Supplementary Material

Soil enzyme activity and soil nutrients jointly influence post-fire habitat models in mixed-conifer forests of Yosemite National Park, USA

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Appendix A – Supplemental figures

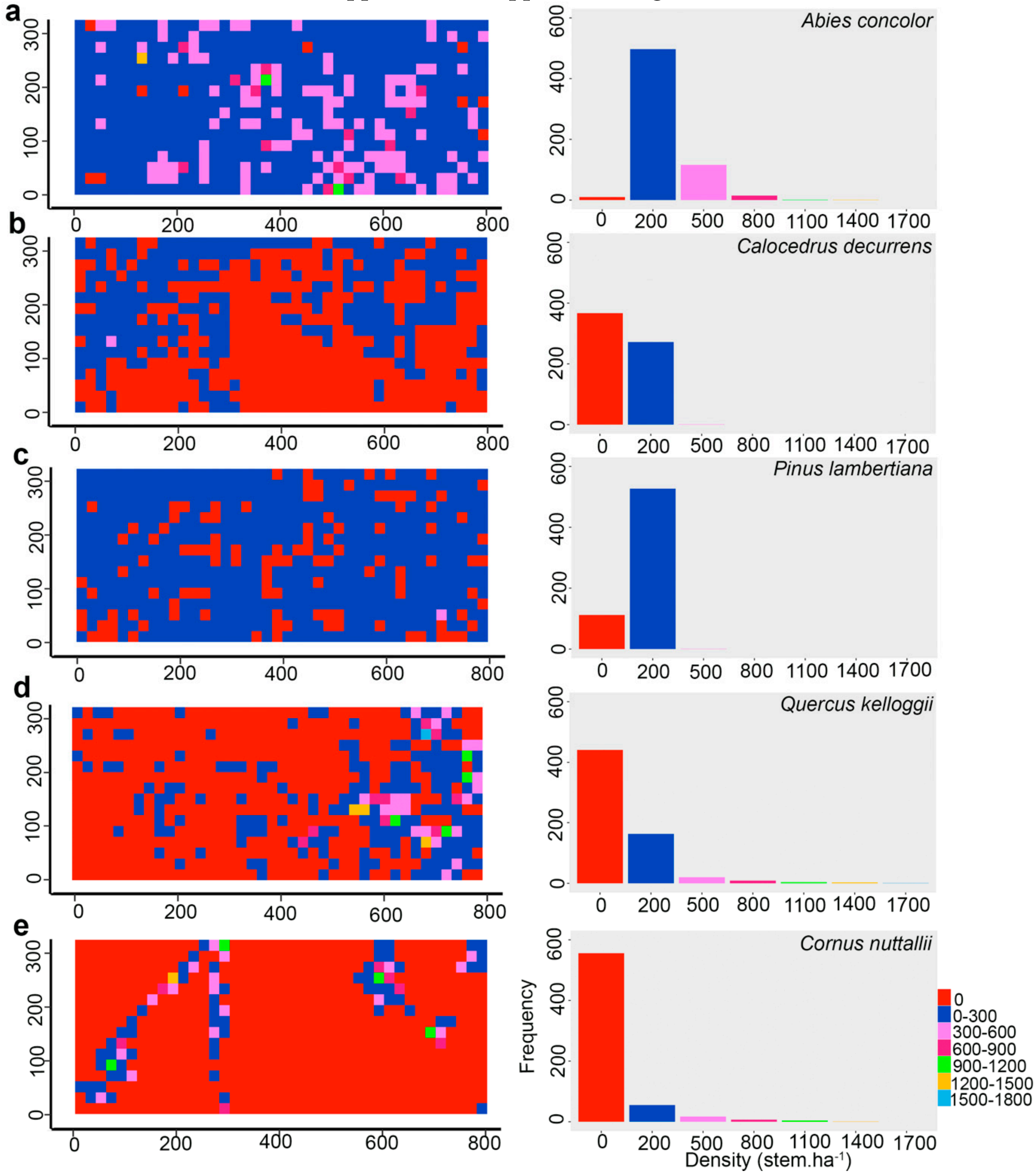

Figure S1. Distribution and abundance of the five most abundant species in the Yosemite Forest Dynamic Plot in 2019, including *Abies concolor* (a), *Calocedrus decurrens* (b), *Pinus lambertiana* (c), *Quercus kelloggii* (d), and *Cornus nuttallii* (e).

