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Ecology and "bird-habitat" relationship in the cedar forest of Aurès mountain (Eastern Algeria)

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Abstract This work aims to compile the birds breeding in the cedar forest of Aurès and to study the "Bird – Habitat" relationships. The data was collected using the progressive frequency sampling method that served as the basis for the diagnosis build on an analytical approach designed around three tools (mutual information, ecological profiles, modelling). Information theory tools allowed us to identify the indicator values of species as well as the most important descriptors. Habitat modelling has been prepared for species with a high indicator value. The logistic models are shown to be well adapted to the nature of the ornithological data. They related the occurrences of the species with the dendro-ecological descriptors. The 70 surveys carried out enabled us to identify 32 bird species. The ecological analysis revealed the most active descriptors and the species with high indicator value. The best-fitting models are those of Short-toed Treecreeper with positive effect of dead wood, density of trees and variability of distances between trees, and European Robin with negative effect of anthropization and general coverage, and positive effect of crown parametres. We conclude that promoting forest structural complexity by diversifying management regimes will be key to maintain avian biodiversity in cedar forests.

Keywords: bird, endemic forest, ecological profiles, modelling, logistic regression

Összefoglalás A cédrus erdők Algéria és Marokkó hegységein előforduló nagyon változatos, őshonos ökoszisztémák. A szerzők az aurès-i cédruserdőben költő madárfajok „madár – élőhely" kapcsolatait vizsgálták. Az adatokat progresszív frekvenciás mintavételi módszerrel gyűjtötték, az elemzéshez három megközelítést használtak: ezek a kölcsönös információ, az ökológiai profilok és a modellezés. Az információelméleti eszközök lehetővé tették a fajok indikátorértékeinek, valamint a legfontosabb erdőállomány-szerkezeti háttérváltozóinak azonosítását. Az élőhely-modellezést magas indikátorértékű fajok esetében végezték. A logisztikus modellek jól illeszkednek az ismert ornitológiai adatokhoz. A magas indikátorértékű fajok előfordulását erdőállomány-szerkezeti változókkal hozták összefüggésbe. Az elvégzett 70 felmérés 32 madárfaj azonosítását tette lehetővé. Az ökológiai elemzés feltárta a magas indikátorértékű fajokat és a legjobb magyarázó értékkel rendelkező háttérváltozókat. A vizsgált faj-élőhely modellek közül a legjobban a rövidkarmú fakusz és a vörösbegy modellje illeszkedett. A kapott eredmények a cédruserdők természetvédelmi kezeléséhez is hozzájárulhatnak.

Kulcsszavak: madár, őshonos erdő, ökológiai profilok, modellezés, logisztikus regresszió

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Introduction

The diversity of the fauna represents an important dimension of global biodiversity through contributing to the proper functioning of ecosystems and by enhancing their resistance (Franklin *et al.* 2002). The importance of its maintenance stems from our efforts invested in the identification of essential species for the continued functioning of ecosystems (Burton *et al.* 1992). At the current state, knowing and understanding the long-term capacity of Mediterranean forests in maintaining their multifunctionality through their different roles, in particular as a refuge for biodiversity, are of major concerns in the ecology of forest conservation (Rykowski 2002).

The Atlas cedar *(Cedrus atlantica)*, an endemic species in North Africa, offers through the various formations that constitute, favourable habitats for a diversified flora and fauna. However, in Algeria, until recently, there has been no work concerned to study the cedar groves as a reservoir of faunistic biodiversity, neither in general nor from the perspective of ornithological biodiversity in particular, even less regarding the species-habitat relationships.

Biodiversity is almost impossible to measure exhaustively, so it is generally accepted to employ its state indicators. However, there is not yet a comprehensive forest biodiversity monitoring system. In parallel with data from forest inventories (height of trees, diameter, basal area, volume of wood, density, etc.), researchers are nevertheless gradually adding data on the abundance of particular species or groups of species, in particular vascular plants, bryophytes, lichens, saproxylic fungi, birds, carabids, etc. Biodiversity monitoring is therefore most often based on data from national forest inventories to organize reporting on forest biodiversity (Burley 2002, Nivet *et al.* 2012).

These biological indicators must satisfactorily reflect the entity they target for analysis, i.e. a taxonomic group, an ecological guild, or even an ecosystem as a whole, which includes the relationships between the different taxa that compose it (Levrel 2007). Moreover, the choice of these bioindicators is also largely subordinated to other considerations, such as the cost of monitoring, the amount of data already available and the technical capacity to monitor taxonomic groups (Dale & Beyeler 2001, Nivet *et al.* 2012).

The "birds" model is justified by the fact that they are the most approved class in bioindication (Bonardi *et al.* 2010). Their ecological characteristics and their sensitivity to habitat modifications (Blondel 1975) make these species good biological indicators (Bibby *et al.* 1992, Drapeau *et al.* 2001).

A multitude of techniques is available to model the distribution of species. They vary in principle by the type of response expected, the adjustment of the model, the weighting of observations, the integration of interactions and the type of prediction (Elith *et al.* 2006). Nevertheless, despite the performance of certain methods, none is effective in all situations (Marini *et al.* 2012).

Logistic regression is a recommended statistical tool for analyzing binary data, such as the presence and absence of avian species. The logistic model belongs to the family of generalized linear models and relates, by a linear combination, the environmental variables to the variable to be predicted by means of a logistic link function (McCullagh & Nelder 1989, Guisan & Zimmermann 2000). Logistic regressions have been used to model the probability of occurrence of many species (Tobalske & Tobalske 1999, Zimmermann & Kienast 1999, Villard & Guénette 2005). Therefore, we applied this approach to our data.

Each bird species may be characterized by a general habitat type, however many species use different features of a forest, requiring a various set of behaviour. For this purpose, we propose to study the population of birds breeding in Algerian cedar forest by analysing their interactions with the environment through a combination of methods inspired by information theory and autecological modelling. This will provide managers with appropriate models for the management and the conservation of the species and the natural environments as well as the development and implementation of protection strategies for these endemic habitats.

Material and Method

Study sites

The Aurès cedar forest, located in Eastern Algeria, is directly influenced by the Sahara. It presents the only cedar stations in North Africa with a semi-arid bioclimate on their southern border. On the northern slopes, the subhumid bioclimate dominates (Abdessemed 1981).

Figure 1. Aurès cedar forest
1. ábra Az Aurès cédrus erdő

Annual rainfall varies between 700 and 1,000 mm depending on altitude and exposure. The maximum is recorded during spring (119 mm). Summer is the least rainy season (73 mm), the rains of which are mostly stormy. The average annual temperature is 12 °C. The lowest average temperature is recorded in January (2.3 °C) and the highest average temperature is recorded in July (22.7 °C).

