Online Resource 2

Conserving Red List plant species by managing landscape fragmentation and permeability

Nicu Alexandru Gîlea[1], Ileana Pătru-Stupariu[2], Athanasios Gavrilidis[2], Simona R. Gradinaru[3], Simona Dumitrița Chirilă[4], Ana-Maria Florescu[5], Andrei Ionuț Mărghescu[5]

[1]Faculty of Geography, Doctoral School Simion Mehedinti, University of Bucharest Bd. N. Bălcescu, 1, 010041 Bucharest, Romania,
[2] Department of Regional Geography and Environment, Faculty of Geography, University of Bucharest, 1 Bd. N. Bălcescu, 010041 Bucharest, Romania
[3] Swiss Federal Research Intitute WSL, Land Use Systems Group
[4] Danube Delta National Institute for Research and Development, Tulcea, Romania
[5] Faculty of Geography, University of Bucharest Bd. N. Bălcescu, 1, 010041 Bucharest, Romania

Corresponding author: Nicu Alexandru Gîlea, email: nicu.gilea@s.unibuc.ro, tel. 0730633963

Landscape Ecology

Methods Applied for Calculating Permeability Scores

Permeability Scores (P.S.) were established through a two-step process, combining statistical analysis and literature-based refinement. In the first step, Resource Selection Functions (RSF) were used to perform statistical calculations of habitat preference, and in the second step, the preliminary scores were adjusted and validated using information from the scientific literature.

The method was applied to the following variables: LULC, SOIL, ASPECT, SLOPE.

Step 1. The methodology for assigning permeability scores (on a 0–10 scale) is based on statistical analysis derived from the principles of RSF. We used the Selection Ratio (w_i) to quantify habitat preference, which was then logarithmically linear normalized (scaled 0–10) to obtain the Permeability Scores (*P.S.*). The Selection Ratio quantifies the relative preference of the species for a particular habitat class (i) by comparing resource use (presence) with its availability (background)(Boyce et al., 2002; Manly et al., 2002).

We used 483 presence points and 5000 pseudo-absence points. Environmental variable values were extracted for each point, and selection ratios (SR) were then calculated. For each class (LULC, SOIL, ASPECT, SLOPE), we calculated the proportion of presence points and the proportion of background points:

Calculation of proportions:

$$\%Presence_i = \frac{n_{presence,i}}{N_{total\ presence}}\ x\ 100$$

$$\%PseudoAbsence_i = \frac{n_{background,i}}{N_{total\ background}}\ x\ 100$$

where,
$n_{presence,\ i}$ = number of presence points in class i
$N_{total\ presence}$ = total number of presence points
$N_{background,\ i}$ = number of background points in class i
$N_{total\ background}$ = total number of background points

Calculation of the Selection Ratio (w_i):

The selection ratio is calculated as the ratio between the proportion of presence points and the proportion of background points:

$$w_i = \frac{\%Presence_i}{\%PseudoAbsence_i}$$

Interpretation:
$w_i > 1$ the habitat class is selected more than expected (preferred)
$w_i < 1$ the habitat class is avoided

Normalization and Scaling to a 0–10 Scale.
To obtain a final intuitive permeability score (P.S.) ranging from 0 to 10, the wiw_iwi values are transformed using a logarithmic linear normalization**,** a simplification of the min–max normalization. This allows the minimum and maximum values to be scaled appropriately:

$$P.S._i = 10 \text{ x } \frac{\ln(1 + w_i) - \ln(1 + w_{min})}{\ln(1 + w_{\max}) - \ln(1 + w_{\min})}$$

where,
$P.S._i$ = permeability score for the class i
w_{max} = max$i$ (w_i) = maximum value of the selection ratio among all classes (the class with $w_i = w_{max}$ receives a score of 10, while classes $w_i = 0$ receive a score of 0)
w_{min} = min (w_i) = minimum value of the selection ratio among all classes.

The results of these calculations, along with the data used for the analysis, are presented in Table 1.

Table 1. Selection ratios (w_i) and calculated permeability scores (*P.S.*) for each class of environmental variables (LULC, SOIL, ASPECT, SLOPE) used in the analysis.