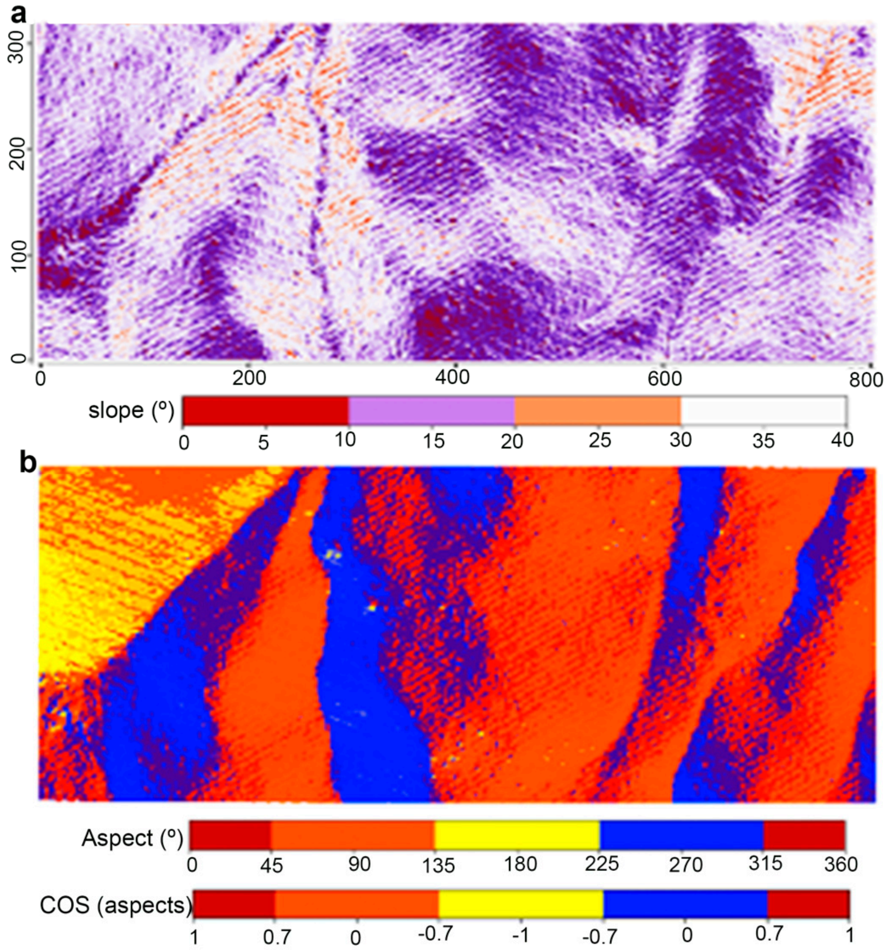

Figure S2. Slope (a) and aspect (b) at the scale of 1 m × 1 m in the Yosemite Forest Dynamic Plot (25.6 ha) in the Yosemite National Park, California, USA.

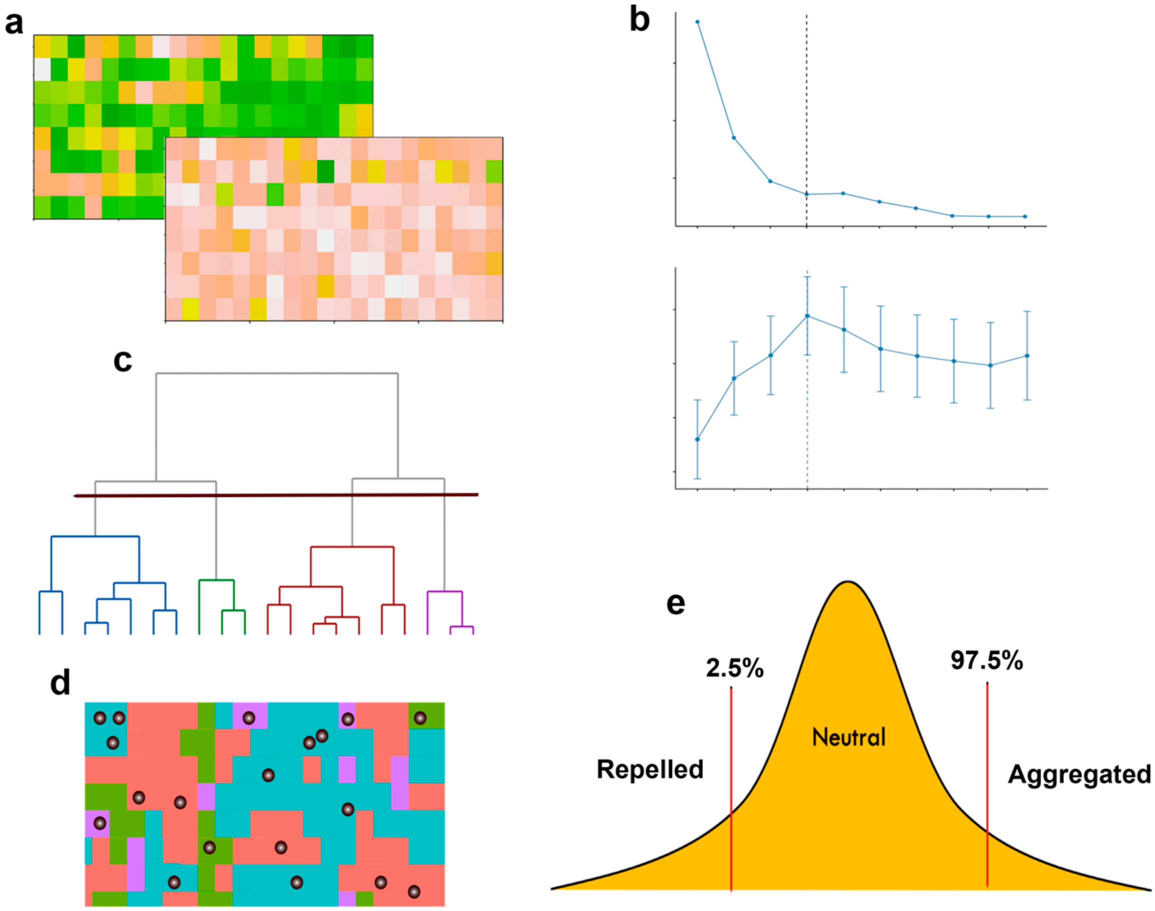

Figure S3. Data flow used to quantify species-habitat association in Yosemite Forest Dynamic Plot. The procedures included: a) environmental variables calculated at 20 m x 20 m quadrat resolution, b) optimal number of habitats determined by elbow, gap statistic, and NbClust package methods, c) hierarchical clustering used to generate dendrogram from environmental variables and selective cut (dark brown line which was determined by optimal number of habitats) and defining habitats, d) torus translation test was conducted to quantify observed abundance of each species in each habitat type and compare this observed value to abundance value calculated for simulated habitat maps (Simulated maps were generated by shifting the actual habitat map in four directions by 20-m increments while the location of the stems did not change), e) determination of species which were significantly positively (aggregated) or negatively (repelled) associated with a specific habitat type (at $\alpha = 0.05$) (observed abundance was higher (lower) than at least 97.5 % (or 2.5%) of the simulated abundance in simulated maps).

