Online Resource 1

Conserving Red List plant species by managing landscape fragmentation and permeability

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Landscape Ecology

Selection of environmental variables for SDM modeling

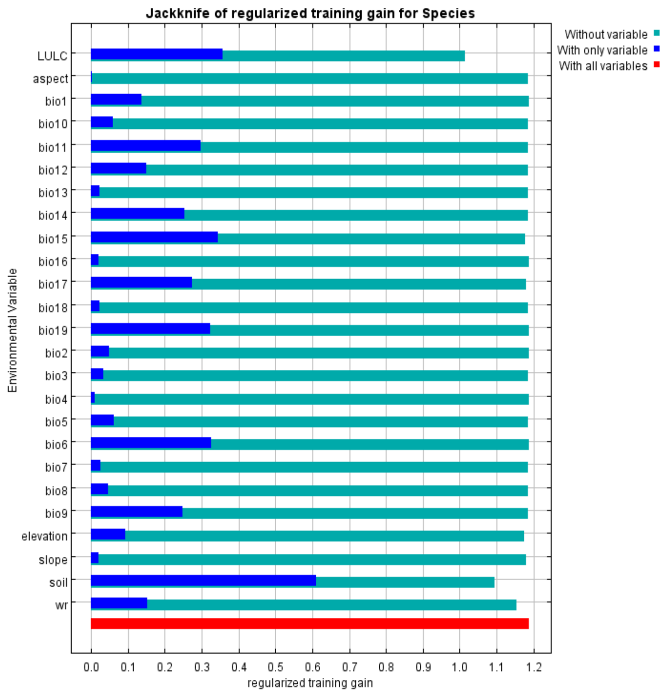
The selection of environmental variables was performed in two distinct steps.

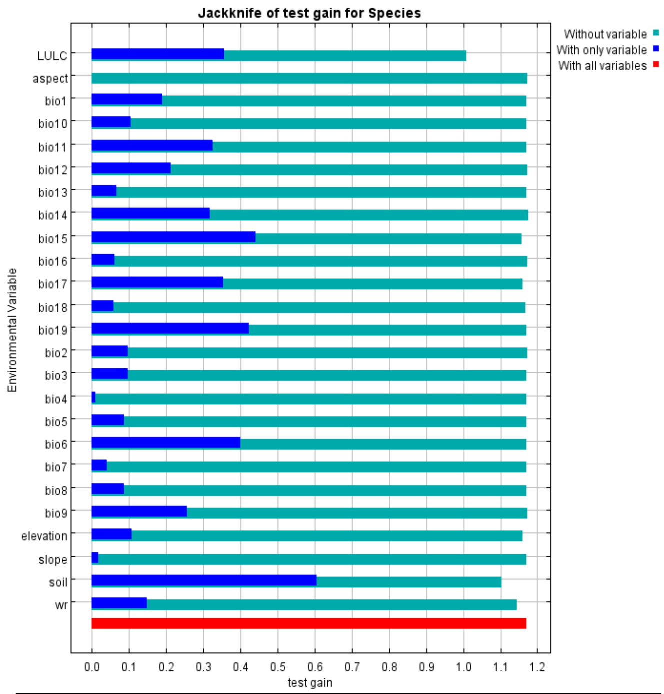
Step 1. Species Distribution Modelling using the Full Set of Variables

