Supplementary materials

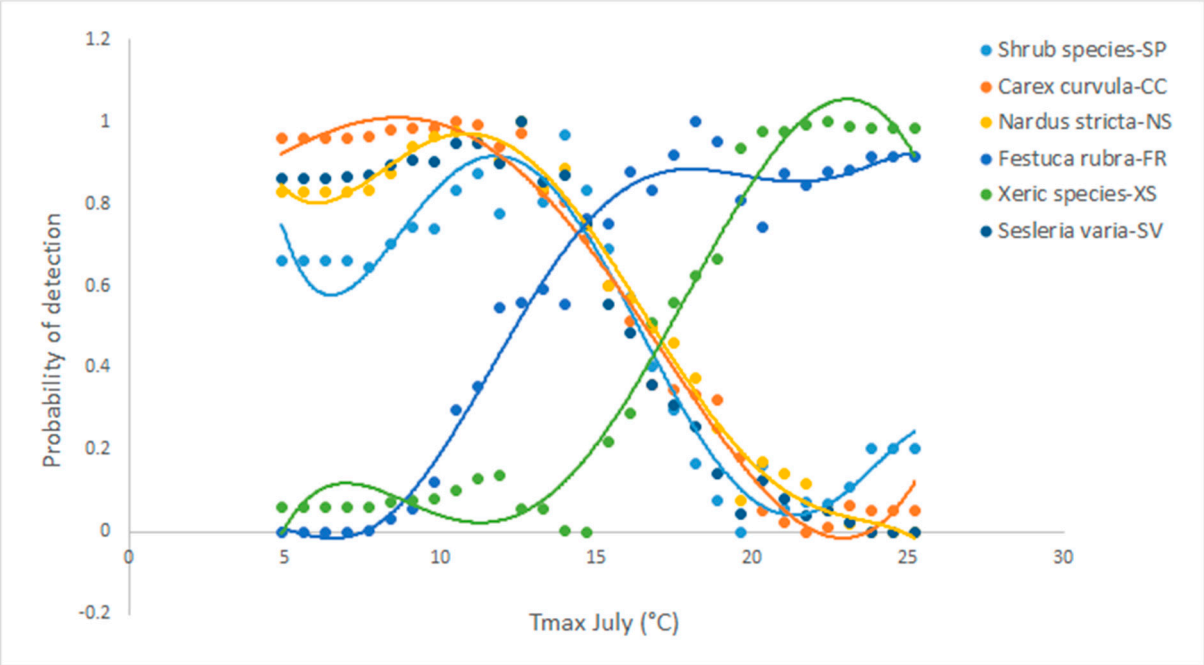

Figure S1. Partial dependence plot of the probability of presence of different macro types versus increasing values of Tmax in July. The original data were interpolated using a polynomial function.

