Ecography

ECOG-01557
Descombes,P., Pradervand, J.-N., Golay, J., Guisan, A. and Pellissier, L. 2015. Simulated shifts in trophic niche breadth modulate range loss of alpine butterflies under climate change. – Ecography doi: 10.1111/ecog.01557

Supplementary material

Appendix 1

Tables

Table A1. Performance of the butterfly abiotic models under two evaluators (TSS and AUC) as the average of ten replicates.

Species	TSS						AUC					
	GLM		GBM		GAM		GLM		GBM		GAM	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Anthocharis cardamines	0.573	0.103	0.558	0.084	0.680	0.119	0.791	0.073	0.805	0.076	0.862	0.046
Aphantopus hyperantus	0.824	0.068	0.810	0.112	0.846	0.068	0.925	0.046	0.915	0.049	0.961	0.017
Argynnis adippe	0.566	0.216	0.434	0.173	0.817	0.076	0.748	0.136	0.670	0.120	0.890	0.064
Argynnis aglaja	0.537	0.117	0.524	0.075	0.582	0.089	0.790	0.070	0.742	0.054	0.821	0.056
Argynnis niobe	0.431	0.132	0.399	0.127	0.742	0.066	0.651	0.091	0.670	0.070	0.874	0.041
Aricia artaxerxes	0.332	0.131	0.339	0.089	0.585	0.100	0.609	0.079	0.601	0.093	0.797	0.050
Aricia eumedon	0.366	0.081	0.351	0.080	0.552	0.058	0.647	0.072	0.651	0.060	0.792	0.043
Boloria euphrosyne	0.466	0.103	0.437	0.091	0.670	0.059	0.736	0.070	0.714	0.069	0.871	0.036
Boloria napaea	0.675	0.121	0.722	0.132	0.815	0.087	0.827	0.076	0.857	0.068	0.923	0.043
Boloria pales	0.778	0.068	0.742	0.103	0.822	0.060	0.917	0.037	0.895	0.053	0.942	0.023
Boloria titania	0.589	0.115	0.533	0.098	0.631	0.121	0.822	0.060	0.800	0.057	0.856	0.057
Brenthis ino	0.723	0.106	0.682	0.174	0.886	0.033	0.827	0.077	0.806	0.112	0.929	0.020
Callophrys rubi	0.433	0.073	0.585	0.143	0.786	0.073	0.620	0.048	0.776	0.052	0.891	0.051
Coenonympha gardetta	0.513	0.103	0.614	0.087	0.686	0.090	0.780	0.060	0.815	0.050	0.868	0.052
Coenonympha pamphilus	0.771	0.084	0.769	0.076	0.815	0.083	0.897	0.058	0.886	0.054	0.941	0.038
Colias alfacariensis	0.560	0.192	0.620	0.242	0.940	0.049	0.753	0.130	0.805	0.107	0.965	0.025
Colias hyale	0.503	0.090	0.482	0.085	0.653	0.100	0.742	0.051	0.714	0.069	0.847	0.052
Colias phicomone	0.567	0.095	0.573	0.071	0.649	0.079	0.788	0.063	0.787	0.034	0.855	0.029
Cupido minimus	0.442	0.159	0.450	0.176	0.535	0.139	0.704	0.111	0.714	0.101	0.786	0.091
Erebia aethiops	0.410	0.053	0.411	0.092	0.480	0.085	0.676	0.034	0.694	0.058	0.771	0.060
Erebia cassioides	0.742	0.195	0.750	0.204	0.997	0.009	0.823	0.130	0.824	0.141	0.997	0.009
Erebia epiphron	0.735	0.073	0.684	0.087	0.906	0.063	0.842	0.052	0.838	0.046	0.959	0.032
Erebia euryale	0.528	0.141	0.449	0.168	0.613	0.102	0.735	0.071	0.688	0.072	0.812	0.054
Erebia gorge	0.872	0.092	0.884	0.096	0.962	0.034	0.957	0.028	0.932	0.076	0.984	0.014
Erebia ligea	0.613	0.117	0.615	0.078	0.724	0.092	0.810	0.082	0.805	0.050	0.866	0.045
Erebia manto	0.558	0.150	0.493	0.120	0.578	0.156	0.818	0.088	0.766	0.081	0.831	0.093
Erebia melampus	0.281	0.079	0.533	0.090	0.664	0.089	0.605	0.075	0.781	0.042	0.855	0.047