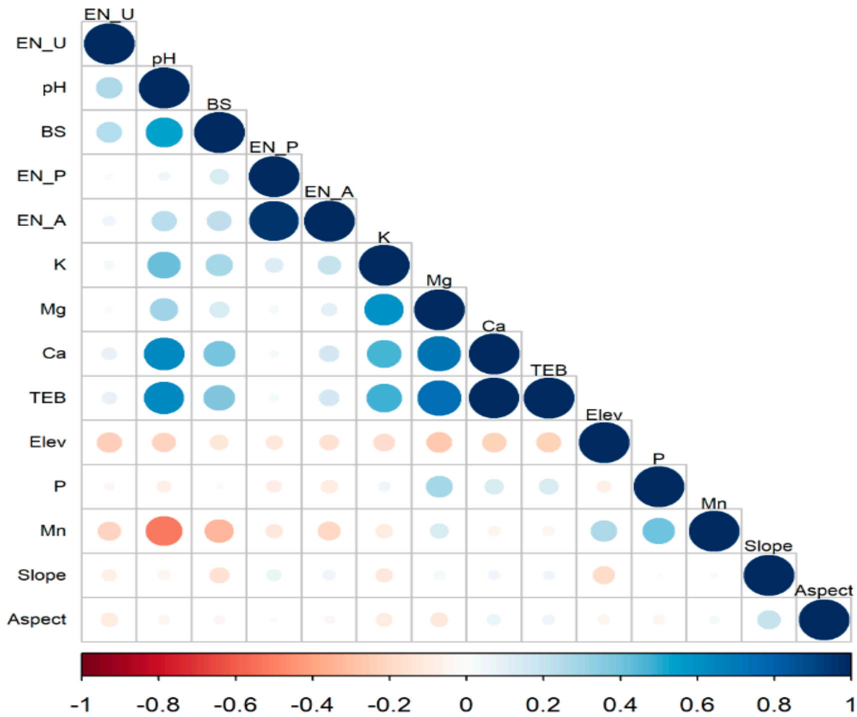

Figure S4. Correlation between environmental variables in each 20 m × 20 m quadrat. Positive correlations are displayed in blue and negative correlations in red. Color intensity and the size of the circle are proportional to the correlation coefficients. In the right side of the correlogram, colors show the correlation coefficients. Environmental variables include: slope, phosphorus (P), base-cation saturation (BS), elevation (Elev), phosphatase enzyme (EN_P), urease enzyme (EN_U), alkaline phosphatase enzyme (EN A), total exchangeable bases (TEB), manganese (Mn), magnesium (Mg).

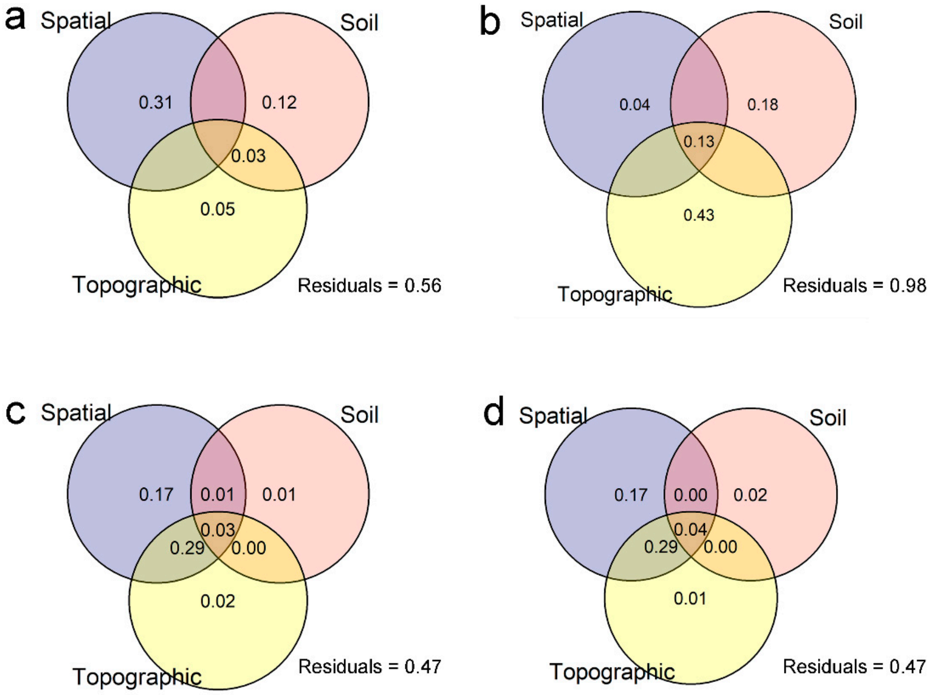

Figure S5. Variation partitioning of 11 live species with ≥ 25 stems in the Yosemite Forest Dynamics Plot in 2019. Numbers show the explained proportion of variation in species abundances in 2019 (a), basal area change in species between (2014 to 2019) (b), mortality (between 2014 to 2019) (c), and recruitment (between 2014 to 2019) (d) by spatial, edaphic (including chemical properties, acid and alkaline phosphatases and urease enzymes), and topographic variables. Negative values of explained variation were not shown in the figures (unlabeled regions).

