

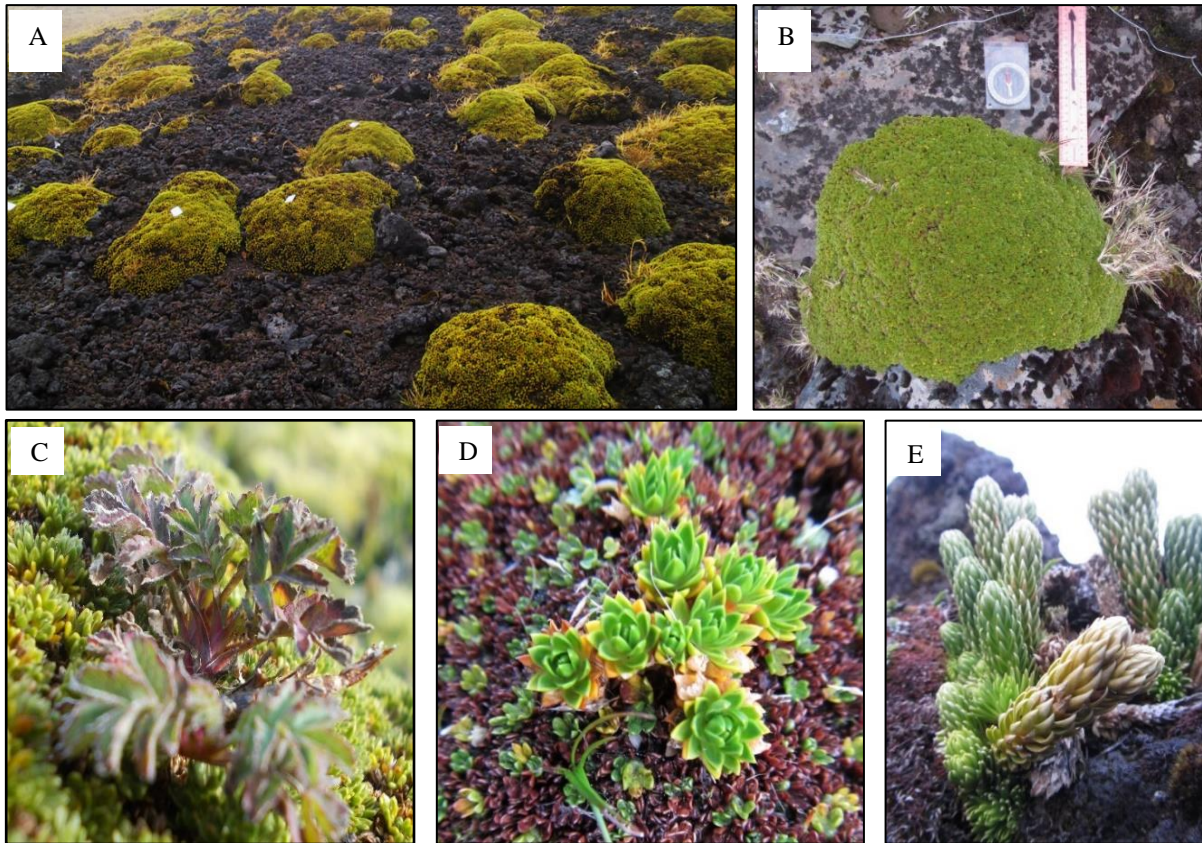
## **Ecosphere**

Positive plant-plant interactions expand the upper distributional limits  
of some vascular plant species