Erebia oeme	0.402	0.085	0.458	0.125	0.518	0.072	0.703	0.065	0.742	0.070	0.795	0.047
Erebia pandrose	0.686	0.115	0.586	0.146	0.746	0.097	0.854	0.060	0.799	0.064	0.887	0.049
Erebia pharte	0.590	0.137	0.583	0.105	0.659	0.116	0.795	0.085	0.803	0.078	0.878	0.051
Erebia pluto	0.884	0.154	0.899	0.108	0.980	0.024	0.941	0.082	0.955	0.062	0.994	0.007
Erebia pronoe	0.404	0.120	0.529	0.122	0.831	0.079	0.612	0.103	0.735	0.054	0.920	0.028
Erebia tyndarus	0.626	0.127	0.676	0.122	0.886	0.063	0.802	0.057	0.828	0.079	0.951	0.038
Euphydryas aurinia	0.569	0.125	0.565	0.086	0.744	0.092	0.792	0.060	0.775	0.051	0.883	0.034
Hamearis lucina	0.747	0.199	0.597	0.335	0.978	0.018	0.822	0.116	0.733	0.241	0.983	0.017
Lasiommata maera	0.365	0.113	0.373	0.096	0.535	0.079	0.649	0.064	0.647	0.058	0.807	0.045
Lasiommata petropolitana	0.340	0.153	0.275	0.178	0.712	0.100	0.589	0.133	0.580	0.129	0.863	0.051
Leptidea realsin	0.659	0.089	0.647	0.073	0.742	0.087	0.846	0.043	0.832	0.035	0.884	0.037
Lycaena hippothoe	0.558	0.106	0.487	0.138	0.700	0.087	0.766	0.105	0.748	0.084	0.850	0.067
Lycaena tityrus	0.471	0.143	0.396	0.139	0.894	0.056	0.719	0.081	0.679	0.084	0.935	0.039
Maculinea arion	0.422	0.124	0.352	0.085	0.703	0.110	0.681	0.085	0.616	0.066	0.874	0.062
Maniola jurtina	0.785	0.088	0.755	0.090	0.823	0.078	0.934	0.034	0.909	0.032	0.950	0.026
Melanargia galathea	0.744	0.185	0.704	0.173	0.906	0.042	0.864	0.116	0.854	0.112	0.972	0.018
Melitaea athalia	0.724	0.083	0.671	0.104	0.795	0.075	0.878	0.035	0.851	0.042	0.921	0.030
Melitaea diamina	0.559	0.088	0.623	0.088	0.670	0.069	0.778	0.102	0.827	0.070	0.885	0.035
Pieris brassicae	0.424	0.138	0.358	0.143	0.606	0.151	0.688	0.078	0.622	0.097	0.822	0.082
Pieris bryoniae	0.412	0.121	0.478	0.094	0.544	0.085	0.671	0.080	0.737	0.058	0.798	0.043
Pieris napi	0.508	0.133	0.535	0.166	0.572	0.125	0.793	0.079	0.769	0.085	0.820	0.081
Pieris rapae	0.314	0.097	0.286	0.147	0.524	0.138	0.629	0.063	0.592	0.098	0.766	0.069
Plebejus argus	0.279	0.142	0.359	0.091	0.829	0.110	0.521	0.108	0.636	0.082	0.909	0.056
Plebejus glandon	0.617	0.195	0.559	0.212	0.954	0.031	0.746	0.130	0.763	0.101	0.969	0.025
Plebejus orbitulus	0.755	0.176	0.683	0.225	0.992	0.014	0.847	0.110	0.808	0.093	0.994	0.010
Polyommatus bellargus	0.544	0.216	0.503	0.255	0.935	0.039	0.725	0.157	0.695	0.202	0.962	0.029
Polyommatus coridon	0.424	0.124	0.283	0.082	0.570	0.127	0.673	0.079	0.573	0.089	0.801	0.066
Polyommatus damon	0.256	0.129	0.324	0.196	0.544	0.075	0.514	0.126	0.553	0.169	0.759	0.073
Polyommatus eros	0.420	0.109	0.358	0.157	0.792	0.113	0.631	0.080	0.620	0.095	0.908	0.040
Polyommatus icarus	0.557	0.059	0.513	0.130	0.729	0.105	0.784	0.033	0.761	0.069	0.895	0.052
Polyommatus semiargus	0.527	0.090	0.519	0.090	0.704	0.099	0.794	0.055	0.789	0.045	0.902	0.050
Polyommatus thersites	0.617	0.162	0.600	0.175	1.000	0.000	0.771	0.089	0.739	0.133	1.000	0.000
Pontia callidice	0.789	0.203	0.728	0.299	0.953	0.032	0.862	0.111	0.826	0.188	0.962	0.033

Table A2. Changes in percentage of butterflies' species with high extinction risk when considering different thresholds (i.e. <1%, <5% and <10%) that define the minimal area species can occupy in the study area before being considered under risk of extinction. The values are shown for the 2010 and the future climate change scenarios (RCP3PD, A1B and A2) and different model types.

Model type	Climate change scenario	Extinction risk thresholds (percent of open habitats)		
		<1%	<5%	<10%
Abiotic models	2010	0	2	12
	RCP3PD 2085	0	10	18
	A1B 2085	13	32	43
	A2 2085	22	38	52
Host plant constrained models	2010	2	20	30
	RCP3PD 2085	3	20	38
	A1B 2085	30	52	63
	A2 2085	40	60	67
Host plant constrained models with diet expansion (int. prob > 0.9)	2010	0	12	24
	RCP3PD 2085	2	19	32
	A1B 2085	24	46	58
	A2 2085	34	51	64
Host plant constrained models with diet expansion (int. prob > 0.5)	2010	0	5	17
	RCP3PD 2085	2	15	27
	A1B 2085	24	41	54
	A2 2085	32	49	63