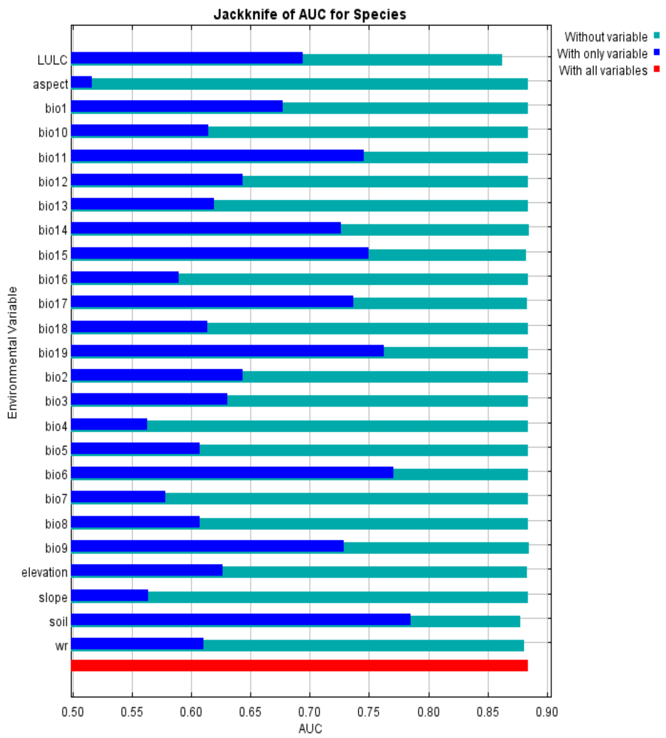
We used Maximum Entropy (Maxent) modeling to predict the potential distribution of the species, using a full set of 25 environmental variables and 483 presence points. In practical terms, this step was also carried out with the aim of selecting and analyzing the environmental variables that contribute the most to the SDM.

Model Calibration and Settings
The model was calibrated with 434 presence records for training and 49 for testing, against a background of 10,434 points. The 25 environmental variables included topographic features (Aspect, Elevation, Slope), 19 bioclimatic layers (Bio1-Bio19), and categorical land cover, soil and average soil water regime variables (LULC, Soil, WR). The model was run with 10 replicates, using linear and quadratic features. The following regularization multipliers were applied: 0.050 for linear/quadratic/product features, 0.250 for categorical features, 1.000 for threshold, and 0.500 for hinge.

Figure 1 illustrates the results of the variable contribution, importance analysis, and jackknife test derived from the SDM modeling using 25 environmental variables.







Variable	Percent contribution	Permutation importance
Soil	42.2	11.4
LULC	26	12.3
WR	8.4	3.7
Bio15	6.1	11.7
Bio9	4	1.8
Bio14	3.4	25.4
Bio7	2.6	1.5
Bio4	2.2	0.4
Bio19	1.6	0
bio17	1.3	18.9
Elevation	1	4.1
Slope	0.7	0.3
Aspect	0.1	0
Bio3	0.1	0.3
Bio5	0.1	3
Bio11	0.1	4.1
Bio6	0.1	0.4
Bio2	0.1	0
Bio16	0	0.5
Bio18	0	0
Bio1	0	0
Bio8	0	0
Bio12	0	0
Bio10	0	0
Bio13	0	0

Fig. 1 Results of the percent contribution, permutation importance, and Jackknife test analysis for the variables used in SDM modeling

Step 2. Correlation analysis and multicollinearity reduction

This step aimed to reduce multicollinearity—the phenomenon where explanatory variables are strongly correlated with each other—to enhance the stability and interpretability of the SDM.

Calculation of Correlation Coefficients

We calculated the Pearson correlation coefficients (r) for all pairs of environmental variables using the *cor* function in the R statistical software (v. 4.5.0). The results of the correlation analysis are presented in Figure 2 and Table 1.

Elimination Threshold and Final Selection

Identification of Strong Correlation: A threshold of $|r| \geq 0.7$ was established to identify strongly correlated variable pairs, in accordance with the recommendations in the literature for mitigating multicollinearity(Dormann et al., 2013).

Variable Elimination: From each pair that exceeded the 0.7 threshold, we eliminated the variable with the lowest ecological significance (Fig. 1) for the specific purpose of our study.

