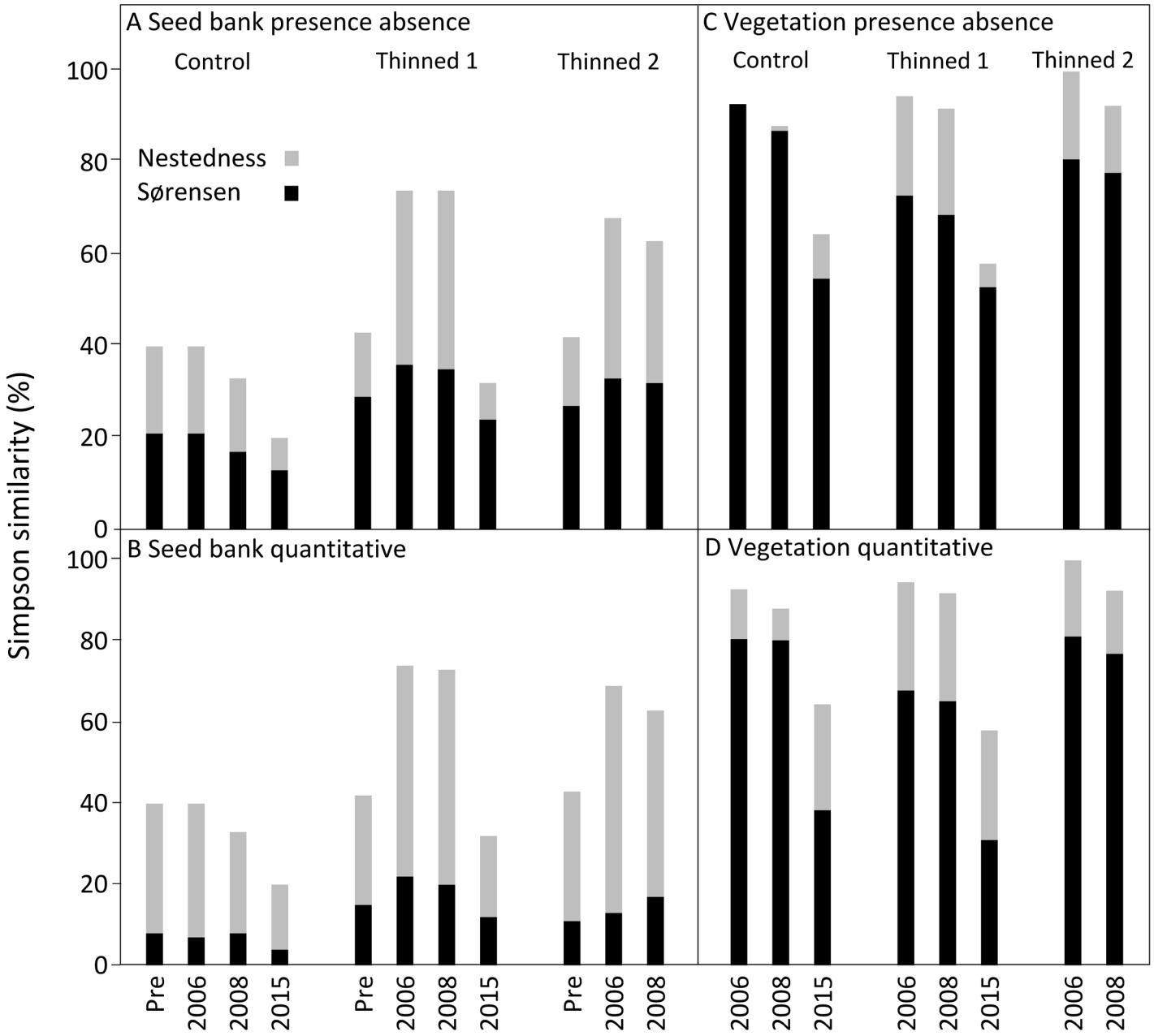

Figure S4. At the treatment group scale, partitioning similarity between pre-treatment (2003) soil seed bank and vegetation species composition with post-treatment vegetation composition (2006, 2008, and 2015) after restoration treatments for locations where large herbivores were excluded in *Pinus ponderosa* forests, Arizona. Restoration treatments included a control (no tree thinning) and two sets of sites where trees were thinned. The panels (A-D) list the component (pre-treatment seed bank or vegetation composition) being compared to vegetation species composition among study years. Data are shown separately for species presence/absence and quantitative data based on relative seed density (for soil seed banks) and relative cover (for vegetation). Similarity constituents include Sørensen similarity (shared abundance as a percentage of total abundance which can include differences in species richness) and similarity attributable to including nestedness accounting for differences in species richness between assemblages.