Attached to the Mauritanian steppe domain, sector of southern Constantine (Yahi *et al.* 2008), it represents a specific vegetation *(Figure 1)* on limestone, dominated by old stands, which develop in a pure or mixed state. The area of the Aurès cedar forests estimated at 17,000 ha is decreasing due to massive tree mortality. The drying out is intense especially in the southern areas subject to Saharan influences, in clumps or entire bands that can reach up to 95% (Kherchouche *et al.* 2012).

Bird survey

The semi-quantitative progressive frequency sampling method was adopted for the bird count. This method can help to make an ecological diagnosis at different levels of precision fixed in advance and which depends on the research objective, the available time for the observer, the spatial extension of the territory to be studied and the ecological characteristics of the area (Blondel 1975).

It is a method of recording in presence-absence which consists in counting the birds observed or heard during a period of 15 to 20 minutes from a fixed point within a fictitious circle of radius fixed or unlimited centred on the observer (Blondel *et al.* 1970, Hutto *et*

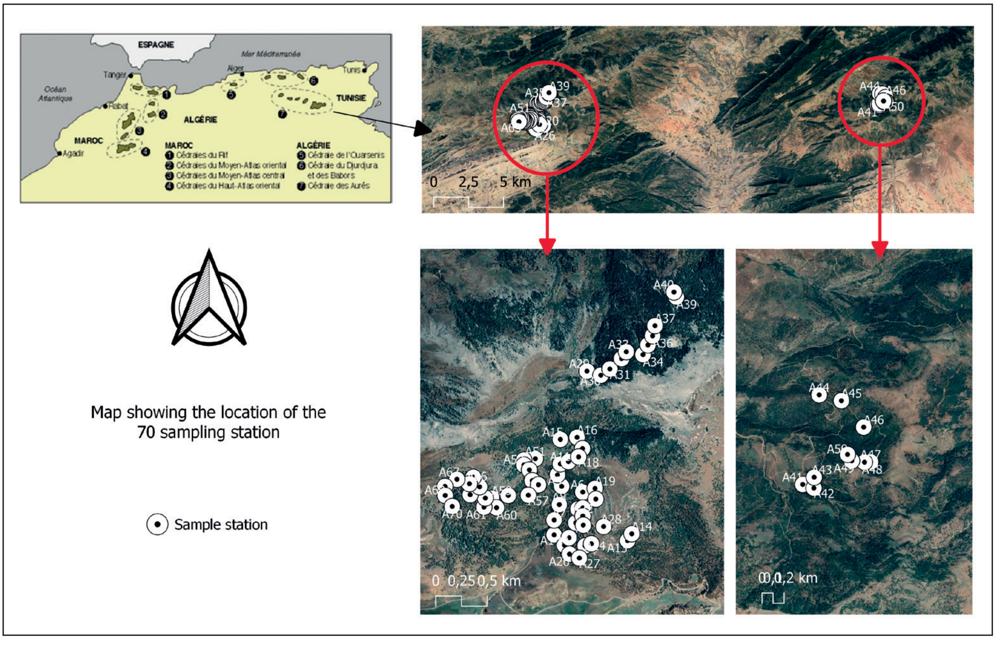

Figure 2. Map showing the location of the 70-sampling station
2. ábra A 70 mintavételi helyszín térképe

Table 1. List of measured and calculated descriptors with indication of their abbreviations
1. táblázat A leíró változók listája, azok rövidítéseivel

Descriptor category	Code	Descriptors	Details
Ecological descriptors 7	ESANT	Trees health status	Visual detection of signs of disease (defoliation, discoloration, parasitic attacks, etc.)
	ANTH	Degree of anthropization	Indications of any actual and/or potential anthropogenic disturbance coded according to their intensity: "0" no disturbance; "1" weak disturbance; "2" medium disturbance; "3" high disturbance.
	EAU	Presence of watercourses	Water bodies, wadi, stream, small ponds, areas of water stagnation. "0" absence, "1" presence.
	ROCH	Presence of rocks	"0" absence, "1" presence.
	CAVT	Presence of cavities on trees	Cavity, cracks, hollow. "0" absence, "1" presence.
	MOSSL	Presence of moss and lichen	"0" absence, "1" presence.
	BMORT	Presence of dead wood	The ratio of dead trees (standing or on the ground) to the total number of trees per station.
Overall vegetation structure 6	RECGRL	General plot cover	Standardized stratification of the vegetation with visual estimation of the leaf index of each stratum (tree, shrub, herbaceous). The general recovery is also estimated. The visual estimation of vegetation cover rates being subjective, it required the use of a cover chart.
	RECARBR	Coverage of the tree layer	
	RECARBU	Shrub layer cover	
	RECHERB	Covering of the herbaceous layer	
	REGEN	Regeneration rate	Percentage of cedar regeneration per station.
	FEUIL	Deciduous trees rate	Number of deciduous trees calculated on the total number of trees per plot.
Vertical stand structure 7	HTARBMoy	Average trees height	All measured trees and averaged data per plot (measurement unit: m).
	HTFUTMoy	Average trunk height	
	HTHOPMoy	Average crown height	
	VOHOPTot	Total crown volume	All measured trees crown and sum data per plot (measurement unit: m^3).
	VOHOPMoy	Average crown volume	All measured trees crown and averaged data per plot (measurement unit: m^3).
	VTot	Total wood volume	All measured trees volume and sum data per plot (measurement unit: m^3). The wood volume per tree is calculated as follows: $V = g * H_{trunk}$ with g = basal area of the tree, H_{trunk} = trunk height.
	VMoy	Average wood volume	All measured trees volume and average data per plot (measurement unit: m^3).
Spatial stand structure 7	DENSARB	Trees density	Number of trees per hectare (trees/ha), calculated by the formula: DENSARB= (N*10000)/s With: N = number of trees counted in the plot, s = area of the plot (in m^2).
	DISARBMoy	Average distance between trees	/
	DIMARBMoy	Average shaft diameter at breast height	/
	SUHOPTot	Total crown area	All measured trees crown area and sum data per plot (measurement unit: m^2/plot). The crown area of a tree (Su_{hop}) is calculated as follows: $Su_{hop} = [\pi * (D_{hop})^2]/4$. With D_{hop} = average diameter of the crown of the tree.
	SUHOPMoy	Average crown area	All measured trees crown area and average data per plot (measurement unit: m^2/trees).
	GTot	Total wood basal area	Sum of the cross-sections at 1.30 m height from the ground, of all the trees inventoried in the plot (measurement unit: m^2/plot). The basal area (g) of a tree is calculated as follows: $g=(\pi/4)*DIMARB^2$ With DIMARB= shaft diameter at breast height.
	GMoy	Average wood basal area	Average of the cross-sections at 1.30 m height from the ground, of all the trees inventoried in the plot (measurement unit: m^2/trees).