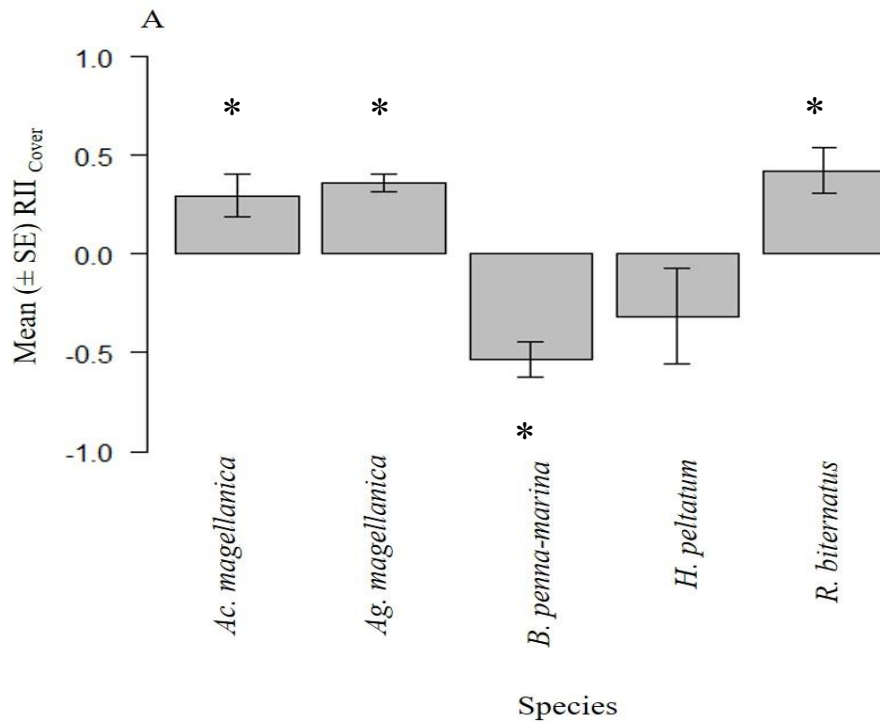
Morgan J. Raath-Krüger, Melodie A. McGeoch, Christian Schöb,

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## **Appendix S1**



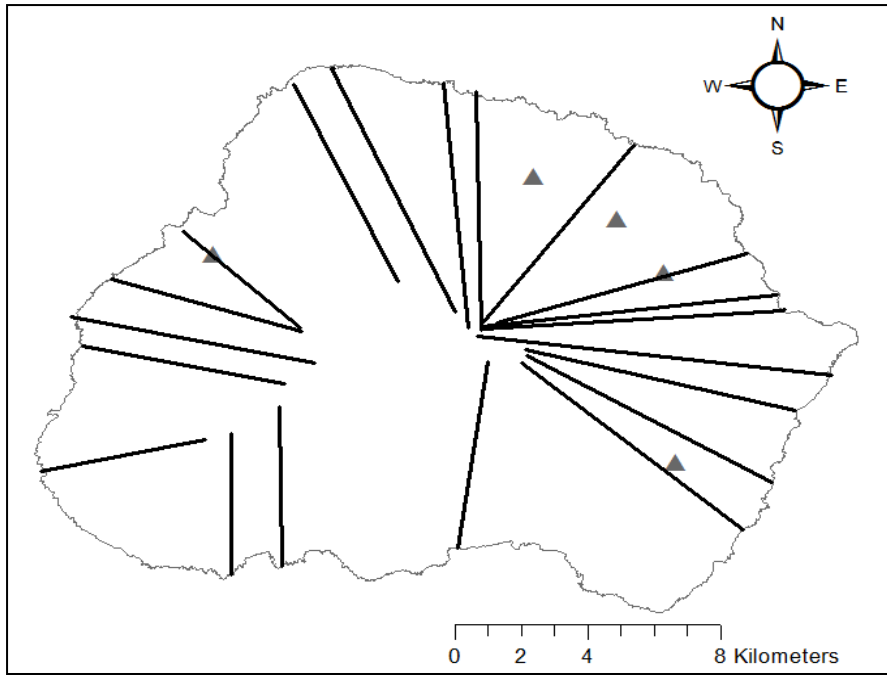
**Fig. S1.** A) *Azorella selago* Hook. (Apiaceae) cushion plants growing at mid-altitudes on Marion Island, B) An individual *A. selago* cushion plant with several *Agrostis magellanica* grasses growing on its edge (15 cm ruler included in the image for scale), C) *Acaena magellanica* (Rosaceae), growing on *A. selago*: Image taken by Christien Steyn, D) *Colobanthus kerguelensis* (Caryophyllaceae) growing on *A. selago* and E) *Lycopodium saururus* (Lycopodiaceae).