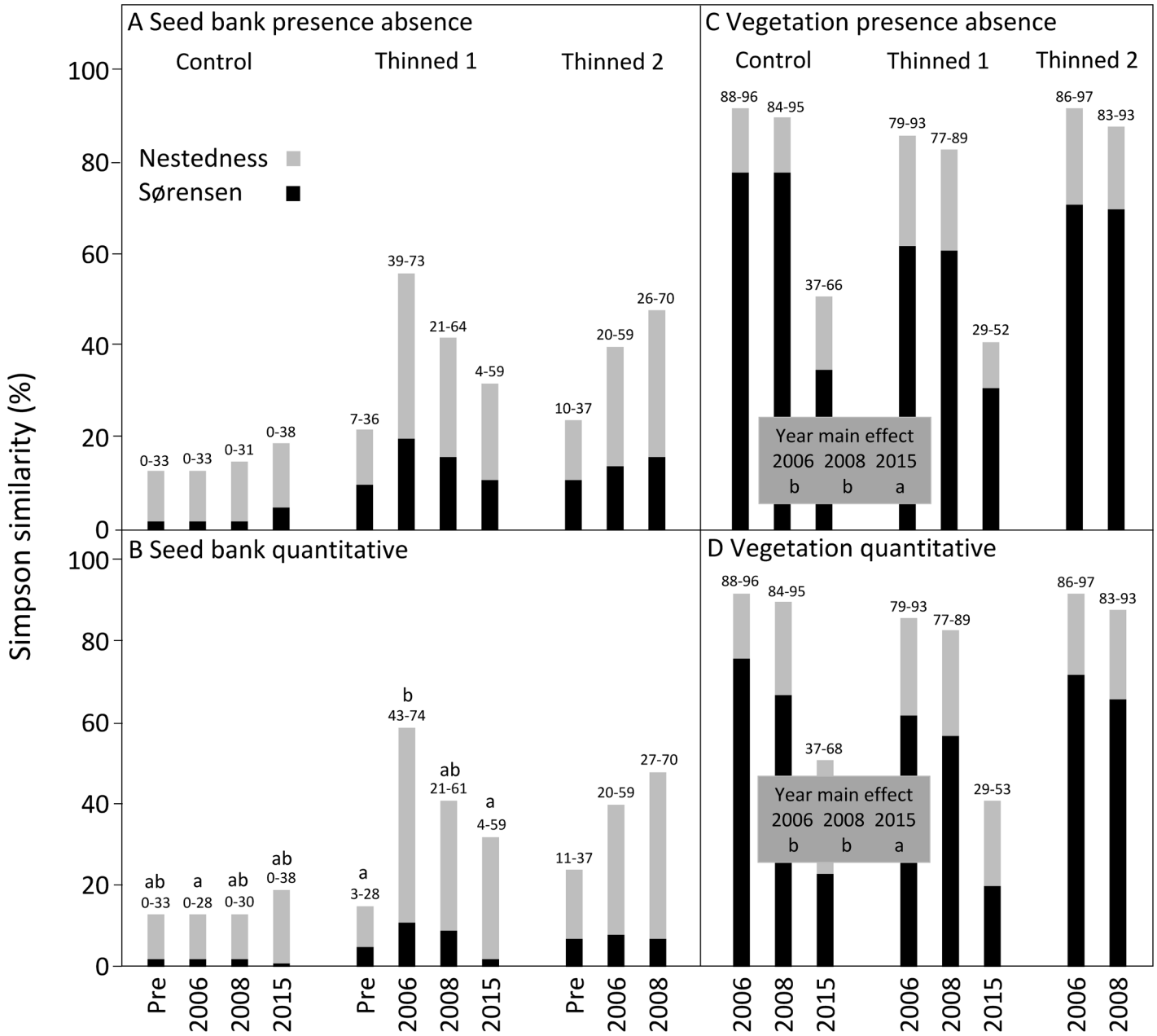

Figure S5. At the site scale, partitioning of mean similarity between pre-treatment (2003) soil seed bank and vegetation species composition with post-treatment vegetation composition (2006, 2008, and 2015) after restoration forest thinning for locations where large herbivores were excluded in *Pinus ponderosa* forests, Arizona. Restoration treatments included a control (no tree thinning) and two sets of sites where trees were thinned. The panels (A-D) list the component (pre-treatment seed bank or vegetation composition) being compared to vegetation species composition among study years. Data are shown separately for species presence/absence and quantitative data based on relative seed density (for soil seed banks) and relative cover (for vegetation). Similarity constituents include Sørensen similarity (shared abundance as a percentage of total abundance which can include differences in species richness) and similarity attributable to including nestedness accounting for differences in species richness between assemblages. Numbers above bars are lower-upper 95% asymmetrical confidence intervals around Simpson similarity means. Within a panel comparing the control and thinning set 1, means without shared letters differ at $p < 0.05$. In (A), the restoration treatment × year interaction was significant ($F_{3,4} = 3.4$, $p = 0.025$; Table S2), but multiple comparisons of means were borderline significant (e.g., $p = 0.055$ for control 2006 c.f. restoration 2006) and letters comparing means are not shown.