Descriptor category	Code	Descriptors	Details
Stand structural variability descriptors 18	DISARBEty	Standard deviation of the mean distance between trees	/
	DISARBCV	Coefficient of variation of the average distance between trees	/
	DIMARBEty	Standard deviation of average diameter per tree	/
	DIMARBCV	Coefficient of variation of average diameter per tree	/
	HTARBEty	Standard deviation of the average height of the trees	/
	HTARBCV	Coefficient of variation of average tree height	/
	HTFUTEty	Standard Deviation of Average Barrel Height	/
	HTFUTCV	Coefficient of variation of average trunk height	/
	HTHOPEty	Standard deviation of average crown height	/
	HTHOPCV	Coefficient of variation of average crown height	/
	SUHOPEty	Standard deviation of the average crown area	/
	SUHOPCV	Coefficient of variation of the average crown area	/
	VOHOPEty	Mean Crown Volume Standard Deviation	/
	VOHOPCV	Coefficient of variation of average crown volume	/
	GEty	Standard deviation of the average basal area of wood	/
	GCV	Coefficient of variation of mean basal area of wood	/
	VEty	Standard Deviation of Mean Wood Volume	/
	VCV	Coefficient of variation of average wood volume	/

al. 1986). In our case, the birds were counted using the fixed circular plot technique with a radius of 150 m for a period of 15 min. Thus, 70 count stations *(Figure 2)* were carried out during the breeding period (April – June). 5 to 8 counting points/day are carried out during the peak of daily activity which corresponds, for diurnal birds, to the first hours after sunrise (from 6 a.m. to 10 a.m.). Each station was sampled only once (one count/station). All birds heard and/or seen were noted.

Eco-dendrometric variables

The study of bird-habitat relationships involves the search for habitat characteristics that are closely related to variations in the abundance and distribution of species. These characteristics should be measured at the same stations and time of taking the bird survey (Bradbury *et al.* 2005).

All the stations of bird surveys were accompanied by an eco-dendrometric description of the habitat. For sampling of habitat characteristics, the circular plot of 20 m radius is used. It is considered fairly representative for the description of bird habitats (Young & Hutto 2002). Inside the plot, all the trees were measured. We were interested in the general environmental conditions of the station, the overall structure of the vegetation, the vertical and spatial structures of cedar stands and the description of their structural variability *(Table 1)*. The eco-dendrometric measurements concerned 2,501 trees including 2,471 cedars.

Data analysis

Before starting the analytical approach, we calculated the specific richness (total number of species contacted at least once), the heritage richness taking into account the protection status of the birds identified by referring to the national legislative texts of Algeria, to the IUCN Red List and the Bern Convention.

We calculated the taxonomic diversity (number of species per family) (Jastrzębska *et al.* 2011). Also, birds were assigned to functional groups based on their diet (insectivorous, granivorous, omnivorous). Similar groupings have been used for the functional classification of birds (De Souza *et al.* 2013, Prajapati & Prajapati 2013).

The analytical approach adopted focused on the principles and tools of the theory of information, initially developed in phyto-ecology by Guillerm (1971), Daget *et al.* (1972), Godron (1968, 1975), and Daget and Godron (1978). This enables the analysis of the distributions of species by using the concepts below.

The profiles of the relative frequencies "F_R" correspond to the profile of the centesimal frequencies used in ornithology. It represents the number of the species present in each class by a factor "L" divided by the number of records made in each class, multiplied by 100.

$$F_R = \frac{FA}{N} * 100$$

FA: Number of individuals or absolute frequency, N: Number of avian surveys.

The distribution of species in different classes of ecological factors corresponds to a set of probabilities of their presence when the number of records becomes sufficiently large (Godron 1968). These probabilities allow us to estimate numerous information: entropy, the quality of the sampling, mutual information, and the most active variables (the most important variables influencing species distribution) (Mangara *et al.* 2010).

Species entropy H(E) is a measurement of the ability of a species to respond to a variable. It grants the possibility of measuring the potential information that each species can relatively provide to a variable (Blondel *et al.* 1978). The species entropy is calculated by the following formula (Guillerm 1971):

$$H(E) = \frac{\sum_I^{NK} U(K)}{NR} log_2 \frac{NR}{\sum_I^{NK} U(K)} + \frac{\sum_I^{NK} V(K)}{NR} log_2 \frac{NR}{\sum_I^{NK} V(K)}$$

NK: number of distinguished classes for the factor L, U(K): number of records in class K within the presence of species E, V(K): number of records in class K where species E is absent, NR: total number of readings.

Entropy factor H(L) determines the quality of sampling and is used in the determination of the most active ecological variables (Guillerm 1971, Daget *et al.* 1972). The overall profile for a factor L, presents a NK number of classes (1, 2, … NK). It is calculated as follows:

$$H(L) = \sum_{I}^{NK} \frac{R(K)}{NR} log_2 \frac{NR}{R(K)}$$

R(K): number of records carried out in class K, NR: total number of records.

The maximum entropy factor, which corresponds to the best sampling is (Guillerm 1971):

$$H(L)max = \sum_{I}^{NK} \frac{1}{NK} log_2 NK = \frac{NK}{NK} log_2 NK = log_2 NK$$

The sampling quality for the factor considered can be assessed by comparing the maximum entropy linked to the factor with that resulting from the sampling data (Touaylia *et al.* 2011). It is given by the report:

$$Q = H(L)/H(L)_{max}$$

Q is the value reflecting the quality of the sampling.

Mutual species-factor information detects the most active factors in the distribution of species and highlights the amount of information provided by the distributions of frequency of each species for the considered descriptor (Blondel *et al.* 1978). It also enables the classification of species according to their sensitivity to the factor considered (Legendre & Legendre 1984). For each factor studied, mutual information is established for all the species encountered in the surveys. Thus, for a species E and a factor L, the mutual information is denoted by H(L, E) and is defined as follows (Daget *et al.* 1972):

$$H(L,E) = \sum_{I}^{NK} \frac{U(K)}{NR} log_2 \frac{\frac{U(K)}{R(K)} * NR}{U(E)} + \sum_{I}^{NK} \frac{V(K)}{NR} log_2 \frac{\frac{V(K)}{R(K)} * NR}{V(E)}$$

NK: number of distinguished classes for the factor L, U(K): number of records of class K in which species E is present, V(K): number of records of class K in which species E is absent, R(K): number of records in class K, U(E): total number of records in which species E is present, V(E): total number of records in which species E is absent, NR: total number of readings.