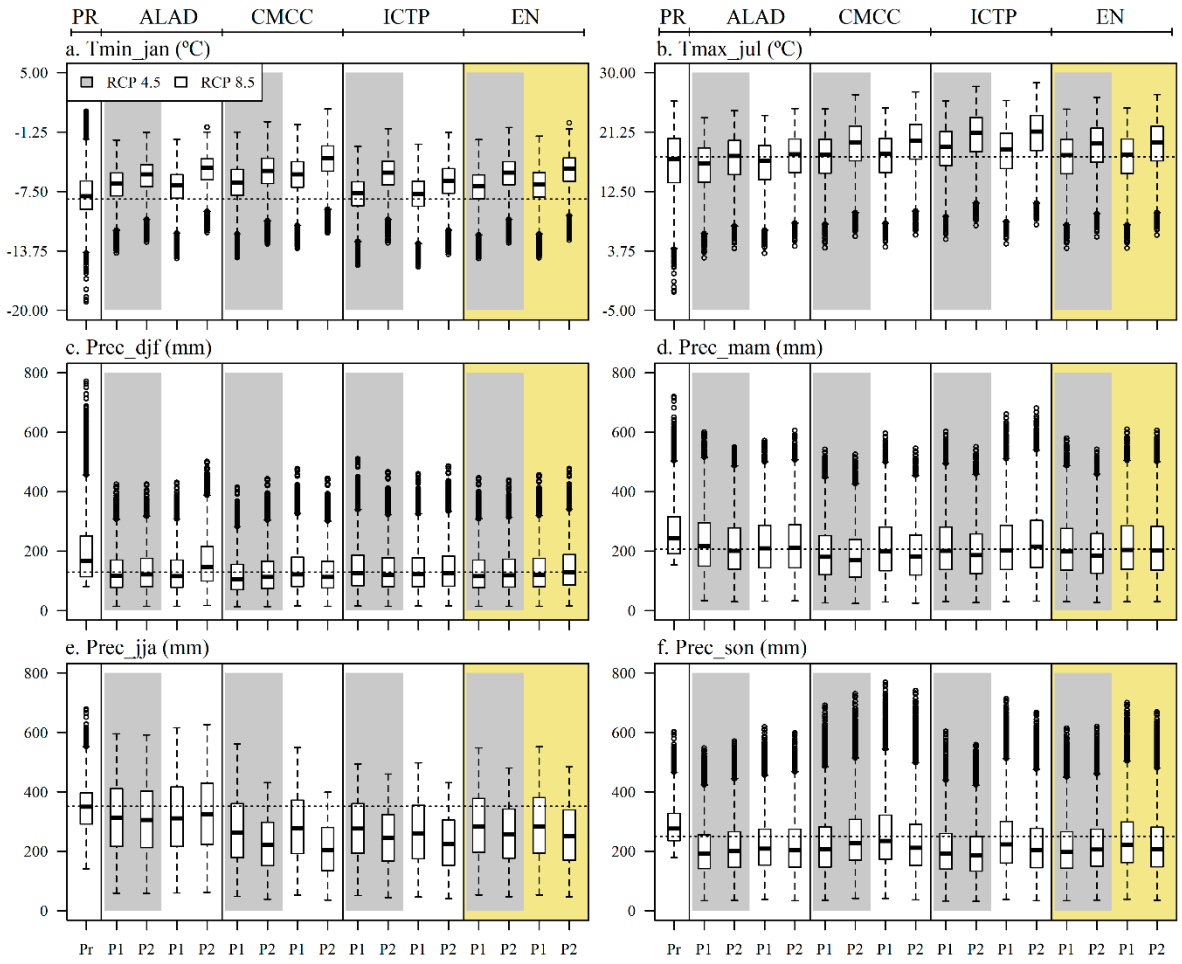

Figure S2. Eastern Alps, trends in independent climatic variables (Tmin_jan = Tmin in January (a), Tmax_jul = Tmax in July (b), and the four seasonal cumulated precipitations, namely Prec_djf (c), Prec_mam (d), Prec_jja (e), Prec_son (f)) calculated over multiple years using the modeling ensemble (EN), for two climate scenarios (RCP 4.5 and 8.5) and time-slices (P1 = 2011–2040 and P2 = 2041–2070) compared to the present (PR = 1970–2000). Black lines show the median while the dotted line represents the median of the present along the scenarios. Boxes delimit the 25th and 75th percentiles. Whiskers are 10th and 90th percentiles.

