

## 1 Supporting Information

2 Biotic interactions and seed deposition rather than abiotic factors determine recruitment  
3 at elevational range limits of an alpine tree

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7 **Table S1.** Abiotic factors (a-c), biotic interactions (d-e), and seed deposition (f) recorded  
8 in the sampling of natural pine recruitment as functions of elevation; (a) mean soil  
9 surface temperature of the three warmest months, (b) mean soil surface temperature of  
10 the three coldest months, (c) proportion of soil moisture, (d) proportion of canopy cover,  
11 (e) proportion of understorey vegetation cover, (f) seed deposition by spotted nutcrackers.  
12 Generalized linear models were fitted with (a) a linear and (b) a linear and quadratic term  
13 of elevation assuming a Gaussian error distribution. A linear and a quadratic term were  
14 fitted assuming quasi-binomial (c-e) and quasi-Poisson (f) error distributions accounting  
15 for overdispersion. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Model	Source of variation	Estimate	SE	p value
<b>a) Mean summer temperature</b>	~ Elevation	0.00	0.00	<b>0.004 **</b>
	+ Region	-0.74	0.26	<b>0.006 **</b>
	+ Year 2013	0.05	0.31	0.883
	+ Year 2014	-0.71	0.31	<b>0.028 *</b>
<b>b) Mean winter temperature</b>	~ Elevation	0.02	0.01	0.113
	+ Elevation ^ 2	-0.00	0.00	0.102
	+ Region	0.30	0.08	<b>&lt; 0.001 ***</b>
	+ Year 2013	0.00	0.10	0.982

	+ Year 2014	0.05	0.10	0.622
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<b>c) Soil moisture</b>	~ Elevation	-0.05	0.02	<b>0.002 **</b>
	+ Elevation ^ 2	0.00	0.00	<b>0.002 **</b>
	+ Region	-0.00	0.11	0.987
	+ Year 2013	-0.50	0.15	<b>0.002 **</b>
	+ Year 2014	-0.72	0.13	<b>&lt; 0.001 ***</b>
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<b>d) Canopy cover</b>	~ Elevation	0.28	0.06	<b>&lt; 0.001 ***</b>
	+ Elevation ^ 2	-0.00	0.00	<b>&lt; 0.001 ***</b>
	+ Region	0.30	0.28	0.302
	+ Year 2013	0.43	0.33	0.199
	+ Year 2014	0.95	0.35	<b>0.009 **</b>
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<b>e) Understorey vegetation cover</b>	~ Elevation	0.11	0.04	<b>0.004 **</b>
	+ Elevation ^ 2	-0.00	0.00	<b>0.005 **</b>
	+ Region	0.41	0.24	0.094
	+ Year 2013	-0.19	0.29	0.505
	+ Year 2014	-0.47	0.30	0.120
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<b>f) Seed deposition</b>	~ Elevation	0.21	0.05	<b>&lt; 0.001 ***</b>
	+ Elevation ^ 2	-0.00	0.00	<b>&lt; 0.001 ***</b>
	+ Region	0.88	0.28	<b>0.003 **</b>
	+ Year 2013	-0.64	0.31	<b>0.043 *</b>
	+ Year 2014	-0.64	0.31	<b>0.043 *</b>

**Table S2.** Abiotic factors (a-b) and biotic interactions (c-e) recorded in seed transplant experiments as functions of elevation; (a) mean soil surface temperature of the three warmest months, (b) proportion of soil moisture, (c) proportion of canopy cover, (d) proportion of understorey vegetation cover, and (e) seed predation by rodents. Generalized linear models were fitted using (a) a linear term of elevation and assuming a Gaussian error distribution, (b-d) a linear and a quadratic term and (e) a linear term assuming a quasi-binomial error distribution accounting for overdispersion. \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Model	Source of variation	Estimate	SE	p value
<b>a) Mean summer temperature</b>	~ Elevation	0.00	0.00	< <b>0.001</b> ***
	+ Region	-0.71	0.15	< <b>0.001</b> ***
	+ Year 2014	-1.19	0.15	< <b>0.001</b> ***
<b>b) Soil moisture</b>	~ Elevation	-0.04	0.01	<b>0.009</b> **
	+ Elevation ^ 2	0.00	0.00	<b>0.008</b> **
	+ Region	0.64	0.10	< <b>0.001</b> ***
	+ Year 2014	0.58	0.10	< <b>0.001</b> ***
<b>c) Canopy cover</b>	~ Elevation	0.25	0.03	< <b>0.001</b> ***
	+ Elevation ^ 2	-0.00	0.00	< <b>0.001</b> ***
	+ Region	0.12	0.15	0.433
	+ Year 2014	-0.17	0.15	0.280
<b>d) Understorey vegetation cover</b>	~ Elevation	0.04	0.02	0.053
	+ Elevation ^ 2	-0.00	0.00	0.074
	+ Region	-0.13	0.14	0.349
	+ Year 2014	-0.22	0.14	0.134

