Disentangling the Roles of Topography, Patch, and Land Use on Conservation Trait Status of Specialist Birds in Marginal Forest Land Use Types

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Abstract: One of the main questions in ecology and conservation is how organisms are governed and affected by their traits within the context of abiotic gradients. The main question of our study addresses how patch, topography, and land use influence conservation trait status (rarity and red-list index) of birds generally, and of farmland and woodland specialists specifically, in marginal forest landscape types. We sampled birds from 68 traditional fruit orchards existing as remnants of agroforestry within the Pardubice Region of the Czech Republic during two consecutive years. We recorded 57 bird species, of which 31 species were forest dwellers and 16 farmland dwellers. Topographical predictors played the most significant role in influencing traits of the bird community as a whole. Farmland bird traits indicated the most balanced values, as they were significantly influenced by all studied predictor sets. Their responses nevertheless differed among the studied traits and also showed a more complex pattern because the values of interaction between some predictor categories were relatively high. Traits of woodland birds were most influenced by the patch configuration. We found that a structurally diversified marginal habitat type of traditional fruit orchards is able to promote a number of specialist species and also reveals important relationships between bird conservation traits and different predictor sets. Researchers should pay more attention to the conservation traits of birds and their interactions with environmental predictors. Furthermore, conservationists should be more attentive to the biodiversity value and sustainable management of traditional fruit orchards.

Keywords: agroforestry; bird conservation; traditional fruit orchard; rarity; red-list index; farmland specialist; woodland birds

1. Introduction

Birds occupy a very wide range of ecological positions. Many species are specialized in their ecological requirements [1]. Even within a single habitat type, such as a temperate deciduous forest, the niches occupied by different species are highly diverse, e.g., [2].

Animal conservationists today are facing the loss of bird species, which is in contrast to the previously accepted notion that it was inconceivable they ever could become threatened. In some cases, they have often been the subject of yearlong and unregulated hunting. This is, for instance, the case of farmland birds in Europe [3]. Extensive and long-term bird breeding atlas data have indicated that certain species of birds are gradually vacating their positions in areas that were formerly their

strongholds. This puts formerly common species taxa at risk. In the worst case, they may become very rare birds [4].

Land managers are calling for answers regarding the main causes of the decline of formerly common species. Furthermore, they seek answers as to the extent that processes influencing the decline are interconnected [5]. Birds have mostly higher dispersal abilities than other taxa [6]. On the other hand, this ability, together with biotic interactions among birds, predisposes them generally to a necessity to utilize habitat patches on larger landscape scales [7]. Considering the generally negative impacts of fragmentation, which causes isolation for most organisms, this could apparently provide an advantage to birds. Nevertheless, as birds search for new territories during times when suitable habitats are lost, this might cause a decline in population densities of individual bird species [8], and especially of specialist species. An additional reason for the decline could be that many species are long-lived and repeated changes in the quality of their habitats during their lifetimes may cause a shortening of the average lifespan of the individual species or a change in species assemblages [9].

The pattern and configuration of habitat patches are thought to be among the most important factors influencing bird distributions. Patches that are highly diversified spatially are known to host more habitat specialists and more species at risk [10,11]. Traditional fruit orchards are relatively conspicuous man-made habitats, and they have high vertical and horizontal stratification compared to other agricultural habitats [12,13]. Orchards and similar landscape patches, such as scrublands, are widely distributed throughout the world and, in most cases, they constitute comparable, although rather marginal and fragmented, habitat types [12,14]. These landscape patches have high potential to host species that avoid the intensively used agricultural and forest land and also those that avoid late successional stages when woodlands are characterized by very closed canopies [10,15].

Values other than species richness of birds remain less studied. Conservation trait status, such as rarity or level of threat, could be predicted to have high relevance for animal conservation. An important question is how organisms are governed by their traits within the context of abiotic environmental gradients [16].

In our study, we are interested in the question of whether birds respond differently regarding their conservation traits in traditional fruit orchards. Another of our aims is to reveal whether the responses of birds as a whole are different from the responses of specialist groups. The last but not least important aim of our study is to reveal the potential impact of different groups of environmental predictors on two different bird traits. We are interested in the extent of the influence of these predictors on bird traits and also to what extent the predictor categories interact, potentially affecting the traits independently and jointly with the other categories.