Figures

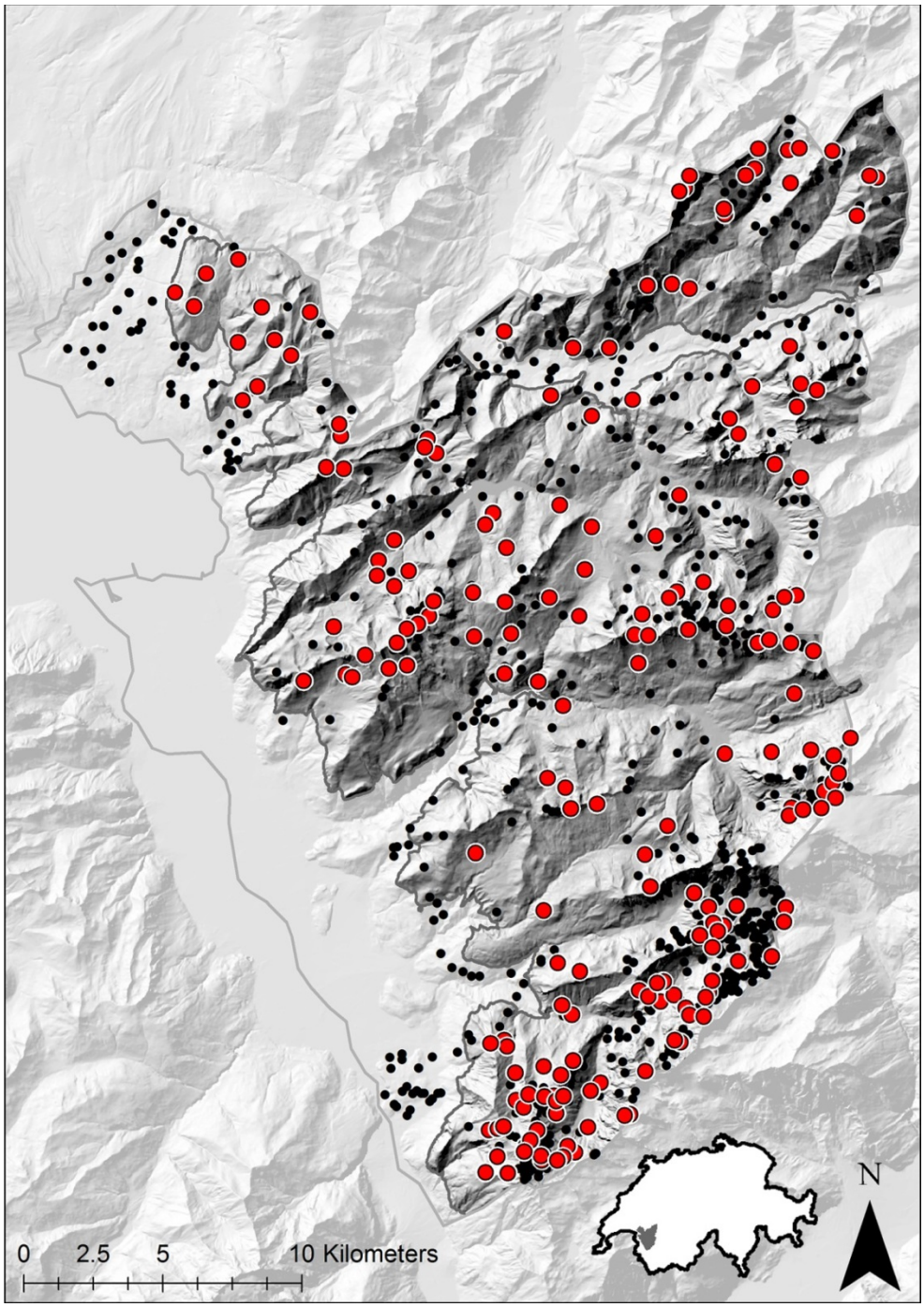

Figure A1. Location of the study area in the western Alps of Switzerland. The dots (black and red) represent vegetation sampling sites. The red dots correspond to the vegetation sites where butterflies were sampled. The light gray line shows the limits of study area. The dark gray line shows the 1000 m isoline (models lower limit).