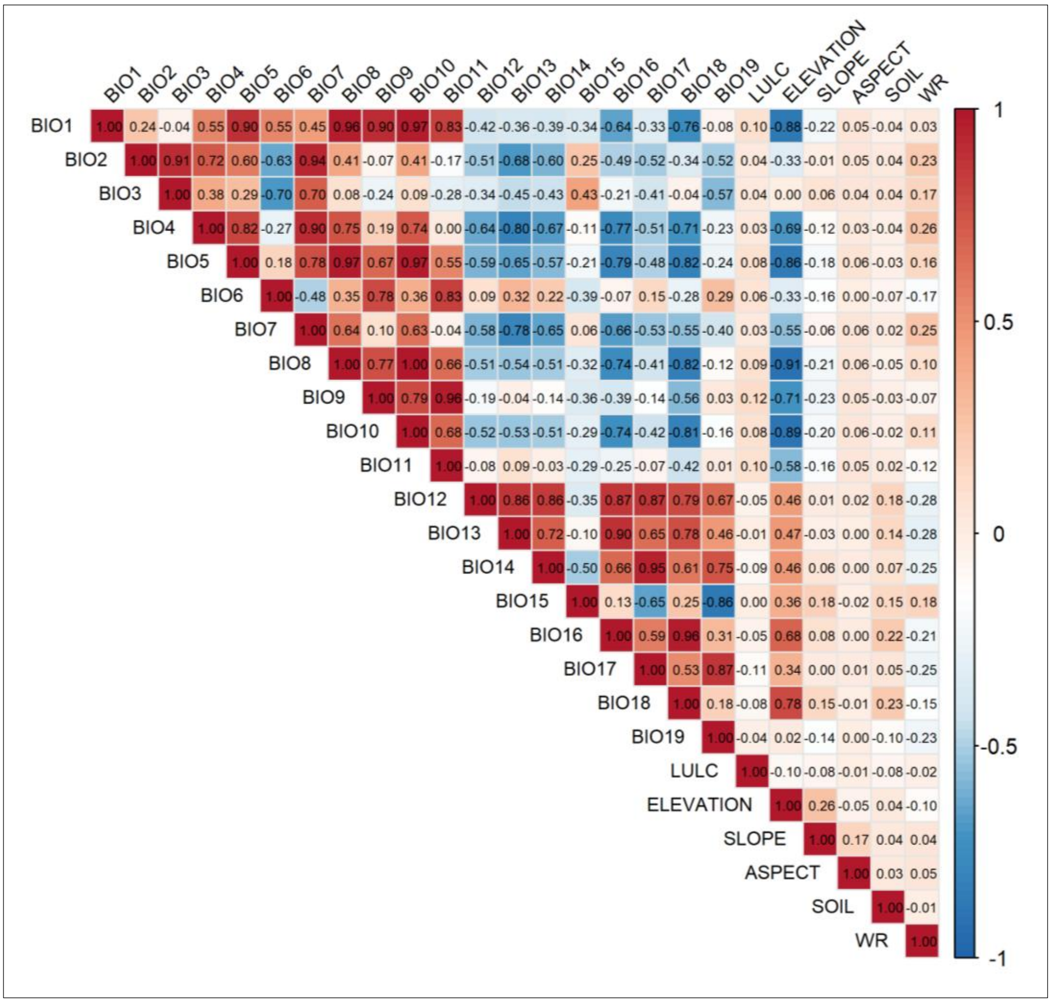


Fig. 2 Correlogram of the 25 environmental variables

Table 1. Pearson correlation matrix for the 25 environmental variables.