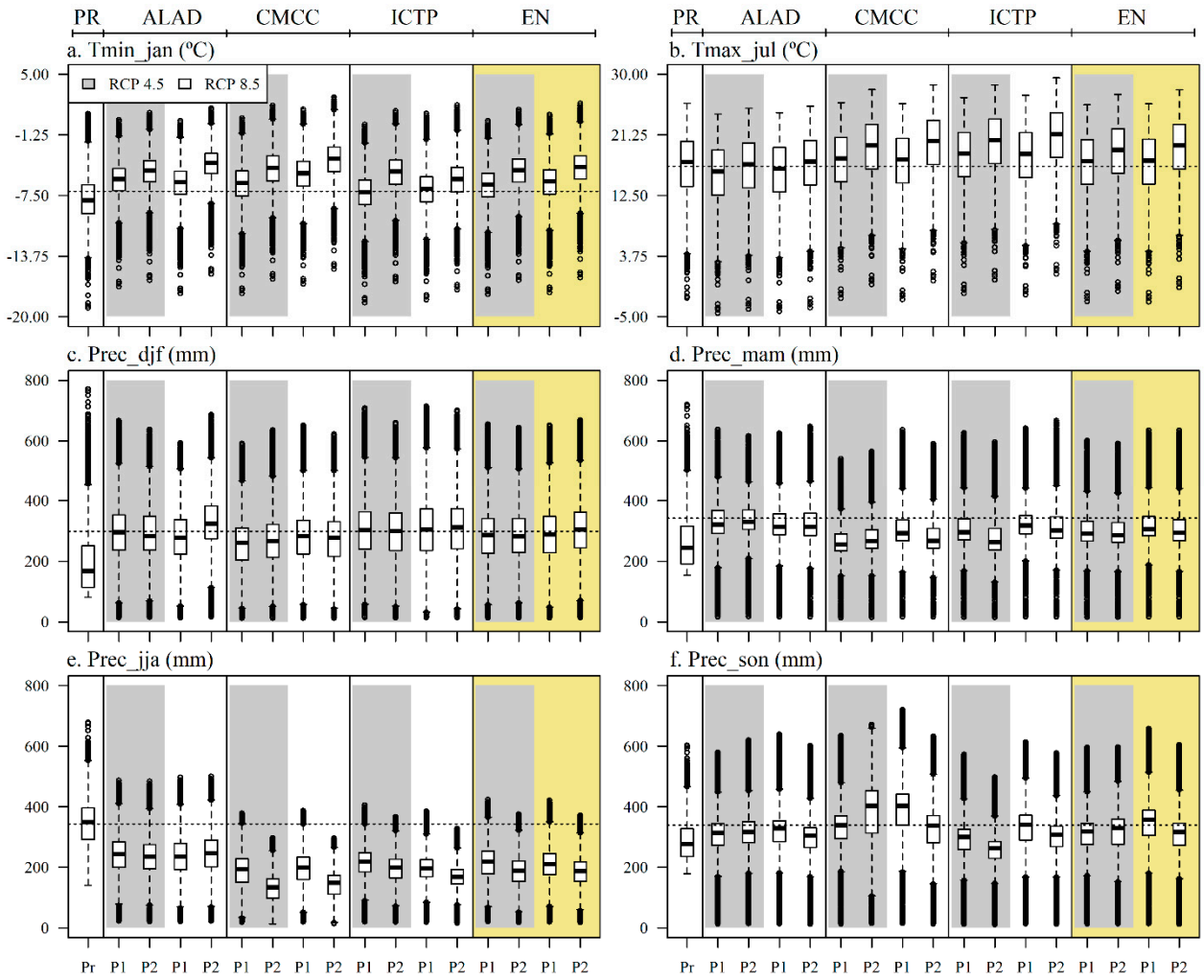

Figure S3. Western Alps, trends in independent climatic variables (Tmin_jan = Tmin of January (a), Tmax_jul = Tmax of July (b), and the four seasonal cumulated precipitation, namely Prec_djf (c), Prec_mam (d), Prec_jja (e), Prec_son (f)) calculated over multiple years using the modelling ensemble (EN), for two climate scenarios (RCP 4.5 and 8.5) and time-slices (P1 = 2011–2040 and P2 = 2041–2070, respectively) compared to the present (PR = 1970–2000). Black lines show the median while the dotted line represents the median of the present along the scenarios. Boxes delimit the 25th and 75th percentiles. Whiskers are 10th and 90th percentiles.