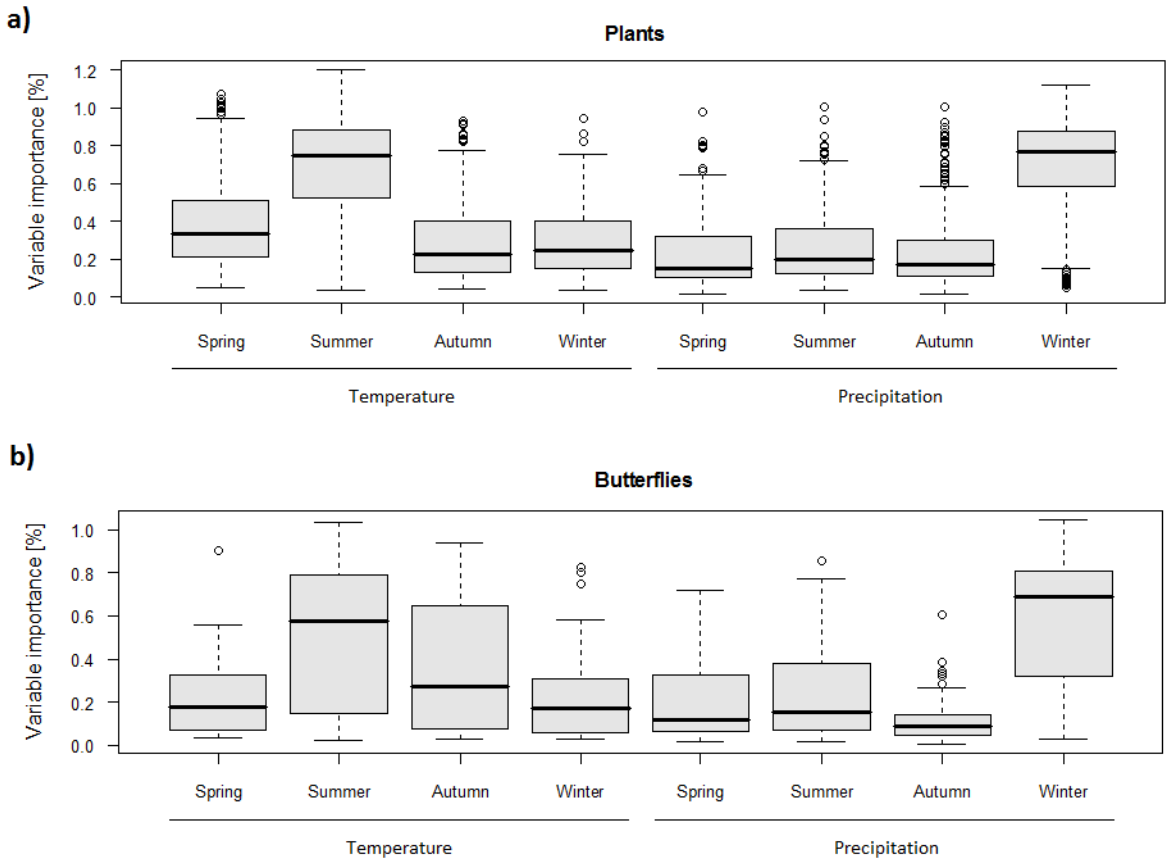

Figure A2. Importance of seasonal climatic variables (temperature and precipitation) in the niche models for plants (a) and butterflies (b). The average winter precipitations (January to March) and summer temperatures (July to September) were the most influencing variables and are therefore good predictors for the species niche modelling. The variable importance was calculated using biomod2 and represents 1 minus the correlation of one model using the variable and one model using the variable randomized. The intermediate line is the median, and the limits of the boxes are the 1st and 3rd quartiles. The lines and the points show the minimum and maximum and the outliers.

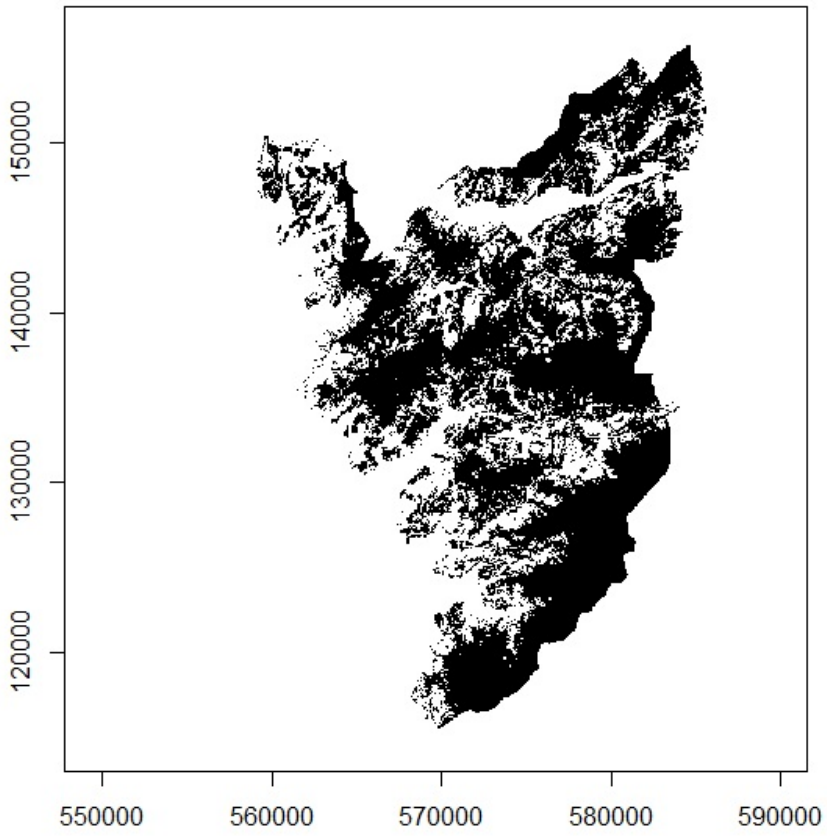

Figure A3. Final area for model projections at a resolution of 50 m (139613 pixels) representing a total surface of 349 km^2.