Global species indicator value: To detect the index value of each species in relation to all the factors, we calculated the average mutual information $H(L, E)_{moy:}$

$$H(L,E)moy = \frac{H(L1,E) + H(L2,E) + \cdots H(LN,E)}{N}$$

E: species, L1, L2, ….: factors, N: number of factors.

The modelling of bird-habitat interactions was addressed according to an autecological approach. We have selected the species which have a high indicator value and whose frequency is greater than 20% to minimize the biases caused by the detectability of the species (Williams 2003).

The 45 potentially effective descriptors included in the regression models were chosen based on the extensive research on the ecological requirements of forest birds. These descriptors underwent a triple selection to highlight their discriminatory power.

Initially, two groups of descriptors were retained during the ecological analysis: those whose mutual information demonstrated relevance and those which were shown to discriminate (Kruskal-Wallis, α <0.05) during the analysis of ecological profiles. Subsequently, through simple regressions, the descriptors were tested individually by logistic regression to identify all the variables statistically linked to the dependent variables. The candidate variables are those whose p-value is less than or equals 0.1. Following these steps, we have retained the descriptors that we deemed relevant by reintegrating some forced descriptors. To overcome the collinearity problem, we have performed a Spearman correlation test for all the selected descriptors. We consider that the two descriptors are strongly correlated when the correlation coefficient is ≥0.8.

The regression procedure adopted is the so-called "top-down stepwise" method to maximize the explanation of the dependent variable with the lowest number of independent variables.

All the processing was carried out using IBM SPSS version 19.0 (IBM Corp. Released 2010) and XLSTAT-Pro 7.5 (Addinsoft 2004).

Results

A total of 24 breeding birds species have been identified in Aurès cedar forest with an average richness of 8.03 species per station. Sixteen species are sedentary and eight are migratory. Additionally, 8 species were contacted outside the stations (auditory or visual contacts made beyond 150 metres). The overall 32 bird species are divided into 27 genera and 16 families. The Muscicapidae dominates with 19%, followed by the Accipitridae with 13%.

Fourteen species are protected by executive decree at national level (No. 12-235 of May 24, 2012, setting the list of non-domestic animal species protected in Algeria), 29 are protected under the Bern Convention. All the species listed are considered to be of a least concern according to the IUCN Red List *(Table 2)*. The most common species are the Coal

Table 2. List of bird species recorded in the Aurès cedar forest
2. táblázat A megfigyelt fafajok listája az Aurès cédrus erdőben

Family	Common Name	Scientific Name	Phenological Status (1)	Protection Status (2)
Accipitridae	Golden Eagle*	*Hieraaetus pennatus*	ME	A, LC, B2
	Red Kite*	*Milvus milvus*	S	A, LC, B2
	Bonelli's Eagle*	*Aquila fasciata*	S	A, LC, B2
	Black Kite*	*Milvus migrans*	ME	A, LC, B2
Certhiidae	Short-toed Treecreeper	*Certhia brachydactyla*	S	LC, B2
Columbidae	Stock Dove	*Columba oenas*	ME	A, LC
	Common Wood Pigeon	*Columba palumbus*	S	LC
	European Turtle Dove	*Streptopelia turtur*	ME	LC, B3
Corvidae	Northern Raven*	*Corvus corax*	S	LC, B3
Emberizidae	Rock Bunting	*Emberiza cia*	S	LC, B2
Falconidae	Common Kestrel *	*Falco tinnunculus*	S	A, LC, B2
	Peregrine Falcon *	*Falco peregrinus*	S	A, LC, B2
Fringillidae	Common Chaffinch	*Fringilla coelebs*	S	LC, B3
	European Serin	*Serinus serinus*	S	A, LC, B2
	European Greenfinch	*Chloris chloris*	S	LC, B2
Muscicapidae	Spotted Flycatcher	*Muscicapa striata*	ME	LC, B2
	Europian Pied Flycatcher	*Ficedula hypoleuca*	ME	LC, B2
	European Robin	*Erithacus rubecula*	S	LC, B2
	Common Redstart	*Phoenicurus phoenicurus*	ME	A, LC, B2
	Moussier's Redstart	*Phoenicurus moussieri*	S	A, LC, B3
	Northern Wheatear	*Oenanthe oenanthe*	ME	LC, B2
Paridae	African Blue Tit	*Cyanistes teneriffae*	S	LC, B2
	Great Tit	*Parus major*	S	LC, B2
	Coal Tit	*Periparus ater*	S	LC, B2
Phylloscopidae	Western Bonelli's Warbler	*Phylloscopus bonelli*	ME	LC, B2
Picidae	Levaillant's Woodpecker	*Picus vaillantii*	S	A, LC
Régulidae	Common Firecrest	*Regulus ignicapilla*	S	A, LC, B2
Strigidae	Tawny Owl *	*Strix aluco*	S	A, LC, B2
Troglodytidae	Winter Wren	*Troglodytes troglodytes*	S	LC, B2
Turdidae	Mistle Thrush	*Turdus viscivorus*	S	LC, B3
	Common Blackbird	*Turdus merula*	S	LC, B3
Upupidae	Eurasian Hoopoe	*Upupa epops*	S	A, LC, B2

(1) Phenological status. S: sedentary, ME: summer migrant
(2) Protective status. A: Algerian law, LC: Least Concern on the IUCN red list, B: Bern Convention and its annexes 1, 2 and 3.
* Species contacted off-station