2. Materials and Methods

2.1. Study Area

The studied area is a central European (Czech Republic) rural agricultural landscape dominated by agricultural land. Nearly 60% of the landscape consisted of arable land and approximately 5% of permanent grasslands. One-fifth of the total area is covered by forests that are dominated by conifer plantations (Scots pine and Norway spruce), with only occasional island-like patches of mixed or deciduous stands (sessile and pedunculate oaks, European beech and hornbeam). Approximately 5% of the total is built-up area, mostly consisting of villages with fewer than 500 inhabitants. Only two towns are present in our study area: Choceň (50.0022 N, 16.2208 E) and Vysoké Mýto (49.9520 N, 16.1626 E). Both towns have less than 15,000 inhabitants.

We sampled a total of 68 sites within agroforestry habitats, these specifically being traditional fruit orchards. The orchards were characterized by regular distances between trees and almost regular tree crowns. The majority of trees were growing on vigorous rootstock and were grafted to the height of an adult man (i.e., approximately 1.8–2 m above the ground) [17]. The total area of traditional fruit orchards did not exceed 1% of the study area, and thus they represented marginal landscape patches.

2.2. Study Taxa, Specialization, and Trait Status

Birds were counted from the center of each traditional fruit orchard. We first waited 5 min after entering until the birds settled down, and then all bird individuals seen and heard (with the exception of birds flying overhead) were recorded for 10-min intervals during each visit. Double counting was minimized by having a second observer keeping track of counted individuals while the first observer counted. The traditional fruit orchards studied were rather small and irregular landscape patches, and thus we optimized our counting for plots covering a maximum of 2500 m^2. In this manner, we avoided the effect of oversampling in large orchards. Counting was carried out from dawn until late morning, only on days with suitable weather conditions. Each orchard was sampled three times during the most appropriate time for the study region, which means spring (April and May) in each of two years (2011 and 2012). That means each site was visited six randomly chosen times. The highest count from the six visits was taken as the resulting abundance of each species on each of the 68 study plots.

Disparate biodiversity indices, such as species richness, abundance, or diversity, are commonly used for evaluating interaction with abiotic gradients. For our analyses, we first divided the observed bird species into farmland and woodland specialists [18]. For a division of species according to rarity and red-list index status (termed "conservation trait status" for purposes of this study), we used a bird atlas popular in the Czech Republic [19]. For rarity, we used the value of unoccupied grid cells in the Czech Republic out of a total of 628 grid cells. For the red-list index, we weighted the species by the ranked values, denoting a constituent species red-list index using IUCN criteria (LC = 1, NT = 2, VU = 3). Hence, the red-list index is a sum of all species observed per number of their individuals and then multiplied by the value of their red-list status, e.g., 1 species with 2 individuals with LC is 2, and 2 species with 1 individual and NT are 4.

2.3. Study Predictors

We considered three categories of predictors (Table 1) potentially influencing the bird species' traits. We use a total of 11 predictors to keep a comparable number of predictors for the three explanatory categories [20–22].

Table 1. Discrimination among predictor categories used in this study and their values (mean, standard error, minimum and maximum) in the 68 studied traditional fruit orchards.

Category	Predictor	Mean	SE	Min	Max
Patch	Canopy openness	78.1	2.2	16.0	100.0
	Shrub coverage	16.4	2.1	0.0	70.0
	Surrounding	2.6	0.1	1.0	4.0
Land use	Rural and urban	3.0	0.3	0.9	11.8
	Forest	19.2	1.5	4.6	51.5
	Grassland	12.5	0.6	3.6	31.1
	Arable	60.0	1.9	27.2	78.5
Topography	Altitude	324.3	4.5	268.8	411.3
	Area	6483.5	755.3	891.0	35,391.0
	Longitude	50.0	0.0	49.9	50.0
	Latitude	16.2	0.0	16.1	16.3

Patch-level predictors (i.e., patch scale) were measured directly inside the surveyed sites and selected with respect to the best reflection of spatial heterogeneity. Shrub coverage (percentages of shrub woody species that are higher than 0.5 m and lower than 2.5 m) was used to represent vertical and horizontal patch heterogeneity. Canopy openness (%) indicated the light conditions of the study patches and was measured using a Canon EF-8-15mm f/4L FishEye USM camera. For each site, photographs were taken on 25 May 2012 (i.e., under full foliage) at four representative locations within each site and at 1.5 m above ground level. All photographs were then evaluated using the software Gap Light Analyzer 2.0. The mean values from all locations were used in the analyses. The number of

surrounding land use types (mentioned below) was used for the analyses because in such marginal patches, it reflected the direct, immediate effect of the surrounding environment, its heterogeneity, and the amount of potential drift fences.