COD	CLASS	Presence	Peudoabsence	%Presence$_i$	%PseudoAbsence$_i$	w_i	w_{max}	w_{min}	Permeability Score$_i$
LULC	Water	0	15	0.0	0.3	0.0	4.0	0	0
	Shrubs (SWF)	47	212	9.7	4.2	2.3	4.0	0	8
	Built-up Area / Artificial Surfaces	1	104	0.2	2.1	0.1	4.0	0	1
	Agricultural Crops / Arable Land	53	1392	11.0	27.8	0.4	4.0	0	2
	Roads	3	26	0.6	0.5	1.2	4.0	0	5
	Orchard	0	69	0.0	1.4	0.0	4.0	0	0
	Bare Land / Sparsely Vegetated Area	7	18	1.4	0.4	4.0	4.0	0	10
	Coniferous Forests	0	57	0.0	1.1	0.0	4.0	0	0
	Deciduous Forests	29	1322	6.0	26.4	0.2	4.0	0	1
	Pastures / Grassland	343	1785	71.0	35.7	2.0	4.0	0	7
SOIL	Argiluvisols	62	2043	12.8	40.9	0.3	3.4	0	2
	Cambisols	70	852	14.5	17.0	0.9	3.4	0	4
	Supplementary Classes (Water)	0	1	0.0	0.0	0.0	3.4	0	0
	Mollisols	217	661	44.9	13.2	3.4	3.4	0	10
	Halomorphic Soils	0	2	0.0	0.0	0.0	3.4	0	0
	Hydromorphic Soils	25	318	5.2	6.4	0.8	3.4	0	4
	Undeveloped/Truncated/Disturbed Soils	98	1077	20.3	21.5	0.9	3.4	0	5
	Organic Soils (Histosols)	0	3	0.0	0.1	0.0	3.4	0	0
	Spodosols	0	2	0.0	0.0	0.0	3.4	0	0
	Umbrisols	0	7	0.0	0.1	0.0	3.4	0	0
	Vertisols	11	34	2.3	0.7	3.3	3.4	0	10
ASPECT	Flat / Level (-1)	0	0	0.0	0.0	0.0	1.8	0	0
	North (0-22.5)	44	525	9.1	10.5	0.9	1.8	0	6
	North-East (22.5-67.5)	66	565	13.7	11.3	1.2	1.8	0	8
	East (67.5-112.5)	50	699	10.4	14.0	0.7	1.8	0	5
	South-East (112.5-157.5)	39	509	8.1	10.2	0.8	1.8	0	6
	South (157.5-202.5)	91	702	18.8	14.1	1.3	1.8	0	8
	South-West (202.5-247.5)	83	483	17.2	9.7	1.8	1.8	0	10
	West (247.5-292.5)	47	631	9.7	12.6	0.8	1.8	0	6

	North-West (292.5-337.5)	30	558	6.2	11.2	0.6	1.8	0	4
	North (337.5-360)	33	328	6.8	6.4	1.1	1.8	0	7
SLOP	0–3°	55	1475	11.4	29.5	0.4	1.7	0	0
	3–10°	275	2299	56.9	46.0	1.2	1.7	0	7
	10–20°	128	1076	26.5	21.5	1.2	1.7	0	7
	20–30°	25	149	5.2	3.0	1.7	1.7	0	10
	>30°	0	1	0.0	0.0	0.0	1.7	0	0

Step 2. In the second step, the preliminary permeability scores were adjusted and validated using information from the scientific literature. This involved integrating habitat characteristics, species preferences, and previously published ecological knowledge to obtain the final P.S. values. Thus, the final scores reflect both the statistical analysis based on presence and background data and the documented ecological information, providing a realistic estimate of habitat permeability for the threatened species (Table 2).

Table 2. Adjusted Permeability Scores for Environmental Variables of Analyzed Species with Justifications and Literature Sources

Environmental variable	CLASS	Preliminary score	Adjusted score	Justification	Literature source(s)
LULC	Water	0	0	-	(D. S. Chirilă, 2022; S. D. Chirilă, 2021; S. D. Chirilă, Bădărău, et al., 2025; S. D. Chirilă, Doroftei, et al., 2025; S. D. Chirilă et al., 2022; S. D. Chirilă & Kiril, 2024; Cieslak, 2013; Cieślak, 2013; FloraVeg.EU, 2025; Mucina et al., 2016; Sádlo et al., 2007)
	Shrubs / Scrub (SWF)	8	8	-	
	Built-up Area/Artificial Surfaces	1	0	Non-habitat	
	Agricultural Crops / Arable Land	2	1	Non-habitat	
	Roads	5	0	Non-habitat	
	Orchard	0	1	Species have also been observed in orchards	
	Bare Land / Sparsely Vegetated Area	10	5	Habitat vegetation cover between 40–90%	
	Coniferous Forests	0	1	The species have also been observed within open (sparse) coniferous forests.	
	Deciduous Forests	1	1	-	
	Pastures / Grassland	7	10	Main habitat type mentioned in the literature	
SOIL	Argiluvisols	2	7	Nutrient-rich, well-drained soils formed on loess, similar to Feozem/Chernozem conditions favorable for the species.	
	Cambisols	4	8	Moderately fertile, well-drained soils with neutral to slightly acidic pH (6.0–7.0), providing suitable conditions for the species	
	Supplementary Classes (Water)	0	0	-	