<b>e) Seed predation</b>	~ Elevation	-0.00	0.00	< <b>0.001</b> ***
	+ Region	-0.52	0.19	<b>0.006</b> **
	+ Year 2014	-0.91	0.19	< <b>0.001</b> ***

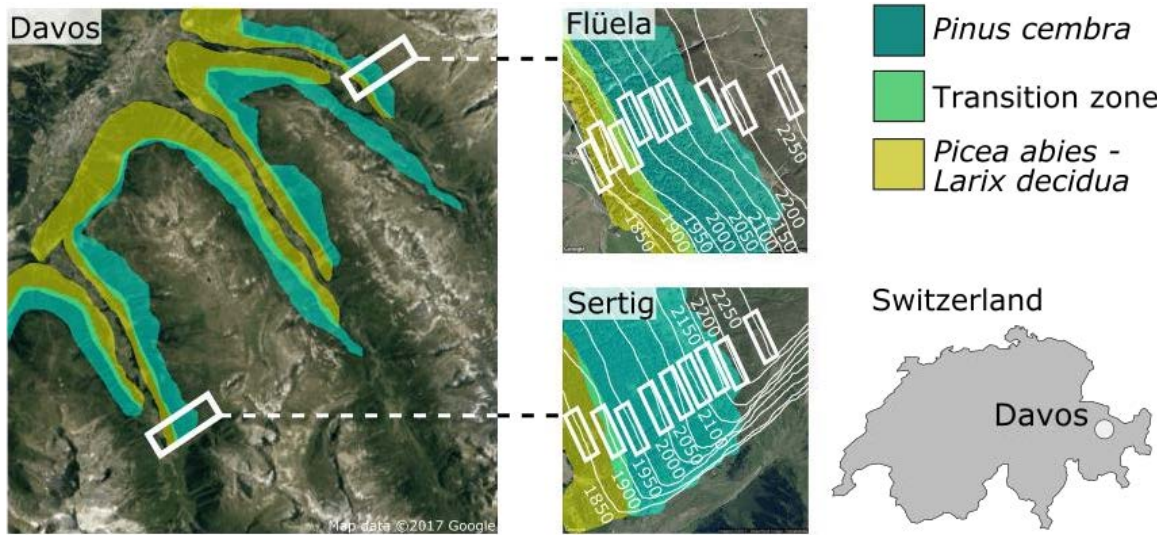
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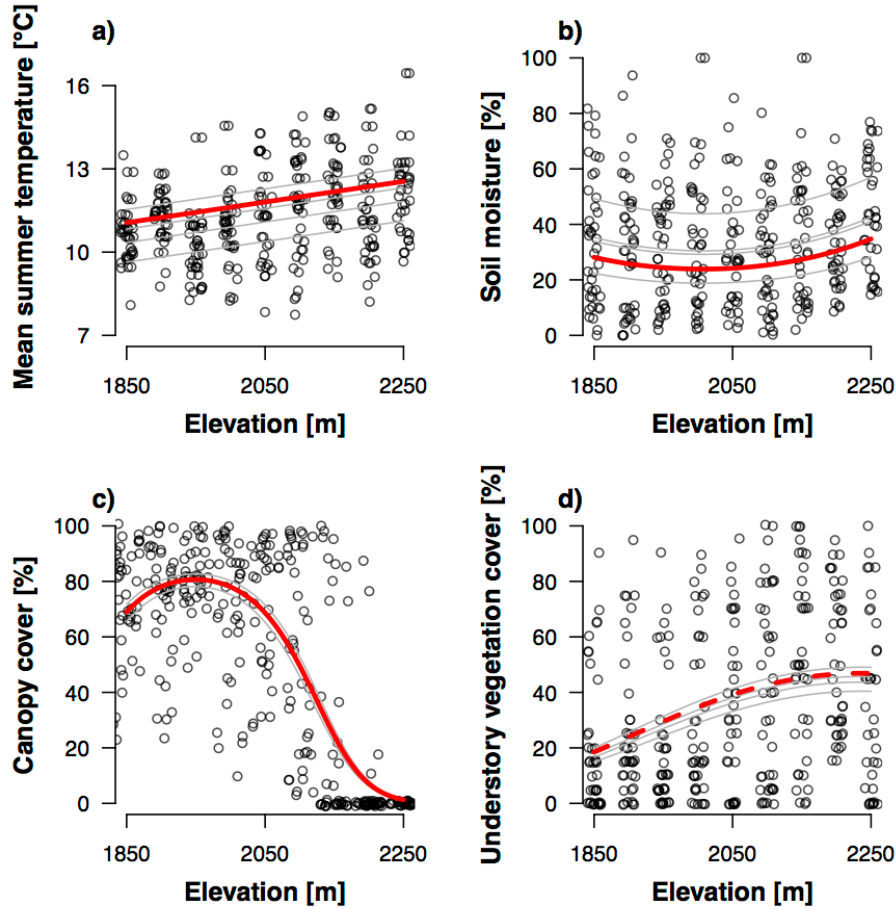
27 **Table S3.** Effects of abiotic factors (including growing degree-days [GDD]), biotic  
28 interactions (including canopy cover) and seed deposition on the number of juveniles (a)  
29 and the probability of experimental seedling establishment (b) across the distribution  
30 range and at the upper and lower range of Swiss stone pine. Generalized linear models  
31 were fitted assuming quasi-Poisson (a) and quasi-binomial (b) error distributions  
32 accounting for overdispersion. Estimates present model averages from qAICc-based  
33 model selection. \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Model	Source of variation	Estimate	SE	p value
<b>a) # juvenile plants</b>	~ Seed deposition	1.00	0.31	<b>0.001 **</b>
Across range	+ Canopy cover	-0.90	0.49	0.074
(1850 – 2250 m a.s.l.)	+ GDD	-0.07	0.24	0.778
	+ Soil moisture	-0.01	0.15	0.995
	+ Region	0.13	0.28	0.663
	+ Year 2013	-0.01	0.10	0.920
	+ Year 2014	-0.00	0.08	0.954
Upper range	~ Seed deposition	0.66	0.63	0.300
(> 2050 m a.s.l.)	+ Canopy cover	-1.15	0.54	0.791
	+ GDD	-0.17	0.22	0.941
	+ Soil moisture	0.03	0.23	0.901
	+ Region	0.02	0.22	0.926
	+ Year 2013	-0.07	0.33	0.841
	+ Year 2014	-0.02	0.16	0.906
Lower range	~ Seed deposition	0.06	0.30	0.842
(< 2050 m a.s.l.)	+ Canopy cover	-0.75	0.58	0.207