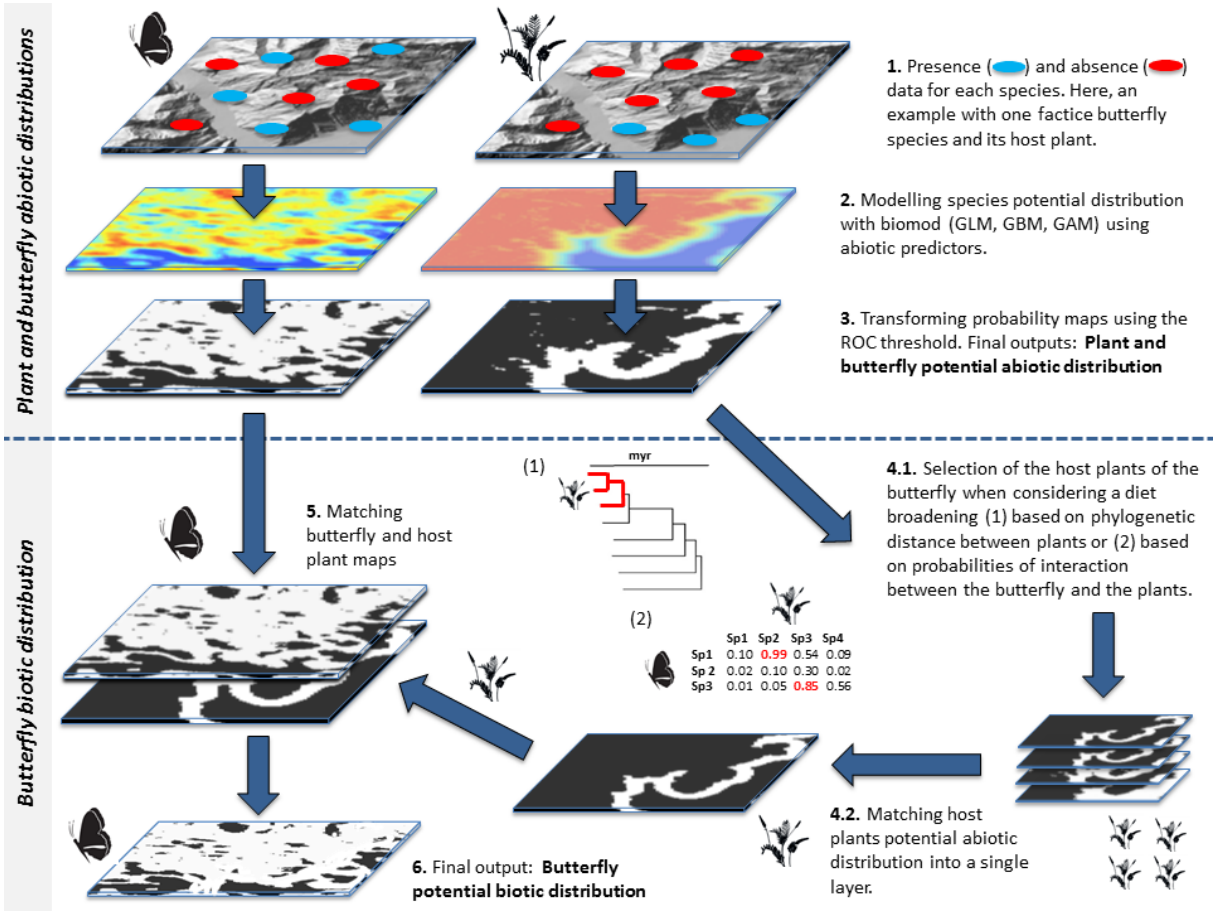

Figure A4. Schematic view of the modeling process from the modelling of individual butterfly and plant species distributions to their combinations considering or not diet expansion.