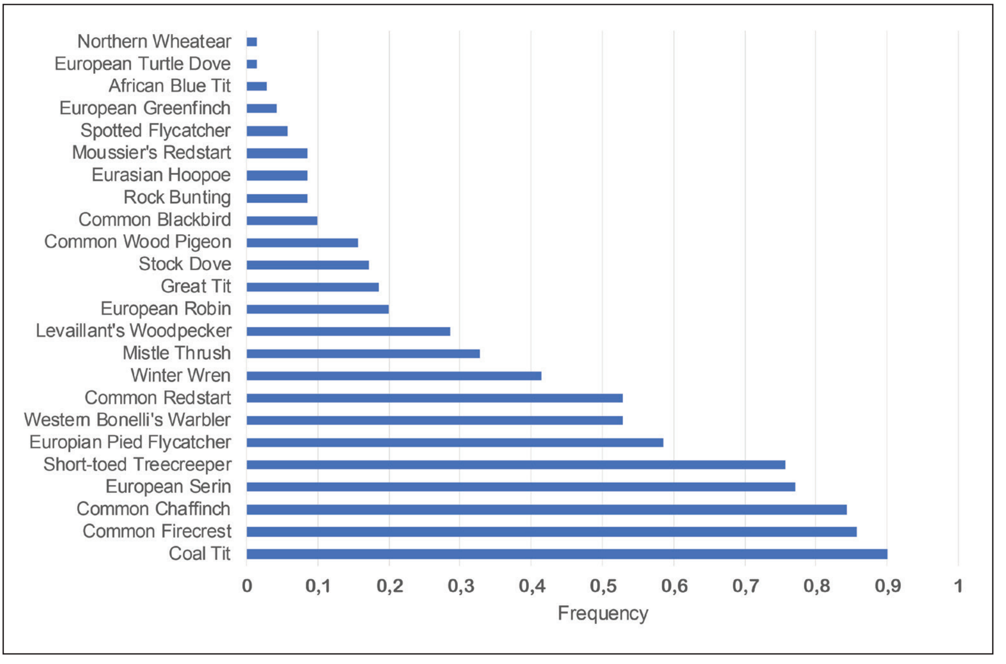

Figure 3. Frequency of bird species in the Aurès cedar forest
3. ábra Madárfajok gyakoriságai az Aurès cédrus erdőben

Tit *(Periparus ater)*, the Common Firecrest *(Regulus ignicapilla)*, the Common Chaffinch *(Fringilla coelebs)*, the European Serin *(Serinus serinus)* and the Short-toed Treecreeper *(Certhia brachydactyla)* (Frequency > 75%). African Blue Tit *(Cyanistes teneriffae)*, European Turtle Dove *(Streptopelia turtur)* and Northern Wheatear *(Oenanthe oenanthe)* are the less frequent (Frequency < 30%) *(Figure 3)*.

Table 4 represents the values of the factor entropy, the maximum factor entropy and the quality of the sampling for all the descriptors selected. Given their respective class number, all the descriptors were well sampled (Q > 0.9).

The species able to respond to variations of the eco-dendrometric descriptors are those with high entropies. These are the ones present in almost 50% of the surveys and for which the indeterminacy in terms of presence/absence is high. Fourteen species show high entropy (> 0.5) *(Table 3)*.

To determine the active eco-dendrometric descriptors in bird species distribution, taken all together, we have calculated the average of the mutual information of each descriptor in relation to its entropy. The most active descriptors are the total crown volume, the total basal area and the average distance between trees (highest average of mutual information) *(Figure 4)*.

The analysis of the bird species selected according to their average mutual information towards all the descriptors informs about the indicator value of each species. Those that have important indicator values in our case are the Stock Dove, the European Robin, the Common Firecrest and the Short-toed Treecreeper *(Figure 5)*.

Table 3. Bird species entropies
3. táblázat Madárfaj entrópiák

Scientific Name	Common Name	FO	Entropy
Emberiza cia	Rock Bunting	0.09	0.422
Muscicapa striata	Spotted flycatcher	0.06	0.316
Ficedula hypoleuca	Europian Pied Flycatcher	0.59	**0.979**
Certhia brachydactyla	Short-toed Treecreeper	0.76*	**0.800**
Turdus viscivorus	Mistle Thrush	0.33	**0.913**
Upupa epops	Eurasian Hoopoe	0.09	0.422
Turdus merula	Common Blackbird	0.10	0.469
Cyanistes teneriffae	African Blue Tit	0.03	0.187
Parus major	Great Tit	0.19	**0.692**
Periparus ater	Coal Tit	0.90	0.469
Picus vaillantii	Levaillant's Woodpecker	0.29	**0.863**
Columba oenas	Stock Dove	0.16	**0.627**
Columba palumbus	Common Wood Pigeon	0.84	**0.627**
Fringilla coelebs	Common Chaffinch	0.53	**0.998**
Phylloscopus bonelli	Western Bonelli's Warbler	0.86*	**0.592**
Regulus ignicapilla	Common Firecrest	0.20*	**0.722**
Erithacus rubecula	European Robin	0.53	**0.998**
Phoenicurus phoenicurus	Common Redstart	0.09	0.422
Phoenicurus moussieri	Moussier's Redstart	0.77	**0.776**
Serinus serinus	European Serin	0.01	0.108
Streptopelia turtur	European Turtle Dove	0.41	**0.979**
Oenanthe oenanthe	Northern Wheatear	0.17	**0.661**
Troglodytes troglodytes	Winter Wren	0.01	0.108
Chloris chloris	European Greenfinch	0.04	0.255

(*) Species selected for ecological profiles and regression. In bold, species with entropy greater than 0.5

To analyse the ecology of bird species through ecological profiles, we treated species with a high indicator value and a frequency greater than 20%, simultaneously. The descriptors retained for each species are those for which the nonparametric test of Kruskal and Wallis is significant ($\alpha = 0.05$).

The descriptors selected for Short-toed Treeceeper are average tree height, average crown surface, total wood basal area and total wood volume. Those selected for Common Firecrest are tree density, total crown surface, total crown volume and total wood volume. For European Robin, the descriptors retained are anthropization degree, shrub cover, the average distance between trees and average wood basal area.

Short-toed Treecreeper showed a marked preference for the upper classes of the various descriptors used. Common Firecrest showed no tendency for wood volume while the middle

Table 4. Logistics regressions models for species with frequencies above 20%
4. táblázat A 20%-nál gyakoribb fajok logisztikus regressziói