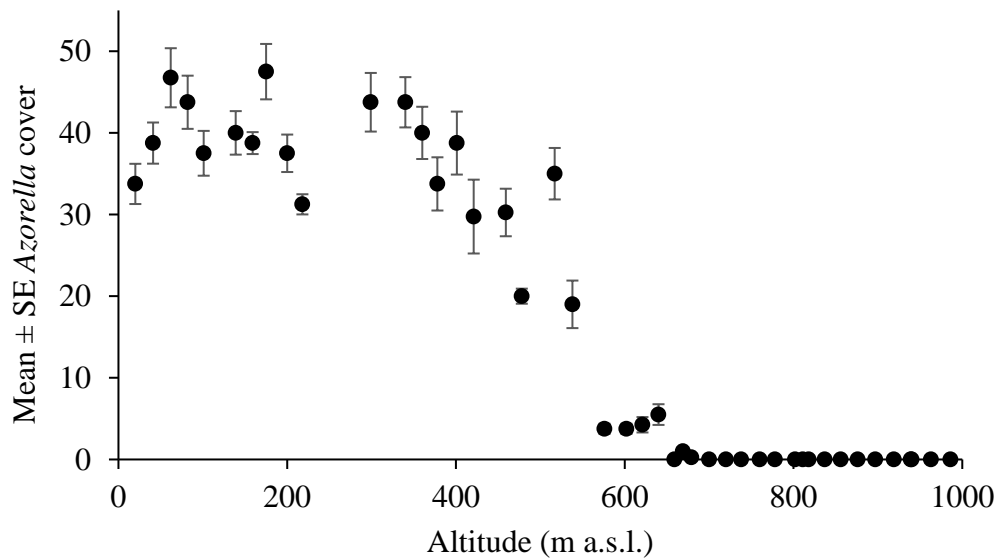
**Fig. S2.** The Relative Interaction Index (RII) for the interaction between *Azorella selago* and five commonly co-occurring plant species. A) Mean ( $\pm$  SE) RII values for *Acaena magellanica*, *Agrostis magellanica*, *Blechnum penna-marina*, *Hymenophyllum peltatum* and *Ranunculus biternatus*, based on the cover of these species when growing on *A. selago* relative to the adjacent substrate. A generalized linear model with a binomial distribution revealed that the RII scores for three species were significantly greater than zero (indicated using asterisks; *Ag. magellanica* [ $z = 4.128$ ,  $p$ -value =  $< 0.001$ ], *Ac. magellanica* [ $z = 2.184$ ,  $p$ -value =  $< 0.05$ ], *R. biternatus* [ $z = 2.924$ ,  $p = < 0.01$ ]), while the mean RII score for *B. penna-marina* was significantly smaller than zero ( $z = -2.714$ ,  $p = < 0.01$ ), and the mean RII score for *H. peltatum* was not significantly different from zero ( $z = -1.155$ ,  $p = 0.248$ ).



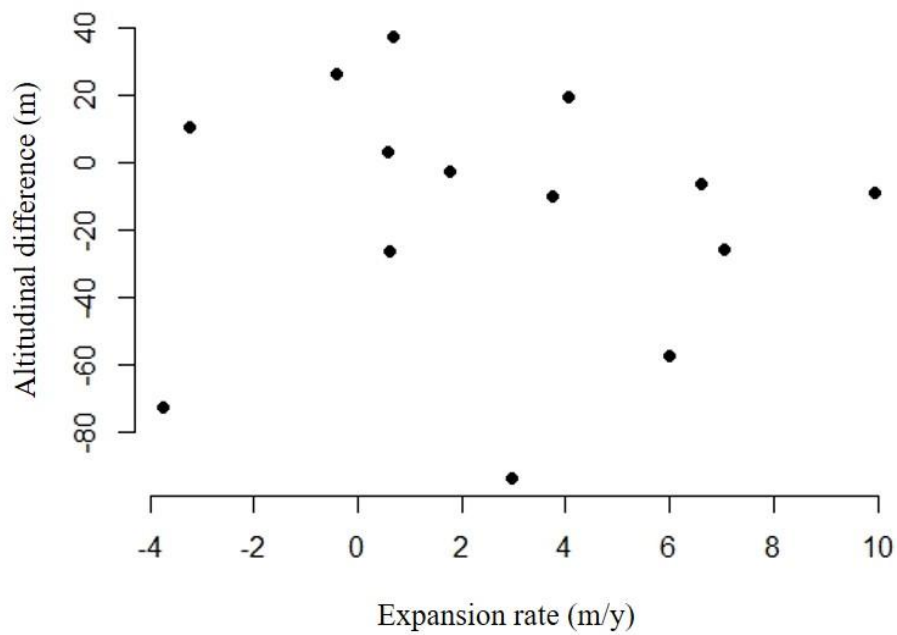
**Fig. S3.** Junior's Kop, one of the surveyed scoria cones on the eastern side of Marion Island.