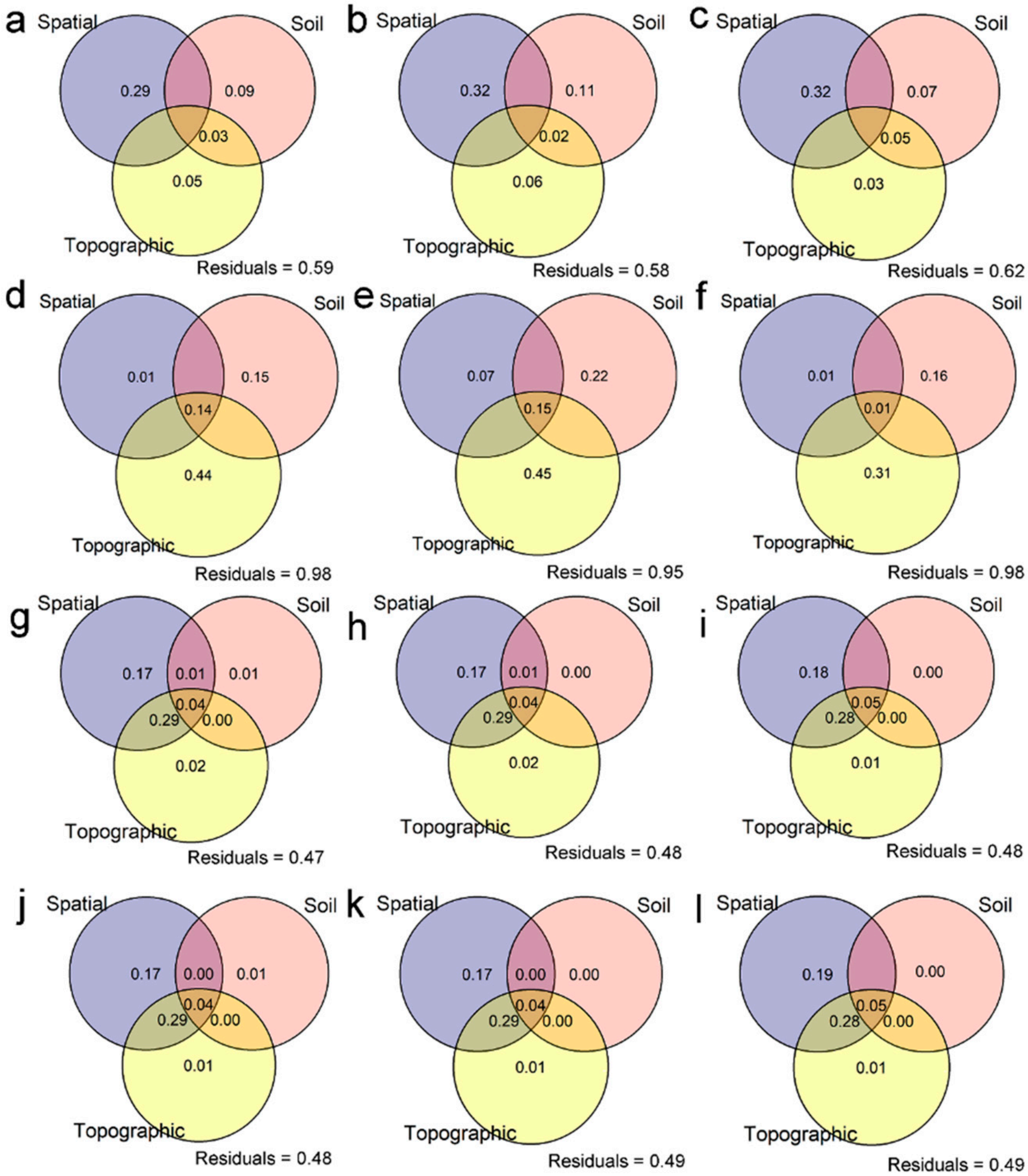

Figure S6. Variation partitioning of 11 live species with ≥ 25 stems in the Yosemite Forest Dynamics Plot in 2019. Numbers show the proportion of variation in species abundances in 2019 (a, b, c), species basal area change (between 2014 to 2019) (d, e, f), mortality (between 2014 to 2019) (g, h, i), and recruitment (between 2014 to 2019) (j, k, l) with considering the hydraulic conductivity in edaphic component. The number of enzymes contribution in soil component changed from the first column to the third column which include alkaline phosphatase + urease + acid phosphatase / urease + acid phosphatase / without enzymes respectively. Negative values of explained variation were not shown in the figures (unlabeled regions).