	BIO 1	BIO 2	BIO 3	BIO 4	BIO 5	BIO 6	BIO 7	BIO 8	BIO 9	BIO 10	BIO 11	BIO 12	BIO 13	BIO 14	BIO 15	BIO 16	BIO 17	BIO 18	BIO 19	LULC	ELEV.	SLOP	ASP.	SOIL	WR
BIO1	1.00	0.24	-0.04	0.55	0.90	0.55	0.45	0.96	0.90	0.97	0.83	-0.42	-0.36	-0.39	-0.34	-0.64	-0.33	-0.76	-0.08	0.10	-0.88	-0.22	0.05	-0.04	0.03
BIO2	0.24	1.00	0.91	0.72	0.60	-0.63	0.94	0.41	-0.07	0.41	-0.17	-0.51	-0.68	-0.60	0.25	-0.49	-0.52	-0.34	-0.52	0.04	-0.33	-0.01	0.05	0.04	0.23
BIO3	-0.04	0.91	1.00	0.38	0.29	-0.70	0.70	0.08	-0.24	0.09	-0.28	-0.34	-0.45	-0.43	0.43	-0.21	-0.41	-0.04	-0.57	0.04	0.00	0.06	0.04	0.04	0.17
BIO4	0.55	0.72	0.38	1.00	0.82	-0.27	0.90	0.75	0.19	0.74	0.00	-0.64	-0.80	-0.67	-0.11	-0.77	-0.51	-0.71	-0.23	0.03	-0.69	-0.12	0.03	-0.04	0.26
BIO5	0.90	0.60	0.29	0.82	1.00	0.18	0.78	0.97	0.67	0.97	0.55	-0.59	-0.65	-0.57	-0.21	-0.79	-0.48	-0.82	-0.24	0.08	-0.86	-0.18	0.06	-0.03	0.16
BIO6	0.55	-0.63	-0.70	-0.27	0.18	1.00	-0.48	0.35	0.78	0.36	0.83	0.09	0.32	0.22	-0.39	-0.07	0.15	-0.28	0.29	0.06	-0.33	-0.16	0.00	-0.07	-0.17
BIO7	0.45	0.94	0.70	0.90	0.78	-0.48	1.00	0.64	0.10	0.63	-0.04	-0.58	-0.78	-0.65	0.06	-0.66	-0.53	-0.55	-0.40	0.03	-0.55	-0.06	0.06	0.02	0.25
BIO8	0.96	0.41	0.08	0.75	0.97	0.35	0.64	1.00	0.77	1.00	0.66	-0.51	-0.54	-0.51	-0.32	-0.74	-0.41	-0.82	-0.12	0.09	-0.91	-0.21	0.06	-0.05	0.10
BIO9	0.90	-0.07	-0.24	0.19	0.67	0.78	0.10	0.77	1.00	0.79	0.96	-0.19	-0.04	-0.14	-0.36	-0.39	-0.14	-0.56	0.03	0.12	-0.71	-0.23	0.05	-0.03	-0.07
BIO10	0.97	0.41	0.09	0.74	0.97	0.36	0.63	1.00	0.79	1.00	0.68	-0.52	-0.53	-0.51	-0.29	-0.74	-0.42	-0.81	-0.16	0.08	-0.89	-0.20	0.06	-0.02	0.11
BIO11	0.83	-0.17	-0.28	0.00	0.55	0.83	-0.04	0.66	0.96	0.68	1.00	-0.08	0.09	-0.03	-0.29	-0.25	-0.07	-0.42	0.01	0.10	-0.58	-0.16	0.05	0.02	-0.12
BIO12	-0.42	-0.51	-0.34	-0.64	-0.59	0.09	-0.58	-0.51	-0.19	-0.52	-0.08	1.00	0.86	0.86	-0.35	0.87	0.87	0.79	0.67	-0.05	0.46	0.01	0.02	0.18	-0.28
BIO13	-0.36	-0.68	-0.45	-0.80	-0.65	0.32	-0.78	-0.54	-0.04	-0.53	0.09	0.86	1.00	0.72	-0.10	0.90	0.65	0.78	0.46	-0.01	0.47	-0.03	0.00	0.14	-0.28
BIO14	-0.39	-0.60	-0.43	-0.67	-0.57	0.22	-0.65	-0.51	-0.14	-0.51	-0.03	0.86	0.72	1.00	-0.50	0.66	0.95	0.61	0.75	-0.09	0.46	0.06	0.00	0.07	-0.25
BIO15	-0.34	0.25	0.43	-0.11	-0.21	-0.39	0.06	-0.32	-0.36	-0.29	-0.29	-0.35	-0.10	-0.50	1.00	0.13	-0.65	0.25	-0.86	0.00	0.36	0.18	-0.02	0.15	0.18