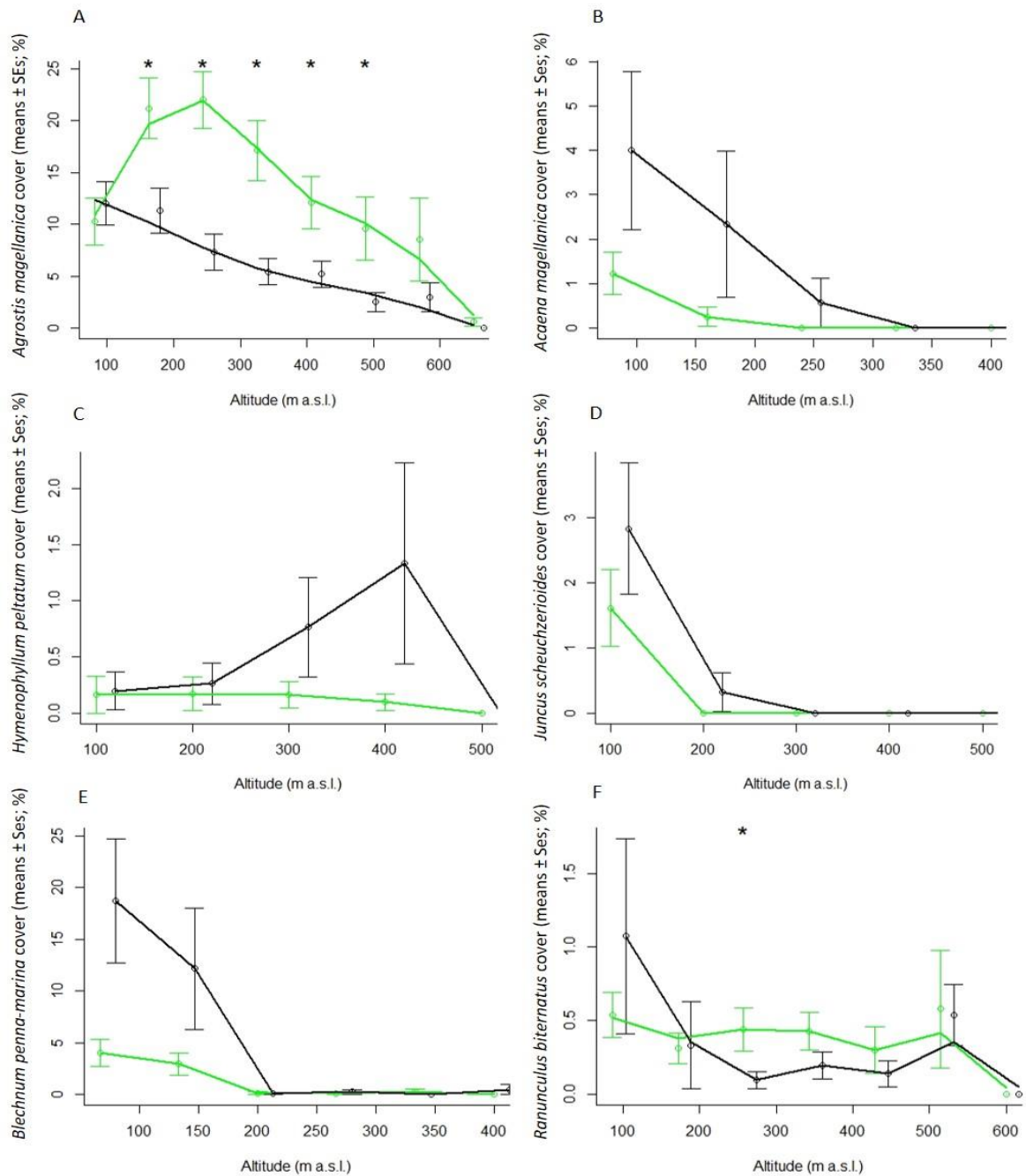
**Fig. S4.** The approximate location of the island-scale altitudinal transects (represented by thick lines) and landform-scale altitudinal transects (surveyed scoria cones represented by triangles) surveyed on sub-Antarctic Marion Island.