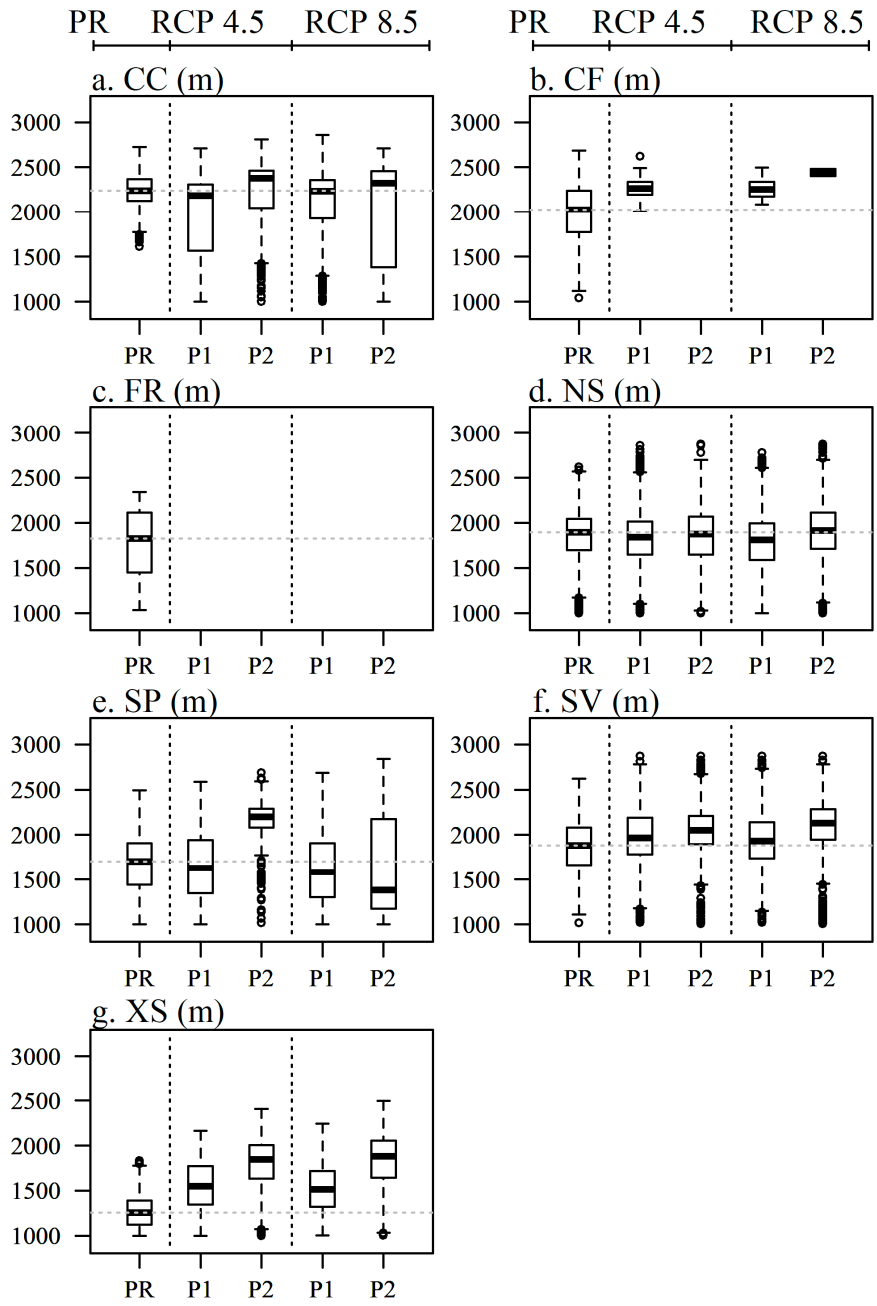

Figure S4. Changes in altitude in the Eastern Alps as reported by modelling ensemble for each of the seven single macro-types calculated over multiple years for two climate scenarios (RCP 4.5 and RCP 8.5) and time-slices (P1 = 2011–2040 and P2 = 2041–2070, respectively) compared to the present (PR = 1970–2000). Black lines show the median of the altitude calculated by the modelling ensemble, while the dotted line represents the median of the altitude for the present along the scenarios. Boxes delimit the 25th and 75th percentiles. Whiskers are 10th and 90th percentiles.