The land use predictors (i.e., landscape scale) were drawn from the present topographic digital base map of the Czech Republic 1:10,000 (ZABAGED) and the Forest Cover Map [23] in GIS. The landscape level was measured for any particular surveyed site within a circle having radius 2263 m (from the center of the site), thereby taking in the surround 1608 ha. This distance was selected because it is known to best reflect the influence of land use types on birds in our study area [7]. The proportion of rural and urban land use type (%) indicated the intensity of settlement and built-up areas in the surroundings of the studied sites. This predictor may influence the distribution of species with high tolerance to anthropogenically disturbed habitat types. The amount of permanent grasslands (%) in the surroundings revealed a dominating agricultural habitat type with a low intensity of management (mowing and/or pasturing) compared to arable land. This land use category also described the understory conditions of traditional fruit orchards, and thus the potential overlap in requirements for some birds (e.g., ground-nesting species). The proportions of forest cover (%) and arable fields (%) in the surroundings reflected the dominant land use types in our study area. Furthermore, forests may partly mimic the overstory conditions of traditional fruit orchards (e.g., for birds nesting and foraging in crowns). As the land cover of forest and arable field land use types showed high collinearity, we used the forest for analyses regarding woodland specialists and the arable fields for farmland birds that prefer agricultural habitats, as well as the interaction of these predictors for analyses of the bird community as a whole.

The role of topography in ecology with respect to use at the optimal space continues to be debated and there is no consensus regarding which spatial scale is optimal for topographical predictors. Recent research has indicated that processes occurring at small spatial scales play important roles even at the large-scale level of an entire country, and vice versa [5]. We chose predictors that are commonly used in biogeography and ecology for describing organismal distribution (i.e., topographical scale). Altitude (m a.s.l.) indicated topographical heterogeneity, and it is mostly correlated with climatic conditions. Area (m^2) of the studied orchard was used to express the amount of potential habitat. Latitude and longitude, as the spatial terms (X and Y) derived from coordinates of the plot centers, were measured directly in the field using a Garmin Colorado 300.

2.4. Statistical Analyses

All statistical analyses were made using SAM v4.0 [24]. We used rarity and the red-list index as dependent variables. Any potential bias caused by collinearity among the studied predictors was controlled using a variance inflation factor (VIF < 2). A linear regression analysis with three predictor sets (patch, land use, and topography) was used. Each set consisted of predictors from the categories in Table 1. The Gaussian distribution of the data was verified [25]. As we were interested in the contributions of particular predictor sets with respect to the studied dependent variable, we analyzed them using partial regression analyses [24]. This type of analysis revealed independent variance explained by particular predictor categories as well as variance explained jointly with other categories, e.g., [26].

3. Results

During the two study seasons, we observed 57 bird species (mean$_{site}$ = 14.7; SE = 0.39; min = 7; max = 21) in 68 studied traditional fruit orchards. Thirty-one species were forest dwellers and 16 were farmland specialists (Table 2).

Table 2. Bird species of traditional fruit orchards in rural agricultural landscape of Pardubice Region, Czech Republic. Preferences, red-list categories, number of unoccupied grids in the Czech Republic (out of a total of 628 grids), number of individuals observed and heard, are indicated for presence at studied plots. VU = vulnerable, NT = near threatened.