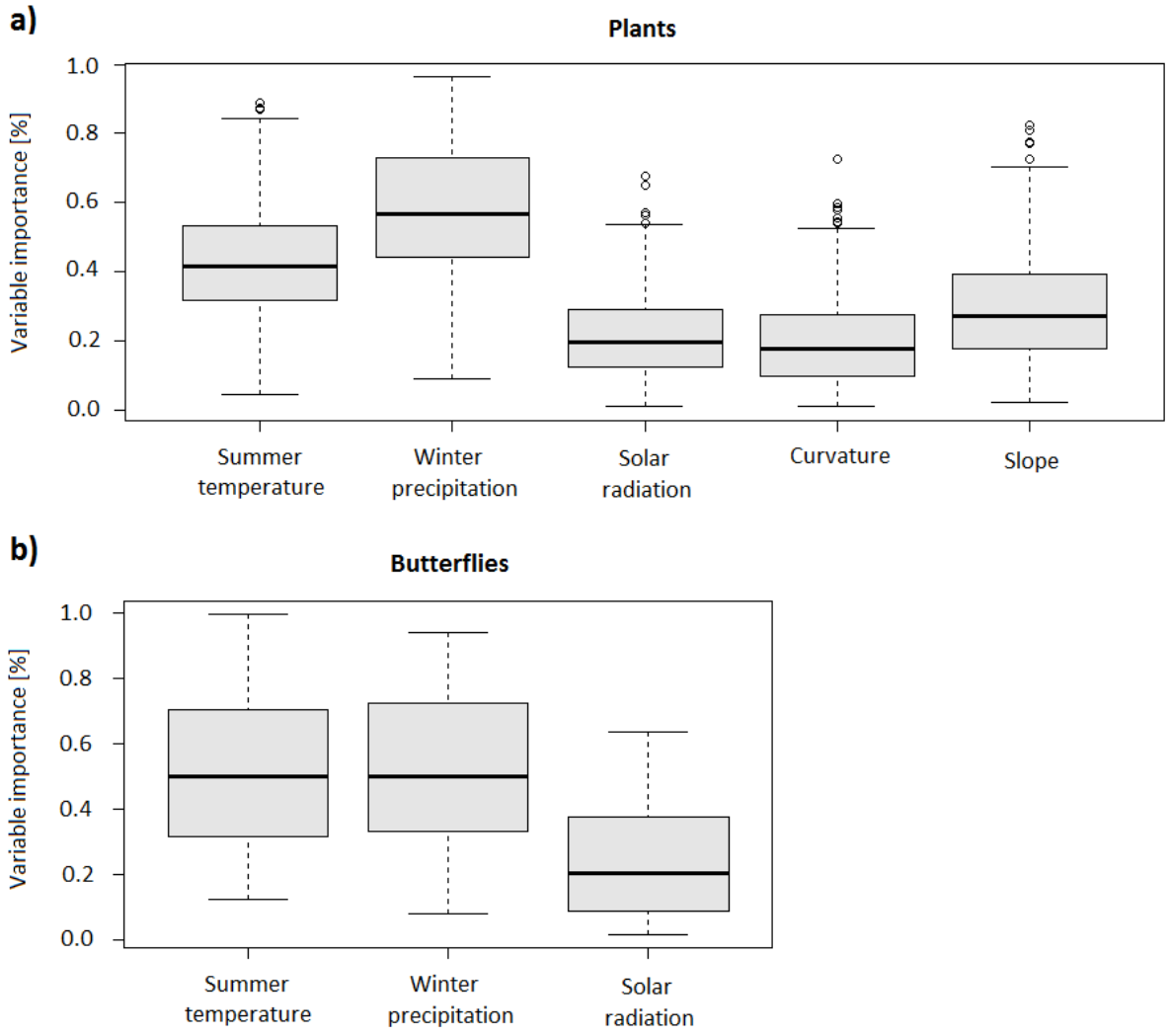

Figure A5. Importance of topo-climatic predictors in the niche models for plants (a) and butterflies (b) used in the final models. The average winter precipitations (January to March) and summer temperatures (July to September) were the most important predictors for both plants and butterflies. The variable importance was calculated using biomod2 and represents 1 minus the correlation of one model using the variable and one model using the variable randomized. The intermediate line is the median, and the limits of the boxes are the 1st and 3rd quartiles. The lines and the points show the minimum and maximum and the outliers.

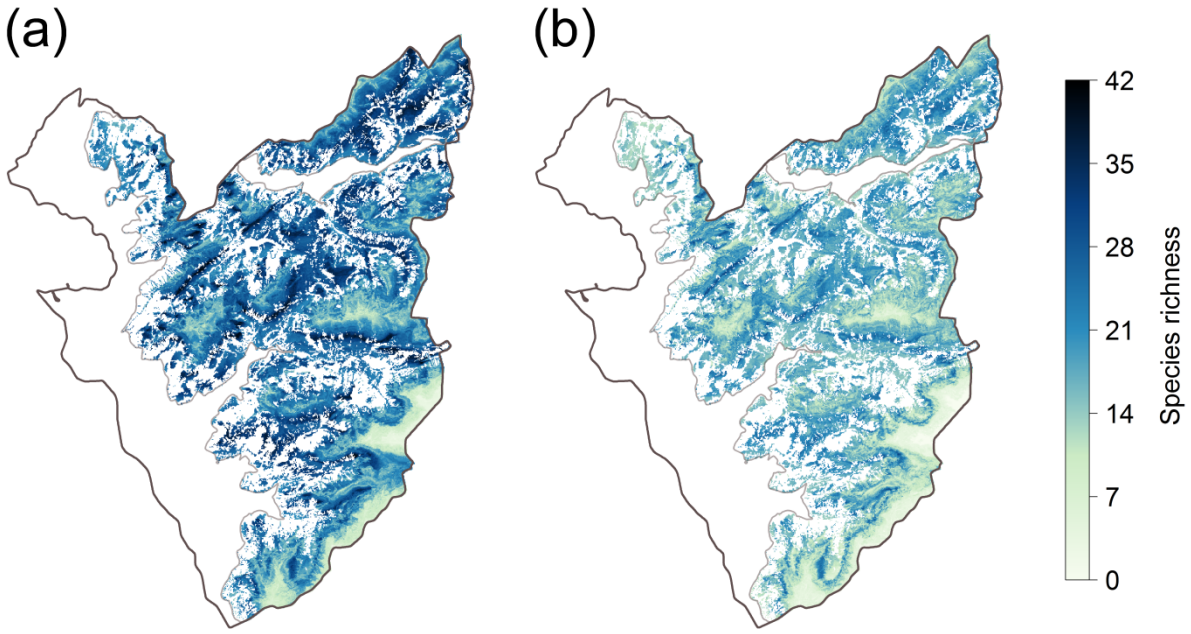

Figure A6. Predicted current (i.e. 2010) butterfly species richness in the study area when (a) considering only butterfly abiotic distribution, and when (b) constraining butterfly abiotic distribution with the abiotic distribution of their known host plants. Constraining the butterfly abiotic distribution by known current trophic interaction decreases the butterfly species richness.