		A	E.S.	Wald	ddl	Sig.	Exp(B)	Exp(B) 95% CI		Nagelkerke 's R^2
								Lower	Upper	
Short-toed Treecreeper	BMORT	21.815	10.18	4.589	1	**.032***	2.980E	6.402	1.39E+18	0.78
	DENSARB	0.038	0.016	5.526	1	**.019***	1.039	1.006	1.072	
	DISARBCV	28.985	12.17	5.67	1	**.017***	3.872E	168.52	8.90E+22	
	DIMARBCV	-29.22	12.08	5.851	1	**.016***	0	0	0.004	
	HTARBCV	-24.85	11.36	4.782	1	**.029***	0	0	0.076	
	SUHOPTot	-0.024	0.012	4.395	1	**.036***	0.976	0.954	0.998	
	SUHOPEty	1.591	0.652	5.964	1	**.015***	4.911	1.369	17.611	
	Constante	-13.93	5.354	6.774	1	0.009	0			
European Robin	ANTH	-2.946	1.186	6.173	1	**.013***	0.053	0.005	0.537	0.681
	RECGRL	-42.33	19.45	4.735	1	**.030***	0	0	0.015	
	RECARBR	21.628	11.66	3.444	1	0.063	2.47E+09	0.297	2.06E+19	
	FEUIL	14.533	7.499	3.755	1	0.053	2049256	0.847	4.96E+12	
	BMORT	9.311	4.87	3.655	1	0.056	11056.3	0.791	1.55E+08	
	HTARBCV	-9.66	5.414	3.184	1	0.074	0	0	2.588	
	HTHOPMoy	0.621	0.28	4.913	1	**.027***	1.861	1.075	3.224	
	SUHOPCV	5.936	2.102	7.974	1	**.005****	378.257	6.146	23280.1	
	Constante	13.782	9.161	2.263	1	0.132	967314			
Coal Tit	RECARBU	-14.02	6.388	4.813	1	**.028***	0	0	0.224	0.481
	DENSARB	-0.011	0.005	4.503	1	**.034***	0.989	0.979	0.999	
	DIMARBEty	-16.79	8.427	3.968	1	**.046***	0	0	0.764	
	HTARBMoy	0.545	0.257	4.512	1	**.034***	1.725	1.043	2.854	
	HTFUTEty	-0.45	0.333	1.823	1	0.177	0.638	0.332	1.225	
	HTFUTCV	2.232	1.81	1.521	1	0.218	9.314	0.268	323.224	
	Constante	2.443	3.043	0.645	1	0.422	11.51			
Common Chaffinch	REGEN	-7.084	2.592	7.471	1	**.006****	0.001	0	0.135	0.451
	HTHOPMoy	-0.419	0.182	5.285	1	**.022***	0.657	0.46	0.94	
	SUHOPEty	-0.208	0.08	6.733	1	**.009****	0.812	0.694	0.95	
	Constante	10.369	3.047	11.58	1	0.001	31843.6			
Western Bonelli's Warbler	RECGRL	15.537	6.509	5.697	1	**.017***	55923.7	16.099	1.94E+12	0.446
	RECHERB	-6.148	2.304	7.121	1	**.008****	0.002	0	0.195	
	BMORT	-6.206	3.234	3.682	1	0.055	0.002	0	1.142	
	DENSARB	-0.02	0.006	10.63	1	**.001*****	0.98	0.969	0.992	
	HTARBEty	0.539	0.216	6.245	1	**.012***	1.714	1.123	2.615	
	HTHOPMoy	0.235	0.125	3.522	1	0.061	1.265	0.99	1.617	
	Constante	-6.148	4.987	1.519	1	0.218	0.002			

		A	E.S.	Wald	ddl	Sig.	Exp(B)	Exp(B) 95% CI		Nagelkerke 's R^2
								Lower	Upper	
European Pied Flycatcher	RECGRL	6.219	5.286	1.384	1	0.239	502.434	0.016	15873647	0.338
	RECHERB	3.038	1.657	3.361	1	0.067	20.856	0.811	536.605	
	FEUIL	-12.74	8.936	2.032	1	0.154	0	0	118.647	
	BMORT	-7.429	3.31	5.039	1	**.025***	0.001	0	0.39	
	DENSARB	-0.012	0.005	5.814	1	**.016***	0.988	0.979	0.998	
	DIMARBEty	-8.670	4.246	4.169	1	**.041***	0	0	0.707	
	HTARBMoy	0.081	0.079	1.064	1	0.302	1.085	0.929	1.266	
	Constante	-1.248	4.637	0.072	1	0.788	0.287			
Common Firecrest	DIMARBEty	-14.94	7.501	3.967	1	**.046***	0	0	0.788	0.321
	DIMARBCV	3.923	2.744	2.044	1	0.153	50.547	0.233	10949.4	
	VOHOPTot	0.001	0.001	3.681	1	0.055	1.001	1	1.002	
	VTot	0.027	0.015	3.144	1	0.076	1.027	0.997	1.058	
	Constante	-0.451	1.241	0.132	1	0.716	0.637			
Common Redstart	ANTH	0.683	0.393	3.019	1	0.082	1.981	0.916	4.282	0.296
	RECHERB	2.914	1.439	4.097	1	**.043***	18.425	1.097	309.523	
	DIMARBCV	-2.421	1.417	2.921	1	0.087	0.089	0.006	1.427	
	VOHOPTot	0.001	0	5.06	1	**.024***	1.001	1	1.001	
	Constante	-3.326	1.494	4.959	1	0.026	0.036			
Winter Wren	DISARBEty	-0.612	0.24	6.505	1	**.011***	0.542	0.339	0.868	0.238
	VOHOPTot	0.001	0	5.643	1	**.018***	1.001	1	1.001	
	Constante	0.14	0.892	0.025	1	0.875	1.151			
Mistle Thrush	ESANT	2.215	0.864	6.572	1	**.010****	9.161	1.685	49.823	0.209
	RECGRL	-8.027	4.709	2.906	1	0.088	0	0	3.327	
	DISARBCV	-3.072	1.7	3.264	1	0.071	0.046	0.002	1.298	
	Constante	7.805	4.25	3.373	1	0.066	2452.86			
European Serin	MOSSL	-1.73	0.965	3.231	1	0.072	0.176	0.027	1.17	0.147
	DISARBMoy	0.181	0.151	1.426	1	0.232	1.198	0.891	1.612	
	Constante	0.557	0.795	0.491	1	0.483	1.745			
Levaillant's Woodpecker	RECGRL	4.301	4.526	0.903	1	0.342	73.7	0.01	525569.34	0.119
	REGEN	-2.784	1.523	3.342	1	0.068	0.062	0.003	1.222	
	BMORT	1.906	1.916	0.989	1	0.32	6.725	0.157	287.488	
	Constante	-4.511	4.018	1.261	1	0.262	0.011			

*: significant (α ≤ 0.05) **: highly significant (α ≤ 0.01) ***: very highly significant (α ≤ 0.001)