	+ GDD	-0.23	0.44	0.616
	+ Soil moisture	0.14	0.63	0.823
	+ Region	0.80	0.74	0.292
	+ Year 2013	0.05	0.28	0.869
	+ Year 2014	-0.21	0.73	0.772
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<b>b) Seedling establishment</b>	~ Seed predation	-2.15	0.31	< <b>0.001</b> ***
Across range	+ Canopy cover	-0.91	0.22	< <b>0.001</b> ***
(1850 – 2250 m a.s.l.)	+ GDD	-0.16	0.22	0.462
	+ Soil moisture	0.26	0.26	0.316
	+ Region	0.11	0.18	0.559
	+ Year	0.00	0.11	0.990
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Upper range	~ Seed predation	-1.40	0.38	< <b>0.001</b> ***
(> 2050 m a.s.l.)	+ Canopy cover	-0.43	0.41	0.298
	+ GDD	-0.16	0.25	0.527
	+ Soil moisture	0.49	0.36	0.181
	+ Region	0.11	0.24	0.642
	+ Year	0.03	0.16	0.851
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Lower range	~ Seed predation	-2.65	0.47	< <b>0.001</b> ***
(< 2050 m a.s.l.)	+ Canopy cover	-0.59	0.31	0.056
	+ GDD	-0.02	0.14	0.888
	+ Soil moisture	-0.01	0.22	0.966
	+ Region	-0.06	0.20	0.755
	+ Year	-0.03	0.16	0.865