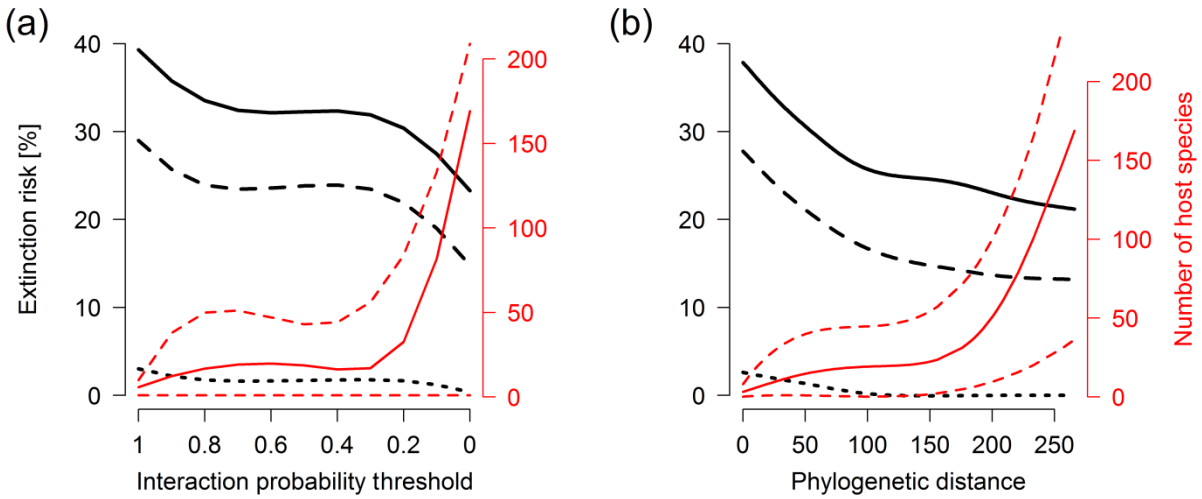

Figure A7. Percent of butterfly species with high extinction risk for the 2085 butterfly host plant constrained predictions under the A2 (black plain line), A1B (black long dashed) and RCP3PD (black short dashed) climate change scenarios when considering an enlargement of the host plants diet based on (a) interaction probabilities between the butterfly and the plants and (b) phylogenetic distances between plants. Species were considered in danger of extinction when their predicted area does not reach 1% of the total available open habitats (i.e., < 3.5 km2). The mean accumulated number of host plants (red line) included in the diet is shown on the right axis (number of host species) where the dashed lines represent the 5 and 95 percentiles. An interaction probability threshold of 1 and a phylogenetic distance of 0 means that only the known host plants from the literature are considered in the diet. Curves were fitted with a GAM function.

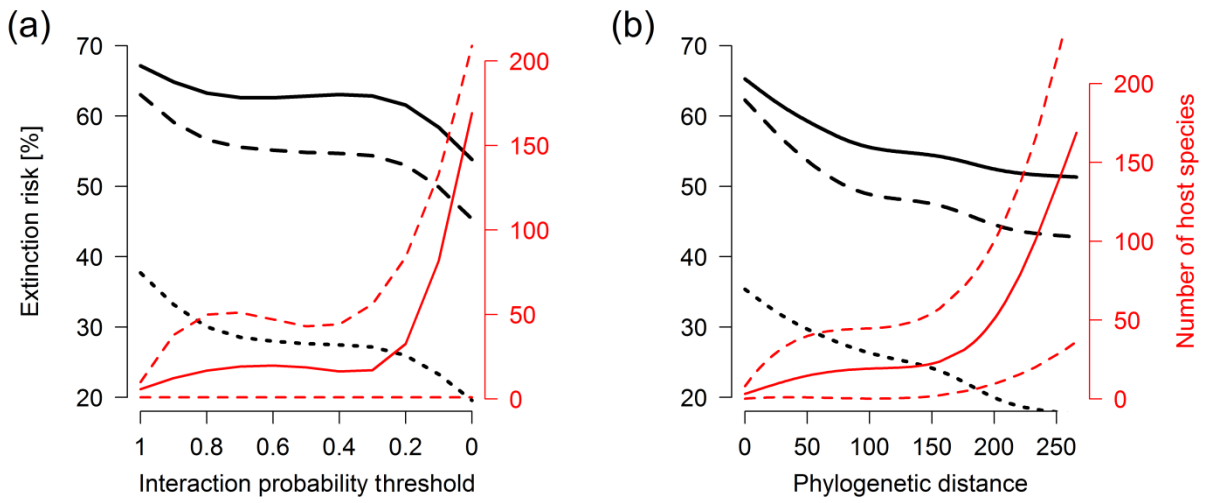

Figure A8. Percent of butterfly species with high extinction risk for the 2085 butterfly host plant constrained predictions under the A2 (black plain line), A1B (black long dashed) and RCP3PD (black short dashed) climate change scenarios when considering an enlargement of the host plants diet based on (a) interaction probabilities between the butterfly and the plants and (b) phylogenetic distances between plants. Species were considered in danger of extinction when their predicted area does not reach 10% of the total available open habitats (i.e., < 34.9 km2). The mean accumulated number of host plants (red line) included in the diet is shown on the right axis (number of host species) where the dashed lines represent the 5 and 95 percentiles. An interaction probability threshold of 1 and a phylogenetic distance of 0 means that only the known host plants from the literature are considered in the diet. Curves were fitted with a GAM function.