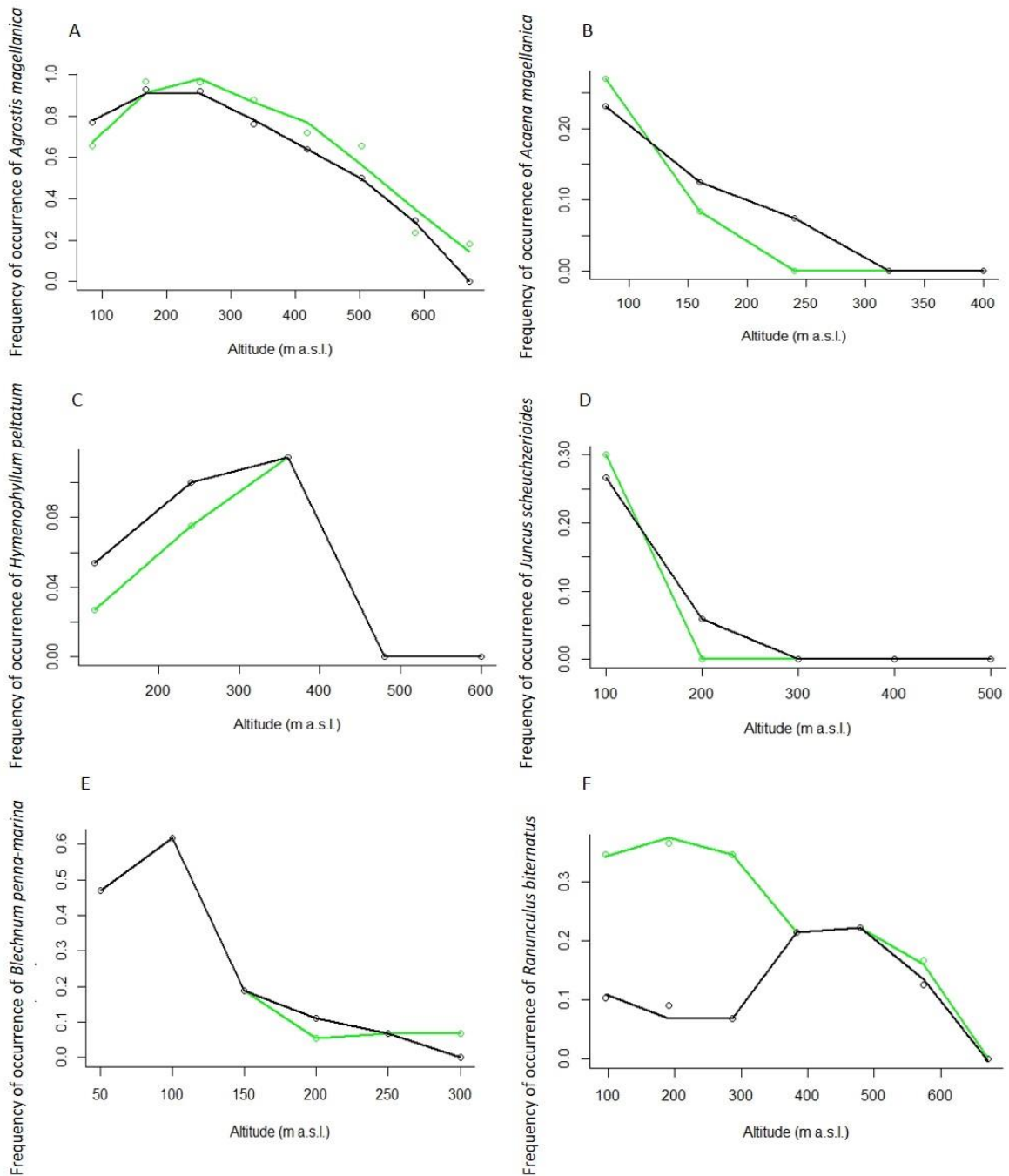
**Fig. S5.** Mean ( $\pm$  SE) *Azorella selago* cover (%) at 20 m elevation intervals across four elevational transects.



**Fig. S6.** Scatterplot showing the relationship between the difference in species' upper altitudinal limits on and away from *Azorella selago* (positive values indicate species have a higher upper altitudinal limit when growing on *A. selago* than when growing on the adjacent substrate) and species' upslope expansion rates between 1966 and the 2000's in response to climate warming (data from le Roux and McGeoch 2008b). The current upper altitudinal range limits of species in the presence of *Azorella* was not correlated with the rate at which the species upper range limits had shifted since the 1960's ( $r = 0.31$ ,  $p = 0.254$ ).