Species	Preference	Red-List	Grids	Individuals	Presence
Acrocephalus palustris	General		52	4	4
Aegithalos caudatus	Woodland		37	1	1
Buteo buteo	Woodland		2	1	1
Carduelis cannabina	Farmland		26	4	4
Carduelis carduelis	Farmland		5	18	14
Carduelis chloris	Farmland		0	54	52
Certhia brachydactyla	Woodland		192	3	3
Columba palumbus	Woodland		2	11	10
Coturnix coturnix	Farmland	NT	41	2	2
Cyanistes caeruleus	Woodland		1	93	67
Delichon urbicum	General	NT	1	4	3
Dendrocopos major	Woodland		1	30	30
Emberiza citronella	Farmland		0	65	53
Erithacus rubecula	Woodland		1	26	26
Ficedula albicollis	Woodland	NT	297	1	1
Ficedula hypoleuca	Woodland	NT	287	2	2
Fringilla coelebs	Woodland		0	66	62
Garrulus glandarius	Woodland		3	18	18
Hippolais icterina	Woodland		38	17	17
Hirundo rustica	Farmland		1	45	33
Jynx torquilla	Woodland	VU	196	7	7
Lanius collurio	Farmland	NT	3	16	16
Lanius excubitor	Farmland	VU	186	1	1
Locustella naevia	General		76	2	2
Motacilla alba	General		0	12	12
Motacilla cinerea	General		37	1	1
Muscicapa striata	Woodland		46	2	2
Oriolus oriolus	Woodland		170	1	1
Parus major	Woodland		0	79	68
Passer domesticus	General		4	47	28
Passer montanus	Farmland		36	73	38
Perdix perdix	Farmland	NT	136	1	1
Periparus ater	Woodland		34	1	1
Phoenicurus ochruros	General		1	36	35
Phoenicurus phoenicurus	Woodland		31	4	4
Phylloscopus collybita	Woodland		3	56	53
Phylloscopus trochilus	Woodland		10	4	4
Pica pica	Farmland		24	10	10
Picus viridis	Woodland		40	2	2
Poecile montanus	Woodland		136	1	1
Poecile palustris	Woodland		49	14	14
Prunella modularis	Woodland		15	1	1
Pyrrhula pyrrhula	Woodland		68	1	1
Saxiola rubetra	Farmland		103	1	1
Serinus serinus	General		3	17	17
Sitta europaea	Woodland		1	2	2
Streptopelia decaocto	General		18	10	10
Streptopelia turtur	Farmland		32	2	2
Sturnus vulgaris	Farmland		3	93	44
Sylvia atricapilla	Woodland		1	55	52
Sylvia borin	Woodland		46	7	7
Sylvia communis	Farmland		12	21	20
Sylvia curruca	Farmland		14	26	25
Turdus merula	Woodland		1	70	68
Turdus philomelos	Woodland		1	35	35
Turdus pilaris	General		38	16	10
Turdus viscivorus	Woodland		42	2	2