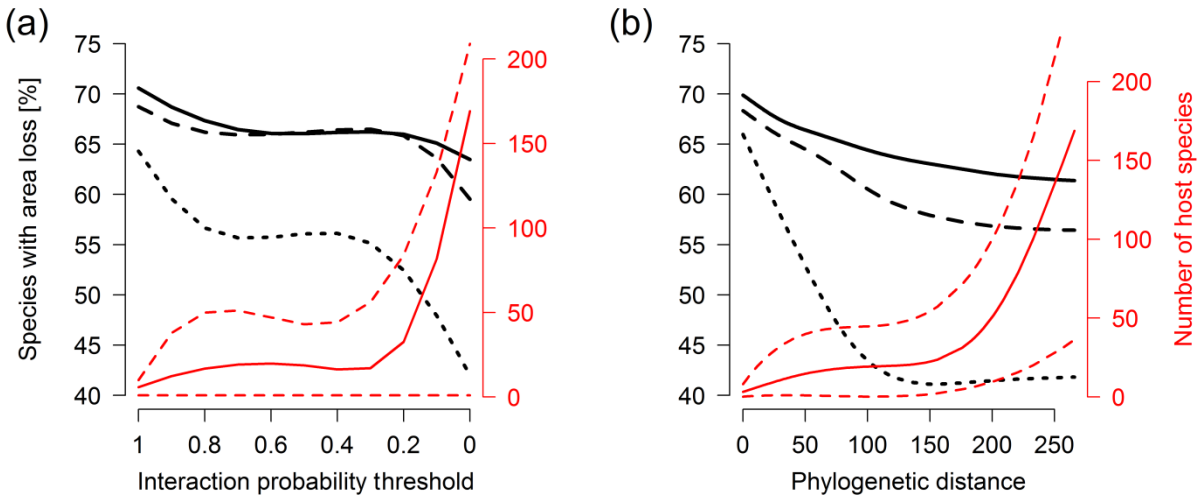

Figure A9. Percent of butterfly species presenting habitat loss (in term of surface) for the 2085 butterfly host plant constrained predictions under the A2 (black plain line), A1B (black long dashed) and RCP3PD (black short dashed) climate change scenarios when considering an enlargement of the host plants dietbased on (a) interaction probabilities between the butterfly and the plants and (b) phylogenetic distances between plants. The mean accumulated number of host plants (red line) included in the diet is shown on the right axis (number of host species) where the dashed lines represent the 5 and 95 percentiles. An interaction probability threshold of 1 and a phylogenetic distance of 0 means that only the known host plants from the literature are considered in the diet. Curves were fitted with a GAM function.

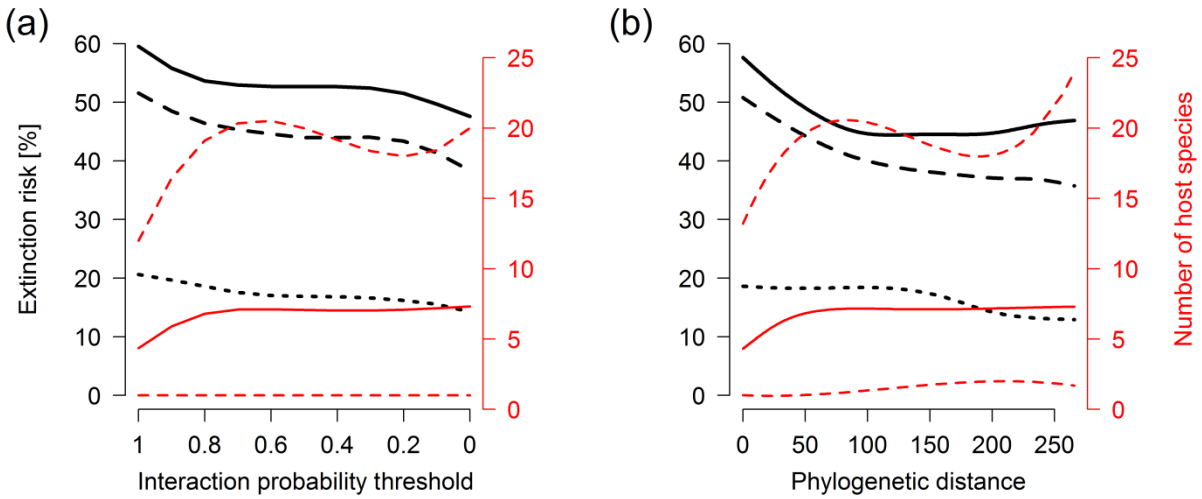

Figure A10. Percent of butterfly species with high extinction risk for the 2085 butterfly host plant constrained predictions under the A2 (black plain line), A1B (black long dashed), RCP3PD (black short dashed) climate change scenarios when considering an enlargement of the host plants diet based on (a) interaction probabilities between the butterfly and the plants and (b) phylogenetic distances between plants. Species were considered in danger of extinction when their predicted area does not reach 5% of the total available open habitats (i.e., < 17.5 km2). The extinction rate was calculated as the mean of ten replicated simulation of enlargement of the host plants diet that was limited by the number of known host plants (maintaining the distinction between generalist and specialist species in term of host plant number of species in the diet). The mean accumulated number of host plants (red line) included in the diet is shown on the right axis (number of host species) where the dashed lines represent the 5 and 95 percentiles. An interaction probability threshold of 1 and a phylogenetic distance of 0 means that only the known host plants from the literature are considered in the diet. Curves were fitted with a GAM function.