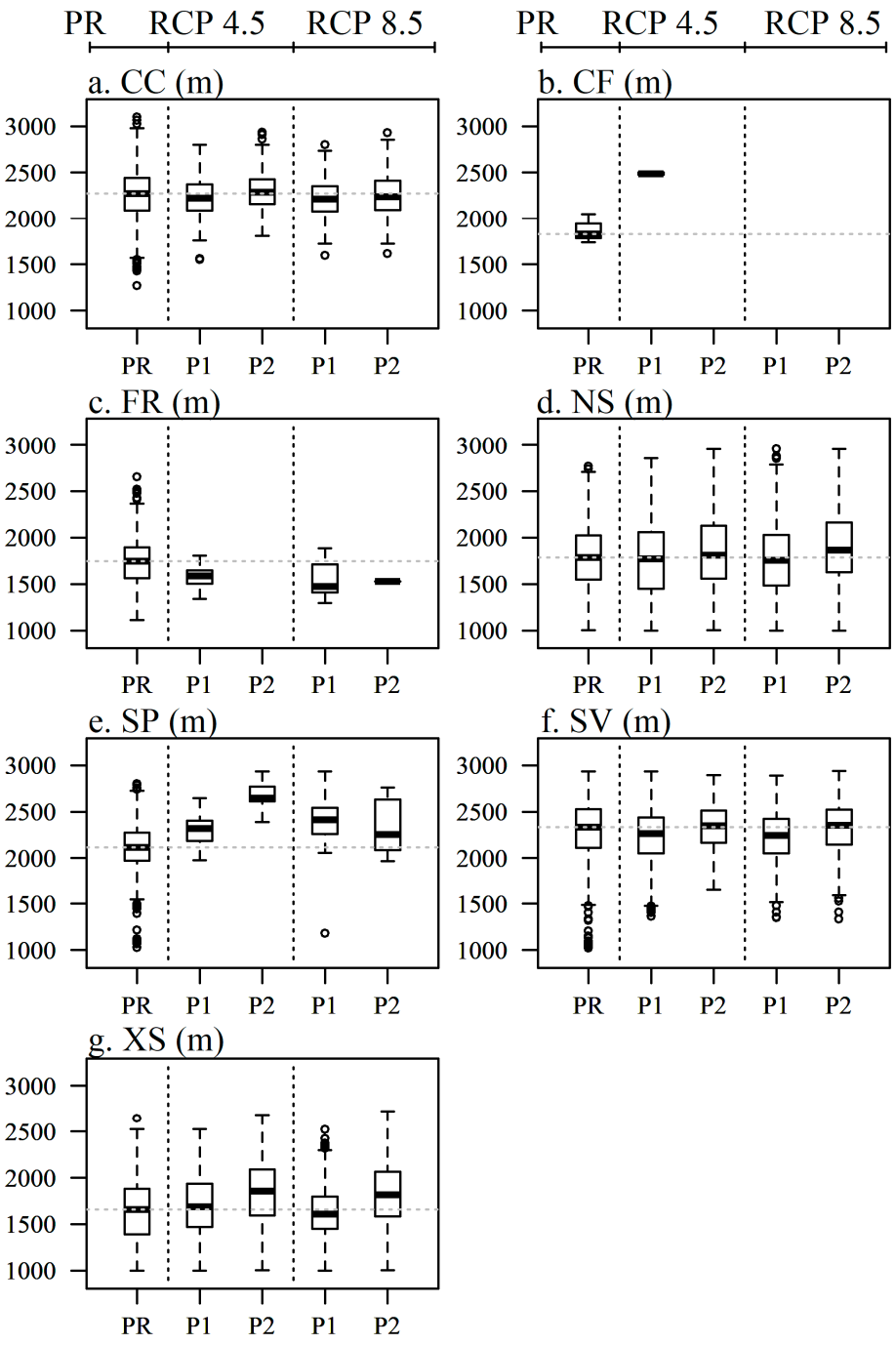

Figure S5. Changes in altitude in the Western Alps as reported by modelling ensemble for each of the seven single macro-types calculated over multiple years for two climate scenarios (RCP 4.5 and RCP 8.5) and time-slices (P1 = 2011–2040 and P2 = 2041–2070, respectively) compared to the present (PR = 1970–2000). Black lines show the median of the altitude calculated by the modelling ensemble, while the dotted line represents the median of the altitude for the present along the scenarios. Boxes delimit the 25th and 75th percentiles. Whiskers are 10th and 90th percentiles.

Table S1. Test for delta change significantly different from 0. The test was performed considering the delta changes samples for each RCMs, variable, and time slice extracted from each macro-type area as delimited in the present period. For each sample, the null hypothesis that these samples were different from zero was tested (*significant for $p < 0.05$,**significant for $p < 0.01$,***significant for $p < 0.001$).