**Fig. S7.** Variation in mean ( $\pm$  SE) cover (%) of A) *Agrostis magellanica* ( $n =$  occurring in 253 of 366 plots), B) *Acaena magellanica* ( $n = 20/366$  plots), C) *Hymenophyllum peltatum* ( $n = 18/366$  plots), D) *Juncus scheuchzerioides* ( $n = 19/366$  plots), E) *Blechnum penna-marina* ( $n = 45/366$  plots) and F) *Ranunculus biternatus* ( $n = 71/366$  plots) across altitude, growing on (green line) vs away from (black line) *Azorella selago*. Asterisks indicate significant differences (as determined from two-sided Wilcoxon signed rank tests). For (A) and (F) loess lines are drawn to reflect the trends.



**Fig. S8.** Variation in frequency of occurrence of A) *Agrostis magellanica* (n = occurring in 253 of 366 plots), B) *Acaena magellanica* (n = 20/366 plots), C) *Hymenophyllum peltatum* (n = 18/366 plots), D) *Juncus scheuchzerioides* (n = 19/366 plots), E) *Blechnum penna-marina* (n = 45/366 plots) and F) *Ranunculus biternatus* (n = 71/366 plots) across altitude growing on (green line) vs away from (black line) *Azorella selago*. For (A) and (F) loess lines are drawn to reflect the trends.

**Table S1.** Mean ( $\pm$  SE) altitude (m a.s.l.) of the highest occurring individual of each vascular plant species per transect growing on vs away from *Azorella selago* for the island-scale transects. Difference = difference in the mean upper altitudinal limit of species in the presence and absence of *A. selago* (limit in the presence of *A. selago* – limit in the absence of *A. selago*). n = number of transects for which paired data (i.e. altitude of species on and away from *A. selago*) were available. V = one-sided Wilcoxon signed rank test statistic. Species are sorted based on their upper altitudinal limit on *A. selago*.

Species	<i>Azorella</i> present	<i>Azorella</i> absent	Present – Absent	Pairs		
	Mean $\pm$ SE (m a.s.l.)	Mean $\pm$ SE (m a.s.l.)		n	V	P
<i>Sagina procumbens</i>	163 $\pm$ 35	190 $\pm$ 38	-27.32	19	66	0.999
<i>Poa annua</i>	200 $\pm$ 33	291 $\pm$ 35	-90.75	16	77	0.999
<i>Juncus scheuchzerioides</i>	228 $\pm$ 25	238 $\pm$ 27	-9.33	18	14	0.970
<i>Crassula moschata</i>	24 $\pm$ 5	24 $\pm$ 5	0.60	10	0	0.500
<i>Cerastium fontanum</i>	262 $\pm$ 22	272 $\pm$ 22	-9.94	17	28	0.993
<i>Pringlea antiscorbutica</i>	328 $\pm$ 28	337 $\pm$ 25	-9.17	6	4	0.789
<i>Lycopodium saururus</i>	339 $\pm$ 21	324 $\pm$ 18	15.45	20	53.5	0.085
<i>Cotula plumosa</i>	34 $\pm$ 5	40 $\pm$ 4	-6.07	14	44	0.995
<i>Uncinia compacta</i>	343 $\pm$ 14	346 $\pm$ 14	-3.45	20	7	0.819
<i>Blechnum penna-marina</i>	383 $\pm$ 13	419 $\pm$ 15	-35.65	20	103	0.999
<i>Grammitis kerguelensis</i>	414 $\pm$ 25	486 $\pm$ 35	-72.14	7	21	0.989

<i>Hymenophyllum peltatum</i>	421 ± 53	478 ± 27	-57.17	6	9	0.950
<i>Acaena magellanica</i>	439 ± 19	412 ± 17	26.40	20	8	0.015
<i>Colobanthus kerguelensis</i>	483 ± 30	446± 26	37.25	16	12	<b>0.034</b>
<i>Lycopodium magellanicum</i>	531 ± 28	557± 11	-26.15	20	37	0.453
<i>Montia fontana</i>	538 ± 8	541 ± 8	-2.55	20	9	0.709
<i>Poa cookii</i>	550 ± 15	540 ± 13	10.50	20	10	0.147
<i>Ranunculus biternatus</i>	552 ± 12	549 ± 14	3.16	19	2	0.395
<i>Agrostis magellanica</i>	591 ± 11	619 ± 12	-27.25	20	114.5	0.992