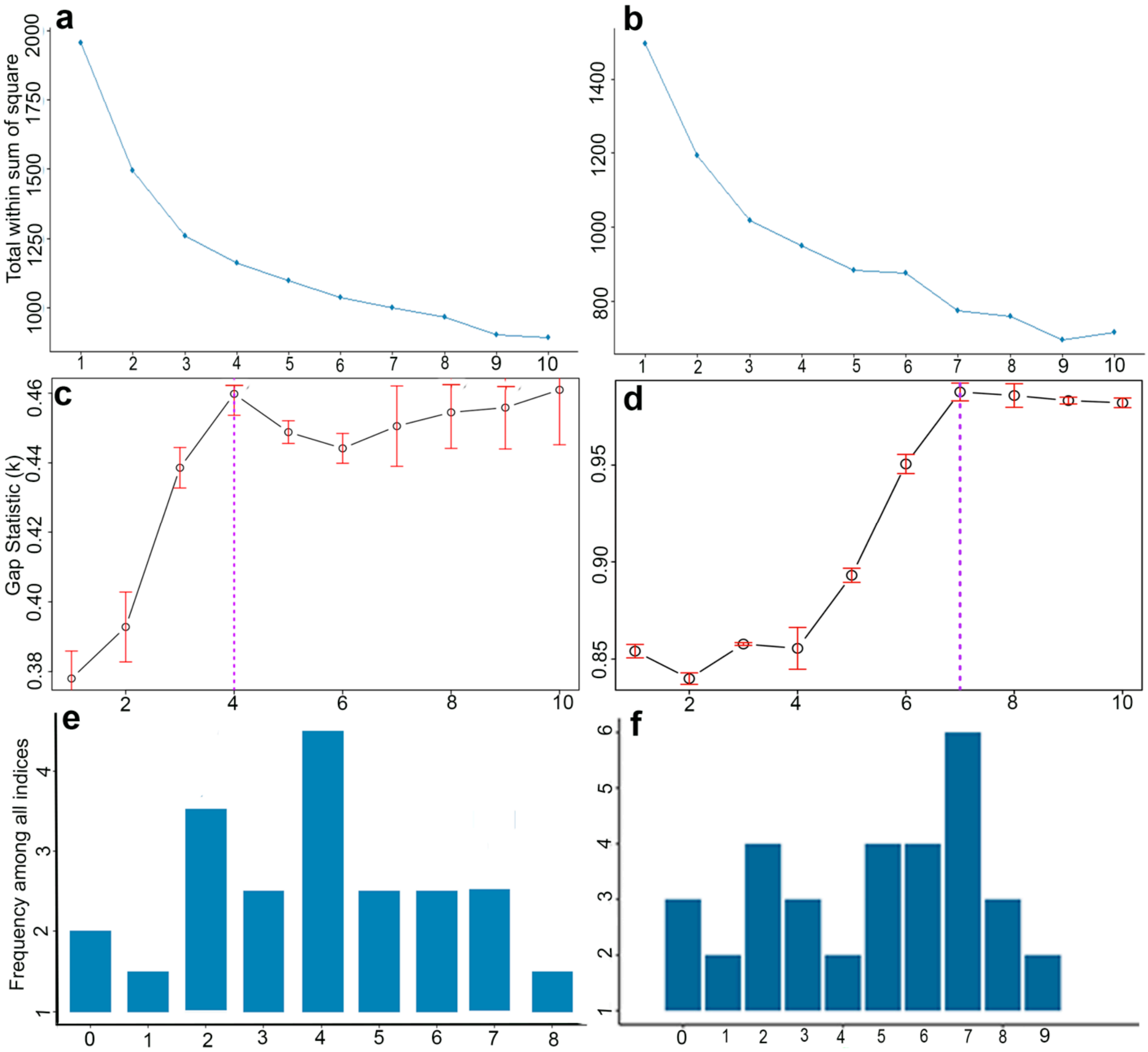

Figure S7. Computation of the optimal numbers of habitats based on topographic (left panels) and soil variables (right panels) in the plot. Elbow (a, b), Gap statistic (c, d), and NbClust package (e, f) were used to compute optimal numbers of habitat types.

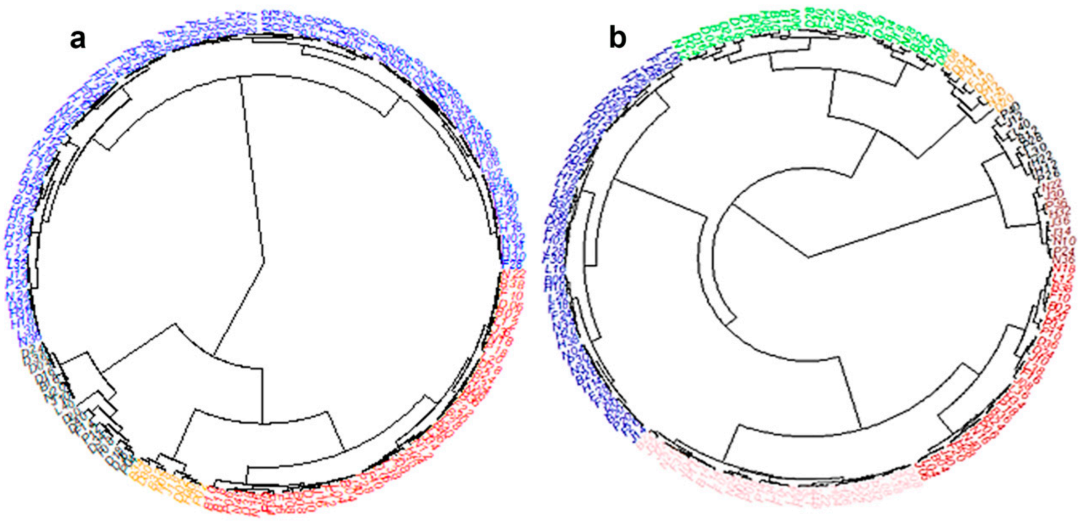

Figure S8. The results of hierarchical clustering for classifying quadrats into four habitats (based on topographic variables) (a) and seven habitats (based on the edaphic factors) (b) within the Yosemite Forest Dynamic Plot.