			2011-2040							2041-2070						
			NS	SP	CC	SV	CF	FR	XS	NS	SP	CC	SV	CF	FR	XS
Aladin	RCP 4.5	Tmin_Jan	-85.7***	-83.07***	-69.62***	-103.69***	-36.08***	-30.59***	-38.79***	-145.97***	-123.84***	-106.92***	-158.45***	-65.09***	-51***	-69.3***
		Tmax_Jul	54.69***	38.07***	16.73***	43.38***	16.97***	25.61***	56.25***	-31.28***	-6.56***	-23.84***	-11.11***	-4.09***	5.31***	12.21***
		Prec_djf	2.45.	-7.17***	12.07***	7.05***	-18.72***	-17.89***	-9.87***	0.93	-8.85***	12.93***	8.3***	-26.28***	-20.65***	-4.91***
		Prec_mam	-15.95***	-27.24***	8.41***	0.9	-35.73***	-14.99***	-13.63***	-13.16***	-21.74***	11.11***	3.87***	-28.75***	-16.87***	-14.95***
		Prec_jja	25.81***	-2.16.	42.96***	31.31***	-25.59***	0.44	11.09***	31.65***	1.55	44.41***	33.86***	-23.7***	1.31	20.44***
		Prec_son	35.46***	2.59**	18.69***	16.07***	0.44	-8.26***	17.25***	22.62***	-6.69***	9.5***	4.93***	-8.36***	-16.8***	14.52***
	RCP 8.5	Tmin_Jan	-66.45***	-70.8***	-55.06***	-89.2***	-29.93***	-25.55***	-30.83***	-184.33***	-147.41***	-145.17***	-195.75***	-90.36***	-60.76***	-88.78***
		Tmax_Jul	23.08***	20.09***	-1.47	19.99***	9.95***	17.52***	42.28***	-54.7***	-18.12***	-39.42***	-29.16***	-9.81***	-1.28	3.05**
		Prec_djf	11.56***	-2.62**	23.88***	17.7***	-21.13***	-14.54***	-7.05***	-43.15***	-32.61***	-2.81**	-12.01***	-50.15***	-38.48***	-30.08***
		Prec_mam	-8.47***	-21.78***	11.55***	3.15**	-33.07***	-15.93***	-10.2***	-9.69***	-24.83***	9.75***	2.59**	-31.44***	-12.67***	-10.15***
		Prec_jja	24.84***	-2.9**	41.22***	29.56***	-28.33***	0.24	13.23***	16.82***	-6.81***	36.27***	24.19***	-34.4***	-2.02	9.13***
		Prec_son	18.27***	-10.88***	7.58***	2.46	-11.4***	-17.72***	6.33***	28.15***	-4.59***	16.88***	12.27***	-14.68***	-10.9***	15.13***
CCLM	RCP 4.5	Tmin_Jan	-79.19***	-73.14***	-47.02***	-87.87***	-33.85***	-22.96***	-42.43***	-177.65***	-133.06***	-98.8***	-176.48***	-60.24***	-55.53***	-89.66***
		Tmax_Jul	-63.13***	-18.11***	-53.79***	-44.36***	-7.61***	-7.12***	-1.14	-196.86***	-79.78***	-122.5***	-134.31***	-44.95***	-40.85***	-74.28***
		Prec_djf	32.85***	5.87***	30.56***	26.25***	-8.93***	-5.67***	4.27***	18.85***	-3.44***	20.62***	15.81***	-18.71***	-13.11***	-1.2
		Prec_mam	37.64***	-1.11	40.18***	34.3***	-16.84***	1.36	13.2***	43.99***	0.42	35.17***	31.95***	-9.57***	-0.18	16.78***
		Prec_jja	64.62***	17.47***	73.06***	59.19***	-5.16***	9.99***	43.89***	121.42***	52.07***	113.24***	96.83***	40.87***	27***	104.37***
		Prec_son	4.87***	-18.42***	5.45***	-2.36	-18.19***	-20.99***	1.47	-25.64***	-28.98***	-6.06***	-20.13***	-27.24***	-29.51***	-20.94***