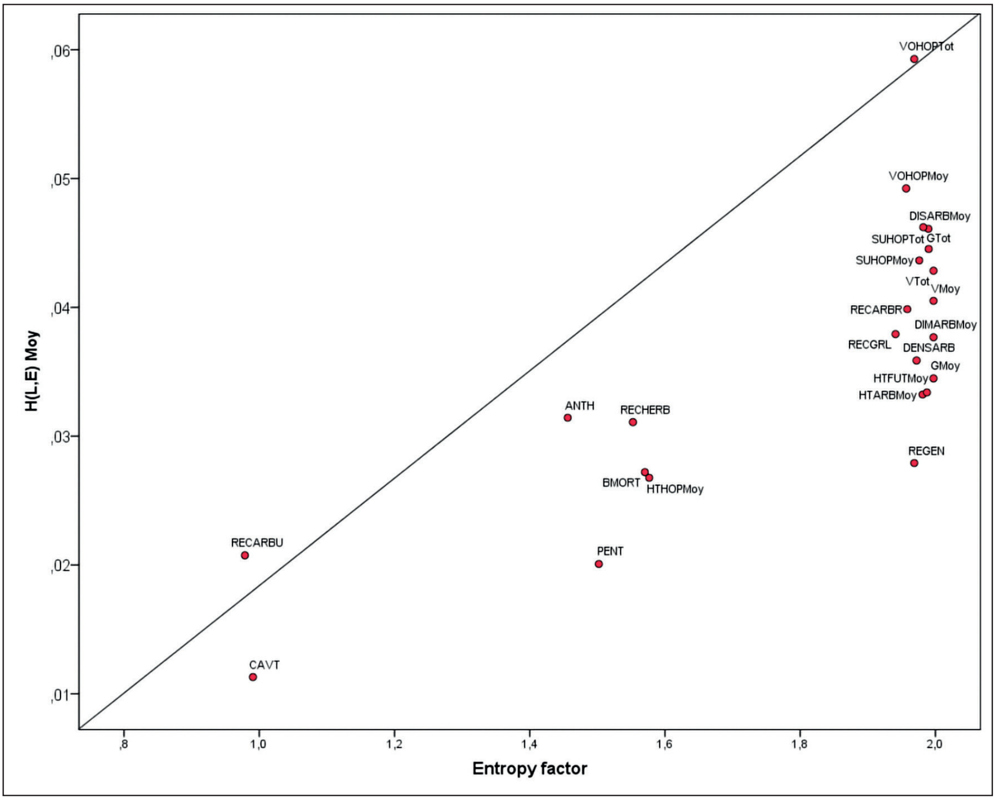

Figure 4. Relationship «Mutual information – Descriptor entropy» defining active descriptors
4. ábra A közös információ és az entrópia kapcsolata

and upper classes of the other descriptors were favourable to it. The European Robin showed a preference for low density and non-anthropogenic forest environments *(Figure 6)*.

The relationship between the twelve species whose frequency is greater than 20% and the eco-dendrometric parameters are described using logistic regression. The models fit assessment are based on Nalgelkerke's R^2. The best-fitting model is the one with a high R^2. We rely on Wald's statistic to assess the statistical significance of the estimated coefficients of the independent variables. The results of the logistics regressions are summarized in *Table 4*.

The best-fitting models are those of Short-toed Treecreeper (Nalgelkerke's $R^2 = 0.78$) and European Robin (Nalgelkerke's $R^2 = 0.68$).

All the descriptors included in the Short-toed Treecreeper model are relevant ($\alpha \leq 0.05$). The rate of dead wood, the density of trees, the variability of distances between trees have a positive effect (Exp (B) > 1) while the variability of diameters and heights of trees, as well as the total surface of the crown and standard deviation of crown surfaces, have negative effects (Exp (B) < 1).

The European Robin model showed a negative effect on anthropization and general coverage, and a positive effect on average crown height and variability of crown surfaces ($\alpha \leq 0.01$).

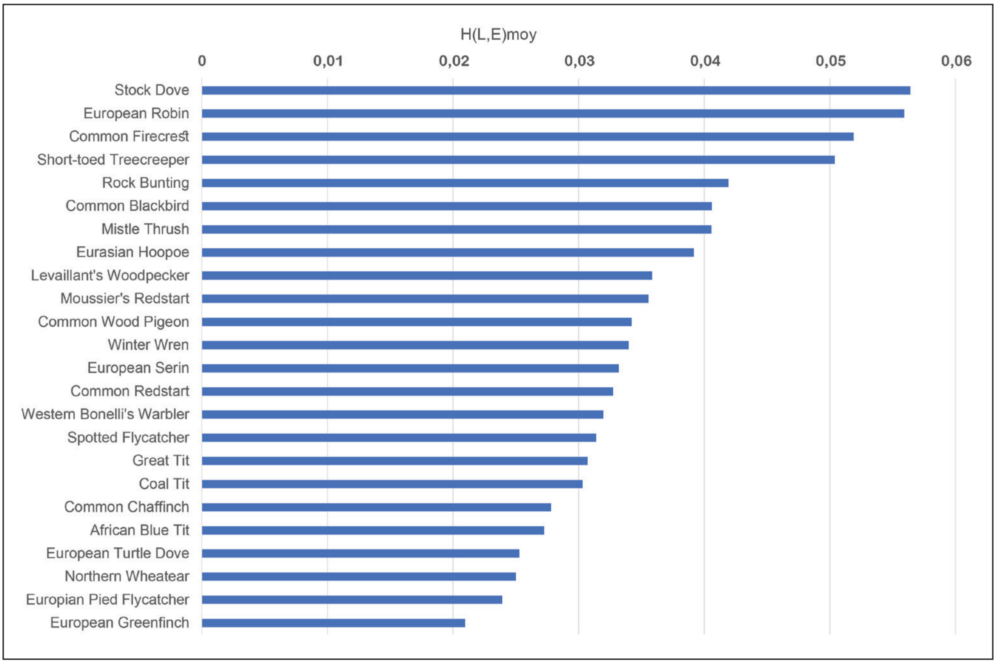

Figure 5. Indicative values of bird species
5. ábra A fajok indikációs értékei

Four effective descriptors (shrub cover, tree density, standard deviation of tree diameter, average tree height) act negatively on the Coal Tit. Common Chaffinch is negatively affected by three descriptors. The average crown height affects its presence significantly ($\alpha \leq 0.05$). The regeneration rate and the standard deviation of crown surfaces affect it highly ($\alpha \leq 0.01$).

In Western Bonelli's Warbler model we note positive effects of general cover and the standard deviation of tree heights, and negative effects of grass cover ($\alpha \leq 0.01$) and tree density ($\alpha \leq 0.001$).

Deadwood rate, tree density and standard deviation of tree diameters negatively affect Europian Pied Flycatcher presence. Only one descriptor (standard deviation of tree diameter) is relevant in the Common Firecrest model with a negative effect.

Common Redstart model contains two relevant descriptors (covering of the herbaceous stratum and the total volume of the crowns) which act positively on the presence of the species. The presence of Winter Wren is negatively affected by the standard deviation of the distance between trees and positively by the total volume of the crown. Tree health is the only descriptor with significant action ($\alpha \leq 0.01$) in the Mistle Thrush model. European Serin and Levaillant's Woodpecker *(Picus vaillantii)* models are very weakly fitted (Nalgelkerke's R^2 = 0.147; 0.117, respectively) and do not present any relevant descriptor.