The relationship of the whole bird community with patch, topography, and land use categories was significant for rarity (whole model: $R^2 = 0.32$; $p < 0.01$) and the red-list index ($R^2 = 0.32$; $p < 0.01$). For the whole bird community, topography played the most important role in the case of both studied traits. The influence of patch and land use was relatively weaker, and their effects were not significant (Figure 1).
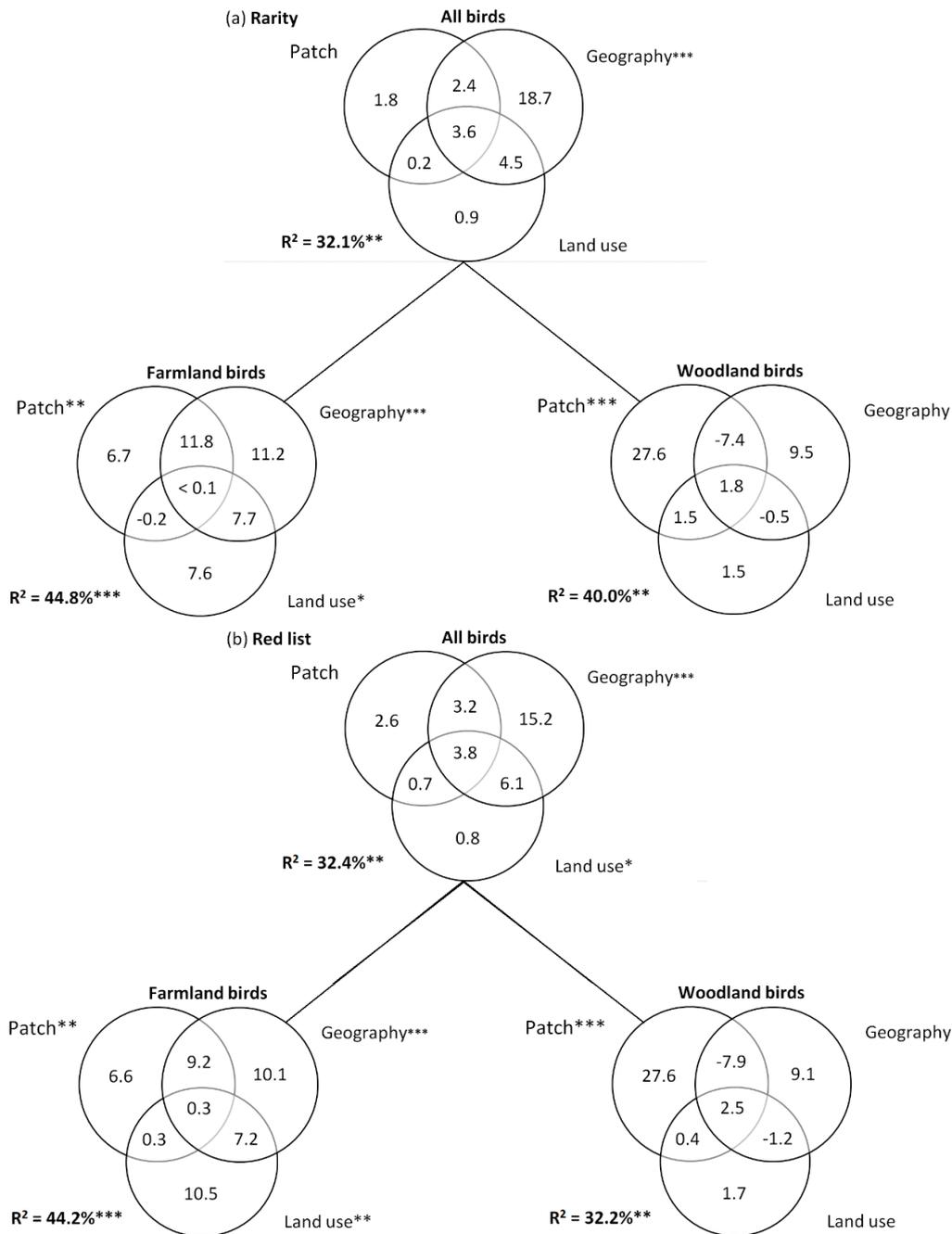
Figure 1. Results of the partial regression analyses for (**a**) rarity and (**b**) the red-list index of all birds, farmland specialists, and woodland specialists for the studied predictor categories representing patch, topography, and land use in traditional fruit orchards. Significance levels are * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Only the net effects (independent R^2) of predictor levels can be tested statistically, while the overlapping sections (shared R^2) cannot be tested. Negative fractions are given by the correlation structure of the predictors, within which direct and indirect positive and negative effects of the individual predictors are combined [27].

A significant relationship was found also for farmland birds regarding rarity ($R^2 = 0.45$; $p < 0.001$) and the red-list index ($R^2 = 0.44$; $p < 0.001$). The traits of farmland birds were significantly influenced by all studied categories. Topography was the most significant, although that influence was at a lower level than determined for the overall bird community. Patch and land use revealed significant and stronger influences than was seen for the overall population of birds. In the case of rarity, the explained variance shared by patch and land use with topography was greater than their independent contributions. This showed that land use and patch categories were interconnected with topography in the case of farmland specialists (Figure 1).

Woodland birds also were found to have significant response for rarity ($R^2 = 0.40$; $p < 0.01$) and the red-list index ($R^2 = 0.32$; $p < 0.01$). Woodland specialists revealed different results than had been found in the previously described analyses. The traits of woodland birds were mostly influenced by the patch configuration of the traditional fruit orchards. In several instances, moreover, this predictor set showed negative values for shared variance explained by land use and topography (Figure 1).