	RCP 8.5	Tmin_Jan	-144.16***	-111.9***	-81.08***	-146.19***	-51.46***	-43.59***	-72.61***	-238.39***	-167.53***	-134.31***	-234.47***	-85.96***	-71.69***	-107.57***
		Tmax_Jul	-66.13***	-19.96***	-48.31***	-41.38***	-9.89***	-6.54***	-2.01	-201.37***	-81.81***	-150.08***	-155.01***	-47.91***	-43.16***	-78.18***
		Prec_djf	4.47***	-9.78***	15.63***	9.41***	-26.22***	-18.22***	-12.1***	16.79***	-1.97	22.28***	16.84***	-16.13***	-12.15***	-8.24***
		Prec_mam	7.54***	-17.56***	15.76***	9.7***	-27.6***	-8.97***	-3.27**	35.31***	-4.83***	30.08***	26.77***	-16.23***	-0.81	12.79***
		Prec_jja	54.34***	16.13***	72.13***	55.31***	-10.36***	9.75***	34.79***	145.38***	62.59***	116.95***	105.62***	56.29***	34.31***	132.15***
		Prec_son	-35.66***	-36.89***	-13.4***	-28.48***	-31.64***	-35.68***	-22.52***	0.8	-20.16***	5.75***	-4.29***	-21.44***	-20.65***	-4.95***
ICTP	RCP 4.5	Tmin_Jan	-5.86***	-33.33***	-15.42***	-30.45***	-9.76***	-4.33***	-7.61***	-144.62***	-119.22***	-91.09***	-159.79***	-59.88***	-49.97***	-67.69***
		Tmax_Jul	-146.06***	-58.68***	-85.54***	-94.02***	-31.8***	-27.3***	-46.47***	-299.44***	-136.34***	-155.91***	-191.86***	-75.06***	-66.11***	-139.25***
		Prec_djf	-13.36***	-18.41***	4.03***	-3.92***	-32.15***	-26.33***	-20.57***	-5.97***	-12.04***	10.46***	3.37***	-27.97***	-21.35***	-16.4***
		Prec_mam	3.52***	-17.22***	15.57***	7.19***	-29.32***	-12.81***	-8.29***	29.89***	-6.2***	27.4***	21.46***	-20.72***	-4.31***	11.28***
		Prec_jja	60.37***	23.29***	67.6***	53.94***	-3.29**	11.46***	47.24***	101.93***	48.83***	84.18***	73.84***	28.44***	23.36***	108.4***
		Prec_son	41.12***	-0.23	23.85***	20.93***	-6.07***	-5.5***	17.9***	67.25***	12.65***	44.37***	42.5***	-0.02	6.91***	38.17***
	RCP 8.5	Tmin_Jan	-16.23***	-38.07***	-21.84***	-39.47***	-8.24***	-7.08***	-20.52***	-100.07***	-85.77***	-60.14***	-108.26***	-38.24***	-30.41***	-58.25***
		Tmax_Jul	-127.13***	-46.66***	-69.68***	-74.89***	-23.95***	-21.27***	-46.02***	-298.2***	-128.35***	-179.77***	-210.09***	-78.29***	-73.38***	-136.93***
		Prec_djf	-8.6***	-15.36***	3.02**	-5.53***	-29.62***	-22.75***	-13.73***	-15.23***	-17.66***	3.47***	-5.56***	-34.15***	-25.59***	-19.37***
		Prec_mam	-8.19***	-22.1***	12.16***	3.81***	-29.67***	-12.6***	-17.17***	-10.15***	-25.21***	8.89***	-0.22	-36.35***	-12.5***	-12.91***
		Prec_jja	66.01***	25.83***	71.76***	59.23***	0.15	12.06***	65.54***	105.79***	48.39***	94.36***	82.91***	34.64***	24.64***	112.67***
		Prec_son	-3.19**	-22.15***	6.53***	-2.39	-24.73***	-20.57***	-3.14**	23.05***	-10.4***	19.16***	14.49***	-15.76***	-10.69***	10.82***