Appendix B – Supplemental tables

Table S1. Van Genuchten parameters for 12 soil texture classes and A values (value relating to Van Genuchten parameters) for a disk with a 2.25 cm radius and suction values (h_0) between 0.5 cm and 6 cm.

			h_0						
			-0.5	-1	-2	-3	-4	-5	-6
Soil Texture			A						
Sand	0.145	2.68	2.84	2.40	1.73	1.24	0.89	0.64	0.46
Loamy Sand	0.124	2.28	2.99	2.79	2.43	2.12	1.84	1.61	1.40
Sandy Loam	0.075	1.89	3.88	3.88	3.89	3.91	3.93	3.98	4.00
Loam	0.036	1.56	5.46	5.72	6.27	6.87	7.53	8.25	9.05
Silt	0.016	1.37	7.92	8.18	8.71	9.29	9.90	10.55	11.24
Silt Loam	0.020	1.41	7.10	7.37	7.93	8.53	9.19	9.98	10.64
Sandy Clay Loam	0.059	1.48	3.21	3.52	4.24	5.11	6.15	7.41	8.92
Clay Loam	0.019	1.31	5.86	6.11	6.64	7.23	7.86	8.55	9.30
Silty Clay Loam	0.010	1.23	7.89	8.09	8.51	8.95	9.41	9.90	10.41
Sandy Clay	0.027	1.23	3.34	3.57	4.09	4.68	5.36	6.14	7.04
Silty Clay	0.005	1.09	6.08	6.17	6.36	6.56	6.76	6.97	7.18
Clay	0.008	1.09	4.00	4.10	4.30	4.51	4.74	4.98	5.22

Table S2. Correlation between environmental variables at 20 m × 20 m scale in the Yosemite Forest Dynamic Plot. Elev, P, Ca, Mn, Mg, EN-P, EN-U, EN-A, BS, and TEB represent elevation, phosphorus, calcium, manganese, magnesium, phosphatase enzyme, urease enzyme, alkaline phosphatase enzyme, base saturation, and total exchangeable bases respectively.

	Elev	Slope	Aspect	EN_P	EN_U	EN_A	pH	P	Ca	Mg	BS	K	TEB	Mn
Elev	-													
Slope	-0.18	-												
Aspect	-0.05	0.20	-											
EN_P	-0.11	0.07	-0.01	-										
EN_U	-0.24	-0.08	-0.11	0.02	-									
EN_A	-0.14	0.06	-0.03	0.96	0.06	-								
pH	-0.22	-0.05	-0.05	0.04	0.27	0.24	-							
P	-0.07	0.00	-0.05	-0.09	-0.03	-0.10	-0.08	-						
Ca	-0.22	0.05	0.07	0.03	0.09	0.15	0.64	0.13	-					
Mg	-0.25	0.04	-0.12	0.03	-0.02	0.1	0.30	0.28	0.73	-				
BS	-0.13	-0.15	-0.04	0.14	0.24	0.23	0.54	0.01	0.39	0.15	-			
K	-0.18	-0.11	-0.10	0.13	0.04	0.20	0.42	0.05	0.46	0.60	0.29	-		
TEB	-0.23	0.05	0.06	0.03	0.08	0.16	0.63	0.14	1.00	0.75	0.39	0.49	-	
Mn	0.26	0.01	0.03	-0.11	-0.21	-0.20	-0.52	0.41	-0.05	0.13	-0.33	-0.11	-0.05	-

Table S3. Average properties (mean ± sd) for four and seven habitats at 20 m × 20 m quadrat in the Yosemite Forest Dynamic Plot.

Habitat	Mean Elevation	Slope	Aspect	pH	P	Ca	Bs	K
High Slope-North	1858 ± 28.3	24 ± 4	0.67 ± 0.33	6.04 ± 0.66	27.61 ± 21.52	2926.79 ± 2225.72	94.62 ± 7.61	146.14 ± 58.72
High Slope-South	1856 ± 28	15 ± 4	0.69 ± 0.31	6.14 ± 0.71	27.42 ± 24.75	2667.99 ± 1518.53	95.87 ± 5.40	175.92 ± 77.94
Low Slope-North	1846 ± 20.6	13 ± 1	0.71 ± 0.29	6.06 ± 0.37	33.34 ± 36.37	2938.10 ± 2093.01	97.22 ± 1.07	165.60 ± 36.97
Low Slope-South	1860 ± 5.1	10 ± 9	0.79 ± 0.21	6.50 ± 0.00	24.70 ± 4.38	2682.05 ± 359.28	98.55 ± 0.49	226.60 ± 52.60
Habitat 1	1856 ± 22.9	15.4± 4	0.53 ± 0.47	6.14 ± 0.60	27.42 ± 24.04	2667.99 ± 2162.47	95.8 ± 27.28	175.92 ± 0.17
Habitat 2	1864 ± 9.0	19 ± 0	0.54 ± 046	5.80 ± 0.40	12.22 ± 7.52	2003.16 ± 601.02	95.80 ± 2.96	179.02 ± 22.13
Habitat 3	1859 ± 25.7	23 ± 2	0.61 ± 0.39	6.11 ± 0.68	28.71 ± 23.36	3024.34 ± 2280.23	96.24 ± 3.87	151.29 ± 60.33
Habitat 4	1857 ± 2 8.3	14 ± 3	0.71 ± 0.29	6.16 ± 0.74	28.97 ± 24.91	2790.60 ± 1631.51	95.77 ± 5.80	173.58 ± 83.02
Habitat 5	1879 ± 17.2	20 ± 8	0.63 ± 0.37	5.76 ± 0.57	20.10 ± 7.61	1652.46 ± 986.70	88.86 ± 1 2.94	163.51 ± 61.42
Habitat 6	1824 ± 35.6	26 ± 7	0.71 ± 0.29	6.10 ± 0.32	37.64 ± 16.27	3098.37 ± 1148.49	92.00 ± 15.84	140.28 ± 42.04
Habitat 7	1827 ± 15.3	18 ± 6	0.71 ± 0.29	6.40 ± 0.55	23.50 ± 13.74	4862.91 ± 2396.60	98.61 ± 61.67	202.15 ± 61.67