4. Discussion

Several recent studies have indicated that some of the artificial habitat types, such as orchards, military training areas, and post-mining areas, could promote high diversity within bird communities [7,10,11,28]. During our brief analysis based on species numbers, we found that traditional fruit orchards hosted more specialist birds than opportunists. Moreover, woodland specialists occurred more frequently than did farmland specialists, and that coincides with the findings of Bailey et al. [12]. They showed that the number of woodland-preferring species and their abundance were greater than were those of other species. Specialist species were dominant, while bird species with no preference for particular habitats constituted 12.5% of the total population. This indicated that marginal land use types of traditional fruit orchards are suitable for species specialized in the dominant land use types within central Europe, which are forests and agricultural land. Furthermore, they also are occupied by forest and agricultural species, including threatened species like the Eurasian wryneck (*Jynx torquilla*) and common quail (*Coturnix coturnix*).

Farmland birds revealed the most contrasting results among the studied predictor sets. They showed higher values of jointly explained variance between and among sets than did woodland specialists and the bird communities as a whole. There was a very broad overlap between topography and patch level predictor sets, thereby indicating a large influence of interaction between these predictor categories on the traits of farmland birds [29], probably due to them being more sensitive to habitat quality as a result of agriculture intensification and other changes in agricultural landscapes [4,30]. Only slightly weaker effects were observed in the interaction of topography and land use. Although some previous studies have indicated different patterns (e.g., [31]) our results seem to be unexceptional. These results confirmed the coincidence with results from the agricultural–forest mosaic [32].

Nevertheless, low proportions were shared among all predictors for rarity. Weak interaction was observed between patch and land use. In this case, this might indicate good empirical discrimination between the predictors included in our categories (e.g., area in topography rather than patch).

The response of woodland specialists seemed to be the most simple. They were highly influenced by patch-level predictors, which is in agreement with the known fact that woodland birds occupy a very wide range of ecological positions in particular forest patches. Furthermore, bird species are specialized within a habitat type, and the positions occupied by different species are diverse [1,2,18,19]. This is mainly caused by vertical diversification of natural forests as primary habitat types for temperate bird assemblages. Habitat types of traditional orchards are thus most probably able to mimic high patch heterogeneity of forests. The relative proportions of shared components between predictor categories were relatively low, as has been indicated in studies dealing with forest birds (e.g., [33]). Nonsignificant responses to the topography and land use might be cited as exceptional because most studies have shown bird distributions to have a clumping tendency [34,35]. Namely, spatial geographical terms might have a clustering effect on observed birds [33]. The spatial structure in bird data may actually

reflect distributions genuinely caused by a clumping of preferred or avoided habitats [32,35]. In our study, topographical predictors played the most significant role in the case of the whole bird community. This also indicated that topography might play a significant role on the broader extent of spatial scales than has commonly been indicated [5,13]. Furthermore, the effect of land use on birds is often prominent (e.g., [35]).

The results of the partial regression analyses for rarity and red-list index were very similar for all studied bird traits and the studied predictor categories. This is probably due to relatively low numbers of threatened species in the studied bird assemblage (only 8 out of a total 57 detected bird species, i.e., 14% of observed bird species, but only 5.5% of individuals recorded).

Although the number of threatened species is relatively low, yet this shows the high importance of old fruit orchards as a refugium of threatened species in the intensively used and changed agricultural landscape. It may mean that the conservation and suitable management of this habitat could help mitigate the decline of farmland bird specialists [4,30] as well as to endangered woodland species.

5. Conclusions

We have presented here results that will contribute to disentangling the roles of topography, patch, and land use on conservation trait status of specialist birds in marginal and structurally diversified habitat types. We found that the diversified habitat of traditional fruit orchards is able to promote a relatively large number of specialist species and we also reveal ecologically important relationships between conservation trait status and different predictor sets.

Researchers in the future should pay more attention to the possible influence of interactions among and between predictors, and especially their categories. Furthermore, conservationists should be more attentive to the biodiversity value and sustainable management of traditional fruit orchards. The scale on which studied processes influence organisms, as well as the extent to which they are interconnected, is also of great importance because some predictors (e.g., topographical) might play a significant role within the broader extent of spatial scales than is commonly indicated. Nevertheless, our results should be interpreted with some caution because we were mainly interested in the influence of pooled environmental factors and we did not analyze trends of individual abiotic factors.

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