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**Table S2.** Mean altitude of vascular plant species growing in the presence and absence of *Azorella selago* in 20 island-scale transects. Difference = difference in the mean upper altitudinal limit of species in the presence and absence of *A. selago* (limit in the presence of *A. selago* – limit in the absence of *A. selago*: Present - Absent). n = number of transects for which paired data (i.e. altitude of species in the presence and absence of *A. selago*) were available. V = one-sided Wilcoxon signed rank test statistic. Species are ordered by their upper altitudinal limit on *A. selago*. Significant and marginally significant p-values are bolded. The altitude of the highest individual across all transects on *Azorella* and away from *Azorella* (on *Azorella*/away from *Azorella*: Az/Away) is given in the last column for each species. The highest occurrence of *Azorella* across all the transects was at 765 m a.s.l.

Species	<i>Azorella</i> present	<i>Azorella</i> absent	Difference	Pairs			Upper limit (Az/Away m a.s.l.)
	Mean ± SE (m a.s.l.)	Mean ± SE (m a.s.l.)	Present – Absent	n	V	p	
<i>Crassula moschata</i> (Cra mos)	24 ± 5	24 ± 5	0.6	10	0	0.500	55/55
<i>Cotula plumosa</i> (Cot plu)	34 ± 5	40 ± 4	-6.1	14	36	0.995	57/60
<i>Sagina procumbens</i> (Sag pro)	145 ± 33	190 ± 38	-45.3	19	55	0.998	451/511
<i>Poa annua</i> (Poa ann)	218 ± 37	291 ± 35	-72.7	16	65	0.998	500/508
<i>Juncus scheuchzerioides</i> (Jun sch)	228 ± 25	238 ± 27	-9.3	18	14	0.971	392/421
<i>Cerastium fontanum</i> (Cer fon)	259 ± 21	269 ± 21	-9.9	18	36	0.995	411/411
<i>Pringlea antiscorbutica</i> (Pri ant)	328 ± 28	337 ± 25	-9.0	6	4	0.789	419/414
<i>Lycopodium saururus</i> (Lyc sau)	343 ± 21	323 ± 18	19.4	20	55.5	<b>0.058</b>	540/475
<i>Uncinia compacta</i> (Unc com)	346 ± 14	346 ± 14	-0.6	20	3	0.605	437/437

<i>Blechnum penna-marina</i> (Ble pen)	383 ± 13	418 ± 15	-35.5	20	90	0.999	526/526
<i>Grammitis kerguelensis</i> (Gra ker)	407 ± 26	500 ± 33	-93.4	8	28	0.993	514/647
<i>Hymenophyllum peltatum</i> (Hym pel)	421 ± 53	478 ± 27	-57.2	6	9	0.949	555/571
<i>Acaena magellanica</i> (Aca mag)	439 ± 19	412 ± 17	26.4	20	8	<b>0.015</b>	581/504
<i>Colobanthus kerguelensis</i> (Col ker)	483 ± 30	446 ± 26	37.3	16	12	<b>0.034</b>	595/575
<i>Lycopodium magellanicum</i> (Lyc mag)	531 ± 28	557 ± 11	-26.2	20	37	0.453	633/633
<i>Montia fontana</i> (Mon fon)	538 ± 8	541 ± 8	-2.5	20	5.5	0.644	607/607
<i>Poa cookii</i> (Poa coo)	550 ± 15	540 ± 1	10.5	20	10	0.147	659/642
<i>Ranunculus biternatus</i> (Ran bit)	552 ± 12	549 ± 14	3.2	19	2	0.395	653/653
<i>Agrostis magellanica</i> (Agr mag)	593 ± 11	619 ± 12	-25.8	20	98.5	0.987	689/743

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**Table S3.** Mean ( $\pm$  SE) altitude (m a.s.l.) of the highest occurrences, using the mean altitude of the five highest individuals, of vascular plant species growing on vs away from *Azorella selago* for the landform-scale transects. Difference = difference in the mean upper altitudinal limit of species in the presence and absence of *A. selago* (limit in the presence of *A. selago* – limit in the absence of *A. selago*). n = number of transects for which paired data (i.e. altitude of species on and away from *A. selago*) were available. V = one-sided Wilcoxon signed rank test statistic. Species are sorted based on their upper altitudinal limit on *A. selago*.