Table S2. Current Eastern alpine occurrence (in terms of number of pixels, i.e., 100 ha wide each) of unclassified pasturelands and expected changes (%) of suitability under future climate conditions, as reported by the three regional circulation models (RCMs) and their ensemble, time slices (2011–2040 and 2041–2070) and RCP scenarios (4.5 and 8.5).

		Number of pixels				%			
RCM	Present	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
-	-	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070
Aladin	11908	11711	8803	11158	8720	-2%	-26%	-6%	-27%
CMCC	11908	8297	7108	9780	7004	-30%	-40%	-18%	-41%
ICTP	11908	7144	3597	9115	5703	-40%	-70%	-23%	-52%
Ensemble	11908	9051	6503	10018	7142	-24%	-45%	-16%	-40%

Table S3. Current Western alpine occurrence (in terms of number of pixels, i.e., 100 ha wide each) of unclassified pasturelands and expected changes (%) of suitability under future climate conditions, as reported by the three regional circulation models (RCMs) and their ensemble, time slices (2011–2070 and 2071–2100) and RCP scenarios (4.5 and 8.5).

		Number of pixels				%			
RCM	Present	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
-	-	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070
Aladin	9472	8221	8228	8146	8290	-13%	-13%	-14%	-12%
CMCC	9472	5128	4400	5572	4595	-46%	-54%	-41%	-51%
ICTP	9472	8682	5991	7733	7103	-8%	-37%	-18%	-25%
Ensemble	9472	7344	6206	7150	6663	-22%	-34%	-25%	-30%

Table S4. Changes of pasture macro-type suitability of the Eastern Alps under future climate scenarios (RC 4.5 and 8.5) and time slices (2011–2040, 2041–2070) with respect to current climate conditions, as reported by the RCMs modelling ensemble. RCP ensemble reports averages of percentage of both RCP 4.5 and 8.5 scenarios. Absolute values (number of pixels, i.e., 100 ha wide each) on the left hand of the table; percentage of variation with respect to the present on the center right hand of the table (light grey background), averages of percentage of variation for both RCP 4.5 and 8.5 scenarios (dark grey) on the right hand of the table (RCP ensemble).

	Scenario	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP Ensemble	
Macro-type	Present	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070
-	-	N° of pixel				(%)				(%)	
Shrub species (SP)	1659	1102	479	1440	729	-34	-71	-13	-56	-24	-64
Carex curvula (CC)	1371	569	297	695	196	-58	-78	-49	-86	-54	-82
Carex firma (CF)	614	117	6	149	2	-81	-99	-76	-100	-79	-100
Nardus stricta (NS)	5128	5603	4281	6045	4808	+9	-17	+18	-6	+14	-12
Festuca rubra (FR)	88	0	0	0	1	-100	-100	-100	-99	-100	-100
Xeric species (XS)	1305	426	734	664	752	-67	-44	-49	-42	-58	-43
Sesleria varia (SV)	1433	1043	566	815	493	-27	-61	-43	-66	-35	-64

Table S5. Changes of pasture macro-type suitability of the Western Alps under future climate scenarios (RC 4.5 and 8.5) and time slices (2011–2040, 2041–2070) with respect to current climate conditions, as reported by the RCMs modelling ensemble. RCP ensemble reports averages of percentage of both RCP 4.5 and 8.5 scenarios. Absolute values (number of pixels, i.e., 100 ha wide each) on the left hand of the table; percentage of variation with respect to the present on the center right hand of the table (light grey background), averages of percentage of variation for both RCP 4.5 and 8.5 scenarios (dark grey) on the right hand of the table (RCP ensemble).

	Scenario	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP Ensemble	
Macro-type	Present	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070	2011-2040	2041-2070
-	-	N° of pixel				(%)				(%)	
Shrub species (SP)	673	66	19	50	60	-90	-97	-93	-91	-92	-94
Carex curvula (CC)	1655	419	451	493	594	-75	-73	-70	-64	-73	-69
Carex firma (CF)	3	3	1	1	0	0	67	-67	-100	-34	-84
Nardus stricta (NS)	4175	3580	3074	4013	3034	-14	-26	-4	-27	-9	-27
Festuca rubra (FR)	168	104	5	36	17	-38	-97	-79	-90	-59	-94
Xeric species (XS)	914	1791	1765	1459	1615	+96	+93	+60	+77	+78	+85
Sesleria varia (SV)	1688	1241	763	962	1215	-26	-55	-43	-28	-35	-42