BIO16	-0.64	-0.49	-0.21	-0.77	-0.79	-0.07	-0.66	-0.74	-0.39	-0.74	-0.25	0.87	0.90	0.66	0.13	1.00	0.59	0.96	0.31	-0.05	0.68	0.08	0.00	0.22	-0.21
BIO17	-0.33	-0.52	-0.41	-0.51	-0.48	0.15	-0.53	-0.41	-0.14	-0.42	-0.07	0.87	0.65	0.95	-0.65	0.59	1.00	0.53	0.87	-0.11	0.34	0.00	0.01	0.05	-0.25
BIO18	-0.76	-0.34	-0.04	-0.71	-0.82	-0.28	-0.55	-0.82	-0.56	-0.81	-0.42	0.79	0.78	0.61	0.25	0.96	0.53	1.00	0.18	-0.08	0.78	0.15	-0.01	0.23	-0.15
BIO19	-0.08	-0.52	-0.57	-0.23	-0.24	0.29	-0.40	-0.12	0.03	-0.16	0.01	0.67	0.46	0.75	-0.86	0.31	0.87	0.18	1.00	-0.04	0.02	-0.14	0.00	-0.10	-0.23
LULC	0.10	0.04	0.04	0.03	0.08	0.06	0.03	0.09	0.12	0.08	0.10	-0.05	-0.01	-0.09	0.00	-0.05	-0.11	-0.08	-0.04	1.00	-0.10	-0.08	-0.01	-0.08	-0.02
ELEVATION	-0.88	-0.33	0.00	-0.69	-0.86	-0.33	-0.55	-0.91	-0.71	-0.89	-0.58	0.46	0.47	0.46	0.36	0.68	0.34	0.78	0.02	-0.10	1.00	0.26	-0.05	0.04	-0.10
SLOPE	-0.22	-0.01	0.06	-0.12	-0.18	-0.16	-0.06	-0.21	-0.23	-0.20	-0.16	0.01	-0.03	0.06	0.18	0.08	0.00	0.15	-0.14	-0.08	0.26	1.00	0.17	0.04	0.04
ASPECT	0.05	0.05	0.04	0.03	0.06	0.00	0.06	0.06	0.05	0.06	0.05	0.02	0.00	0.00	-0.02	0.00	0.01	-0.01	0.00	-0.01	-0.05	0.17	1.00	0.03	0.05
SOIL	-0.04	0.04	0.04	-0.04	-0.03	-0.07	0.02	-0.05	-0.03	-0.02	0.02	0.18	0.14	0.07	0.15	0.22	0.05	0.23	-0.10	-0.08	0.04	0.04	0.03	1.00	-0.01
WR	0.03	0.23	0.17	0.26	0.16	-0.17	0.25	0.10	-0.07	0.11	-0.12	-0.28	-0.28	-0.25	0.18	-0.21	-0.25	-0.15	-0.23	-0.02	-0.10	0.04	0.05	-0.01	1.00

Selected Variables Used in the Final MaxEnt Model

The final set of environmental variables selected for the MaxEnt model included:

- Land use/cover - LULC
- Soil class - SOIL
- Mean temperature of coldest quarter - BIO11
- Precipitation of driest month - BIO14
- Precipitation seasonality - BIO15,
- Elevation/Altitude - ELEVATION
- Dominant annual average soil water regime class of the soil profile - WR.

Reference:

1. Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J. R. G., Gruber, B., Lafourcade, B., Leitão, P. J., Münkemüller, T., McClean, C., Osborne, P. E., Reineking, B., Schröder, B., Skidmore, A. K., Zurell, D., & Lautenbach, S. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, *36*(1), 27–46. https://doi.org/10.1111/j.1600-0587.2012.07348.x