Species	<i>Azorella</i> present	<i>Azorella</i> absent	Difference	Pairs		
	Mean $\pm$ SE	Mean $\pm$ SE	Present - Absent	n	V	p
<i>Uncinia compacta</i>	208 $\pm$ 7	212 $\pm$ 8	-3.6	13	9	0.95
<i>Pringlea antiscorbutica</i>	219 $\pm$ 7	239 $\pm$ 9	-20.3	8	30	0.96
<i>Lycopodium saururus</i>	231 $\pm$ 7	224 $\pm$ 5	6.7	12	11	0.095
<i>Lycopodium magellanicum</i>	231 $\pm$ 8	230 $\pm$ 6	1.4	7	2	0.395
<i>Poa cookii</i>	232 $\pm$ 7	233 $\pm$ 8	-1.3	17	33	0.73
<i>Acaena magellanica</i>	238 $\pm$ 6	240 $\pm$ 6	-1.8	19	38	0.972
<i>Grammitis kerguelensis</i>	241 $\pm$ 15	256 $\pm$ 13	-15.3	8	15	0.985
<i>Blechnum penna-marina</i>	242 $\pm$ 5	255 $\pm$ 6	-13.2	20	101	0.991
<i>Ranunculus biternatus</i>	255 $\pm$ 6	252 $\pm$ 9	2.8	21	47	0.377
<i>Colobanthus kerguelensis</i>	261 $\pm$ 8	263 $\pm$ 10	-1.8	10	11	0.336
<i>Montia fontana</i>	261 $\pm$ 9	270 $\pm$ 9	-8.8	13	23.5	0.955

<i>Cerastium fontanum</i>	264 ± 10	277 ± 7	-13.2	5	10	0.979
<i>Agrostis magellanica</i>	273 ± 6	276 ± 5	-2.6	20	33.5	0.746

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**Table S4.** Comparison of functional trait values (mean  $\pm$  standard error) of all study species for which data were available from Marion Island (from Mathakutha et al. in press). Trait values were compared between the species that occurred at higher altitudes in the presence of *Azorella selago* (“Higher species”) vs. the species that did not occur higher in the presence of *A. selago* (“No effect species”). n = the number of samples for which functional trait data were available. Leaf toughness was measured as force to puncture through a leaf, and frost tolerance was measured through electrolyte leakage after freezing.

Trait	Higher species	No effect species	p
Height (mm)	68.5 $\pm$ 6.7 (n = 75)	119.8 $\pm$ 5.1 (n = 420)	0.898
Leaf area (mm <sup>2</sup> )	5302.6 $\pm$ 608.5 (n = 75)	519.4 $\pm$ 51.3 (n = 248)	<b>&lt; 0.01</b>
Specific leaf area (mm <sup>2</sup> mg <sup>-1</sup> )	13.9 $\pm$ 0.8 (n = 72)	19.0 $\pm$ 0.6 (n = 234)	0.955
Leaf chlorophyll content (mg)	363 $\pm$ 9.1 (n = 114)	323.3 $\pm$ 4.8 (n = 299)	0.989
Leaf toughness (N)	0.1 $\pm$ 0.02 (n = 69)	1.1 $\pm$ 0.06 (n = 344)	0.955
Frost tolerance ( $\mu$ S g <sup>-1</sup> )	7005.28 $\pm$ 1551.38 (n = 13)	4767.91 $\pm$ 490.85 (n = 71)	0.945

## Text S1

The altitude of the five highest occurring individuals of each vascular plant species growing on and away from *Azorella selago* were recorded using a handheld GPS unit. Additionally, for a subset of transects, altitude was also recorded using a barometric altimeter and was extracted from a digital elevation model (DEM). There were no significant differences between these three measurements of altitude, both broad scales and fine scale (DEM:  $t = 1.5$ ,  $df = 410.99$ ,  $p\text{-value} = 0.123$ ; barometric altimeter:  $t = 0.997$ ,  $df = 417.61$ ,  $p = 0.319$ ) and fine scales (DEM:  $t = 1.7$ ,  $df = 410.99$ ,  $p\text{-value} = 0.083$ ; barometric altimeter:  $t = 0.997$ ,  $df = 417.61$ ,  $p = 0.319$ ). The absolute mean difference between altitudes from the GPS and DEM and from the GPS and the barometric altimeter were 9.76 and 5.1 m, respectively.