Table S3 (continued). Average properties (mean ± sd) for four and seven habitats at 20 m × 20 m quadrat in the Yosemite Forest Dynamic Plot.

Habitat	K	Mg	TEB	Mn	Acid Phosphatase	Alkaline Phosphatase	Urease
High Slope-North	146.14 ± 58.72	92.88 ± 53.99	15.7 ± 11.56	48.09 ± 35.74	0.41 ± 0.20	0.36 ± 0.16	46.80 ± 11.05
High Slope-South	175.92 ± 77.94	94.09 ± 48.74	14.54 ± 7.93	38.99 ± 37.54	0.46 ± 0.20	0.37 ± 0.14	47.01 ± 15.36
Low Slope-North	165.60 ± 36.97	93.52 ± 38.88	15.8 ± 10.74	44.12 ± 14.05	0.36 ± 0.20	0.39 ± 0.16	47.80 ± 11.32
Low Slope-South	226.60 ± 52.60	76.60 ± 20.50	14.60 ± 1.69	29.35 ± 8.41	0.44 ± 0.01	0.41 ± 0.17	49.75 ± 1.06
Habitat 1	175.92 ± 0.17	94.09 ± 240.25	14.5 ± 11.16	38.99 ± 25.68	0.37 ± 0.10	0.35 ± 0.19	45.18 ± 12.15
Habitat 2	179.02 ± 22.13	86.92 ± 24.21	11.18 ± 3.14	56.00 ± 44.56	0.38 ± 0.15	0.37 ± 0.14	50.25 ± 10.46
Habitat 3	151.29 ± 60.33	91.27 ± 50.54	16.2 ± 11.81	42.93 ± 33.10	0.43 ± 0.20	0.33 ± 0.13	49.22 ± 9.90
Habitat 4	173.58 ± 83.02	97.28 ± 51.67	15.18 ± 8.53	40.45 ± 40.59	0.43 ± 0.20	0.43 ± 0.17	50.23 ± 10.10
Habitat 5	163.51 ± 61.42	58.16 ± 24.96	9.15 ± 5.23	73.75 ± 37.35	0.37 ± 0.10	0.43 ± 0.17	41.83 ± 13.73
Habitat 6	140.28 ± 42.04	115.38 ± 80.50	16.78 ± 6.22	35.95 ± 9.72	0.30 ± 0.10	0.32 ± 0.10	56.70 ± 1.69
Habitat 7	202.15 ± 61.67	162.45 ± 17.80	26.1 ± 11.90	35.25 ± 11.90	0.42 ± 0.21	0.40 ± 0.11	52.15 ± 7.69

Table S4. Significant spatial variables selected by forward selection (P < 0.05) showing adjusted cumulative square of sum of all variables, F-test (F), and p-value (P = significant variable) show in the table.

	Variable	Cumulative Adjusted R^2	F	P
	PCNM 4	0.01	3.87	0.004
	PCNM 79	0.03	3.80	0.003
	PCNM 28	0.04	3.24	0.002
	PCNM 88	0.06	3.28	0.005
	PCNM 25	0.07	3.32	0.006
	PCNM 70	0.08	3.14	0.007
	PCNM 1	0.10	3.12	0.007
	PCNM 3	0.11	3.05	0.011
	PCNM 6	0.12	2.85	0.008
	PCNM 12	0.13	2.79	0.008
	PCNM 44	0.14	2.75	0.015
	PCNM104	0.15	2.71	0.021
	PCNM 71	0.16	2.74	0.019
Space	PCNM 35	0.17	2.70	0.012
	PCNM 75	0.18	2.74	0.015
	PCNM 13	0.19	2.76	0.014
	PCNM 64	0.20	2.62	0.017
	PCNM 67	0.21	2.62	0.021
	PCNM 5	0.22	2.63	0.019
	PCNM 78	0.22	2.41	0.016
	PCNM 72	0.23	2.25	0.024
	PCNM 48	0.24	2.21	0.036
	PCNM 85	0.24	2.17	0.038
	PCNM 49	0.25	2.18	0.039
	PCNM 32	0.26	2.17	0.040
	PCNM 2	0.26	2.17	0.034
	PCNM 22	0.27	2.16	0.049

Table S5. The contribution of spatial, soil and topographic variables for each species within the Yosemite Forest Dynamic Plot with respect to stem density in each quadrat (400 m^2) in 2019. 1 = the pure spatial component; 2 = the spatially structured environmental component; 3 = the pure Environmental component; 4 = the proportion explained by soil variables; 5 = the proportion explained by topographic variables; 6 = the topographically structured edaphic component.