	Mollisols	10	10	-	
	Halomorphic Soils	0	0	-	
	Hydromorphic Soils	4	0	The species does not tolerate excessive soil moisture; hydromorphic soils are generally unsuitable for establishment.	
	Undeveloped/Truncated/Disturbed Soils	5	5	-	
	Organic Soils (Histosols)	0	0	-	
	Spodosols	0	0	-	
	Umbrisols	0	0	-	
	Vertisols	10	5	Clay-rich, poorly drained soils may hinder establishment despite high nutrient content.	
ASPECT	Flat / Level (-1)	0	0	-	
	North (0-22.5)	6	5	Less favorable exposure habitats	
	North-East (22.5-67.5)	8	8	-	
	East (67.5-112.5)	5	8	Eastern-exposed habitats are also preferred	
	South-East (112.5-157.5)	6	8	South-eastern-exposed habitats are also preferred	
	South (157.5-202.5)	8	10	Ideal exposure habitats	
	South-West (202.5-247.5)	10	10	Ideal exposure habitats	
	West (247.5-292.5)	6	8	Western-exposed habitats are also preferred	
	North-West (292.5-337.5)	4	7	North-western-exposed habitats are also preferred	
	North (337.5-360)	7	5	Less favorable exposure habitats	
SLOP	0–3°	0	5	Habitats with slightly preferred slope. Species were observed rarely.	
	3–10°	7	10	Habitats with ideal slope. Species were observed frequently.	
	10–20°	7	9	Habitats with optimal slope. Species were observed regularly.	
	20–30°	10	7	Habitats with optimal slope. Species were observed regularly.	
	>30°	0	5	Habitats with slightly preferred slope. Species were observed rarely.	

Reference:

Boyce, M. S., Vernier, P. R., Nielsen, S. E., & Schmiegelow, F. K. A. (2002). Evaluating resource selection functions. *Ecological Modelling*, *157*(2–3), 281–300. https://doi.org/10.1016/S0304-3800(02)00200-4

Chirilă, D. S. (2022). Analysis of the characteristics of some populations of Crambe tataria Sebeók from Romania. *Acta Oecologica*, *114*, 103810. https://doi.org/10.1016/j.actao.2021.103810

Chirilă, S. D. (2021). Ecological And Chorological Studies Of The Species Crambe Tataria Sebeók From Romania. *Rom. J. Biol. – Plant Biol, Bucharest*, *66*, 39–54.

Chirilă, S. D., Bădărău, A., & Milanovici, S. (2025). Ecology and distribution of Pontechium maculatum in Romania. *Comprehensive Plant Biology*, *49*(1), 23–38. https://doi.org/10.2298/CPB2501023C

Chirilă, S. D., Cara, I. G., & Motrescu, I. (2022). Habitat preference of the endangered species Crambe tataria (Brassicaceae) from Romania. *Tuexenia*, *42*, 275–296. https://doi.org/10.14471/2022.42.009

Chirilă, S. D., Doroftei, M., & Gigea, G. (2025). Ecology and distribution of Paeonia tenuifolia species in Romania. *Biologia*. https://doi.org/10.1007/s11756-025-01902-x

Chirilă, S. D., & Kiril, V. (2024). Habitat preference for the populations of the endangered species Pontechium maculatum (Boraginaceae) in Romania. *Tuexenia*, *44*, 131–157. https://doi.org/10.14471/2024.44.005

Cieslak, E. (2013). Variation and genetic structure of Serratula lycopifolia populations (Vill.) Kern. (Asteraceae) in Poland and adjacent regions. *Acta Societatis Botanicorum Poloniae*, *82*(1), 67–75. https://doi.org/10.5586/asbp.2013.006

Cieślak, E. (2013). Variation and genetic structure of Serratula lycopifolia populations (Vill.) Kern. (Asteraceae) in Poland and adjacent regions. *Acta Societatis Botanicorum Poloniae*, *81*(4), 67–75. https://doi.org/10.5586/asbp.2013.006

FloraVeg.EU. (2025, September 28). *FloraVeg. EU: Information about species*. https://floraveg.eu/taxon/

Huettmann, F. (2003). "Resource Selection by Animals" by B. J. Manly et al. 2002. [book review]. *The Canadian Field-Naturalist*, *117*(2), 325. https://doi.org/10.22621/cfn.v117i2.717

Manly, B. F. J. ., McDonald, L. L. ., Thomas, D. L. ., McDonald, T. L. ., & Erickson, W. P. . (2002). *Resource Selection by Animals : Statistical Design and Analysis for Field Studies*. Springer Netherlands.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., García, R. G., Chytrý, M., Hájek, M., Di Pietro, R., Iakushenko, D., Pallas, J., Daniëls, F. J. A., Bergmeier, E., Santos Guerra, A., Ermakov, N., … Tichý, L. (2016). Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science*, *19*(S1), 3–264. https://doi.org/10.1111/avsc.12257

Sádlo, J., Chytrý, M., & Pyšek, P. (2007). Regional species pools of vascular plants in habitats of the Czech Republic Druhy cévnatých rostlin v biotopech České republiky. *Preslia*, *79*, 303–321. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.preslia.cz/article/pdf?id=278