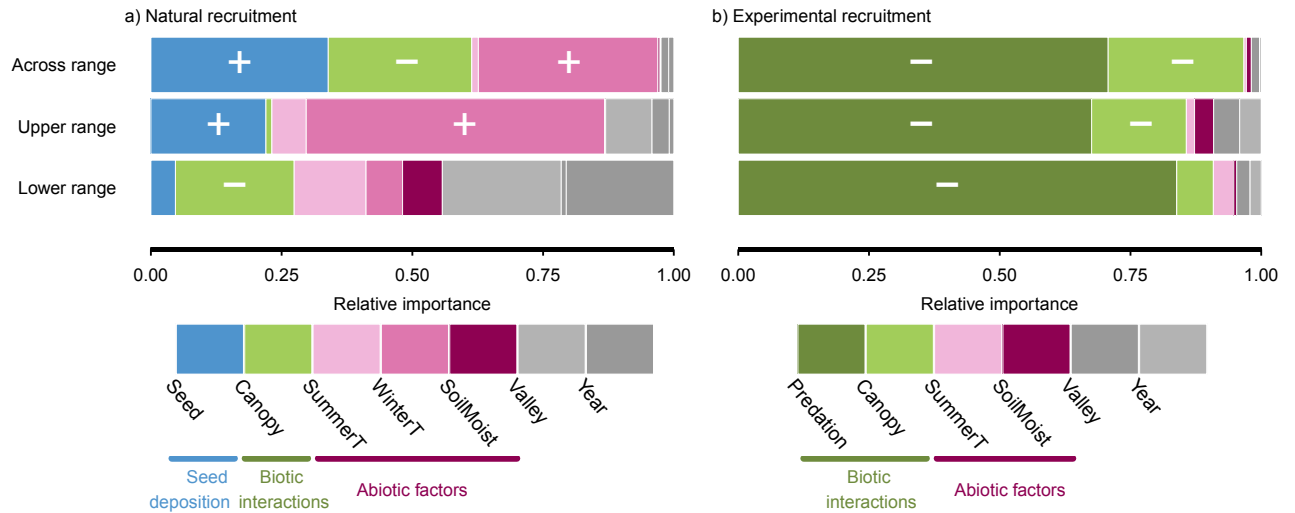


**Fig. S1.** Study area in the Swiss Alps, Canton of Grisons. Location of field sites in the Flüela and Sertig valley across the elevational distribution of Swiss stone pine (*Pinus cembra*). Background images: Google Earth.



**Fig. S2.** Abiotic factors (a-b) and biotic interactions (c-d) recorded in seed transplant experiments as functions of elevation; (a) mean soil surface temperature of the three warmest months, (b) proportion of soil moisture, (c) proportion of canopy cover, and (d) proportion of understorey vegetation cover. Generalized linear models were fitted with a linear and a quadratic term assuming a quasi-binomial (b-d) error distribution accounting for overdispersion. In (a) a linear term was fitted assuming a Gaussian error distribution. Circles indicate jittered raw data. Grey lines show model fit for the different valleys and years, the red solid line shows the overall model fit (solid:  $p < 0.05$ , dashed:  $p > 0.05$ ). Note that seed predation by rodents is presented in Fig. 3 in the main text. Model statistics are presented in Table S2.





**Fig. S3.** Relative importance of abiotic factors (violet), biotic interactions (green) and seed deposition (blue) on the natural recruitment of Swiss stone pine (a) and the probability of seedling establishment in transplant experiments (b) across the elevational range. Models were conducted across the entire range (1850 m – 2250 m a.s.l.) and at the lower (< 2050 m a.s.l.) and upper range (> 2050 m a.s.l.) of pine distribution. +/- indicate the direction of the most important effects. Seed = seed deposition by spotted nutcrackers, Canopy = Canopy cover, Predation = seed predation by rodents, SummerT = mean temperature of the warmest three months, WinterT = mean temperature of the coldest three months, SoilMoist = soil moisture, Year = study year, Valley = study valley.