Species	1	2	3	4	5	6
Abies concolor	0.430	0.300	0.040	0.130	0.300	0.120
Pinus lambertiana	0.560	0.280	0.000	0.060	0.280	0.040
Calocedrus decurrens	0.180	0.060	0.070	0.110	0.130	0.040
Cornus nuttallii	0.070	0.060	0.030	0.036	0.054	0.030
Arctostaphylos patula	0.000	0.080	0.040	0.180	0.004	0.020
Cornus sericea	0.480	0.040	0.060	0.080	0.100	0.060
Quercus kelloggii	0.220	0.000	0.270	0.100	0.200	0.030
Corylus cornuta var. *californica*	0.044	0.020	0.030	0.046	0.020	0.020
Prunus virginiana	0.000	0.001	0.004	0.001	0.004	0.002
Sambucus racemosa	0.000	0.012	0.010	0.016	0.014	0.000
Chrysolepis sempervirens	0.000	0.001	0.004	0.200	0.000	0.053

Table S6. The contribution of spatial, soil and topographic variables for each species within the Yosemite Forest Dynamic Plot with respect to basal area increment in each quadrat (400 m^2) from 2009 to 2014. Numbers 1 = the pure spatial component; 2 = the spatially structured environmental component; 3 = the pure Environmental component; 4 = the proportion explained by soil variables; 5 = the proportion explained by topographic variables; 6 = the topographically structured edaphic component.

Species	1	2	3	4	5	6
Abies concolor	0.100	0.207	0.080	0.190	0.019	0.080
Pinus lambertiana	0.152	0.059	0.039	0.050	0.033	0.015
Calocedrus decurrens	0.244	0.094	0.243	0.153	0.032	0.062
Cornus nuttallii	0.295	0.087	0.030	0.046	0.046	0.221
Arctostaphylos patula	0.008	0.000	0.000	0.000	0.000	0.000
Cornus sericea	0.520	0.050	0.070	0.070	0.040	0.019
Quercus kelloggii	0.319	0.072	0.031	0.100	0.110	0.072
Corylus cornuta var. *californica*	0.062	0.060	0.000	0.000	0.000	0.060
Prunus virginiana	0.080	0.000	0.000	0.000	0.000	0.000
Sambucus racemosa	0.070	0.000	0.000	0.000	0.000	0.000
Chrysolepis sempervirens	0.038	0.010	0.000	0.000	0.000	0.010

Table S7. The contribution of spatial, soil and topographic variables for each species within the Yosemite Forest Dynamic Plot with respect to mortality in each quadrat (400 m^2) from 2014 to 2019. Numbers 1 = the pure spatial component; 2 = the spatially structured environmental component; 3 = the pure Environmental component; 4 = the proportion explained by soil variables; 5 = the proportion explained by topographic variables; 6 = the topographically structured edaphic component.

Species	1	2	3	4	5	6
Abies concolor	0.340	0.223	0.060	0.040	0.030	0.040
Pinus lambertiana	0.080	0.010	0.030	0.030	0.010	0.020
Calocedrus decurrens	0.080	0.010	0.030	0.030	0.010	0.020
Cornus nuttallii	0.150	0.040	0.120	0.040	0.120	0.010
Arctostaphylos patula	0.000	0.000	0.090	0.060	0.020	0.000
Cornus sericea	0.109	0.083	0.000	0.084	0.020	0.020
Quercus kelloggii	0.280	0.011	0.070	0.060	0.120	0.000
Corylus cornuta var. *californica*	0.000	0.000	0.000	0.002	0.001	0.000
Prunus virginiana	0.000	0.000	0.090	0.070	0.020	0.000
Sambucus racemosa	0.000	0.000	0.000	0.004	0.002	0.000
Chrysolepis sempervirens	0.029	0.015	0.048	0.090	0.025	0.002

Table S8. The contribution of spatial, soil and topographic variables for each species within the Yosemite Forest Dynamic Plot with respect to recruitment in each quadrat (400 m²) from 2014 to 2019. Numbers 1 = the pure spatial component; 2 = the spatially structured environmental component; 3 = the pure Environmental component; 4 = the proportion explained by soil variables; 5 = the proportion explained by topographic variables; 6 = the topographically structured edaphic component.

Species	1	2	3	4	5	6
Abies concolor	0.240	0.040	0.000	0.040	0.000	0.040
Pinus lambertiana	0.210	0.050	0.000	0.050	0.000	0.000
Calocedrus decurrens	0.050	0.000	0.040	0.030	0.010	0.010
Cornus nuttallii	0.110	0.030	0.100	0.030	0.100	0.010
Arctostaphylos patula	0.000	0.000	0.090	0.070	0.020	0.000
Cornus sericea	0.040	0.020	0.031	0.022	0.010	0.020
Quercus kelloggii	0.260	0.070	0.060	0.050	0.040	0.000
Corylus cornuta var. *californica*	0.000	0.037	0.042	0.011	0.001	0.000
Prunus virginiana	0.000	0.000	0.090	0.070	0.020	0.000
Sambucus racemosa	0.000	0.001	0.000	0.002	0.002	0.002
Chrysolepis sempervirens	0.000	0.001	0.000	0.002	0.000	0.001