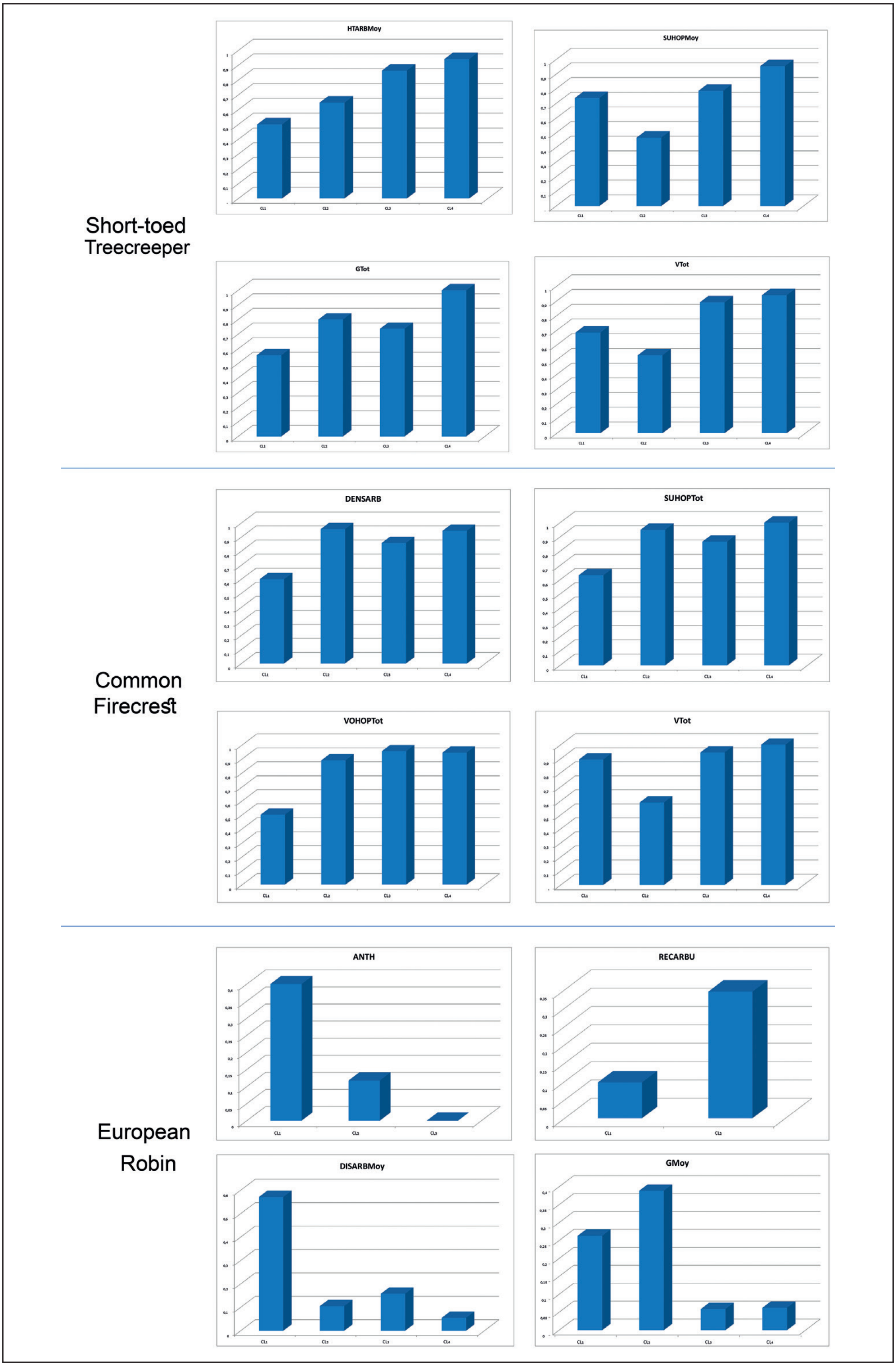

Figure 6. Ecological profiles
6. ábra Ökológiai profilok

Discussion

Our diagnostic was based on establishing an ornithological portrait in an endemic forest in North Africa, based on multiple analytical approaches (exploratory analysis, ecological profiles, mutual information and logistic models). The ornithological diagnosis highlighted the ecological heritage characteristics and peculiarities of the cedar forest birds and their ecological requirements.

The bird species richness of the Aurès cedar forest was estimated at 32 species. However, it should be pointed out that the absence of a species does not necessarily mean that it does not present in this type of habitat in one-visit point counts. Some species may not appear during sampling (Royle *et al.* 2005) or are very discreet and pose the problem of detectability (Alldredge *et al.* 2007, Pacifici *et al.* 2008, Stanislav *et al.* 2010). The habitat structure, as well as the observation period, have a considerable influence on the detection of avian species (Alldredge *et al.* 2007, Brewster & Simons 2009, Simons *et al.* 2009, Basile *et al.* 2020).

The heritage bird's value is reflected by the presence of raptors which constitute excellent biological indicators (Kirk 2003, Farmer *et al.* 2007, Santangeli & Girardello 2021) and also by the number of species with national and international protection status. The analysis of the birds' taxonomic and phenological composition revealed the reception capacity of the cedar forest offering heterogeneity which promotes the coexistence of a multitude of species. This diversity is due to the strategic location of the Mediterranean region (Blondel *et al.* 1978).

Mutual information "species – descriptor" highlighted the most determining descriptors in the cedar forest. The first features of the information collected provide an appreciation of the species' reaction to the descriptors. These findings are further refined by the ecological profiles.

The most active descriptors identified are crown volume, wood basal area and distance between trees. Several authors (Blondel *et al.* 1978, Menard & McNeil 1982, Lebreton *et al.* 1987, Boubaker 1996) using mutual information methods "species-ecological factor" asserted the influences of the quoted descriptors on birds.

The species with high indicator values are sylvatic species restricted to coniferous/mixed forests and cool mountain areas (Blondel 1970, Dronneau 2007).

The Common Firecrest model displays a single relevant descriptor (standard deviation of tree diameter) with a negative effect, which could reflect a preference for regular forest (trees with same age and similar dimension). This conifer specialist bird reaches its maximum abundance in the fir forest of the Morvan in the high forest stage with trees 25 metres high (Marion & Frochot 2001). In the Ardennes oak forest, the average tree circumference affects the Common Firescrest negatively (Delahaye 2006). In El Kala pine forest, the species' presence is linked to the development of the tree layer and its maximum abundance occurs in the old stages of the succession where the cover and the height of the trees determine its presence (Benyacoub 1993).

All the descriptors included in the Short-toed Treecreeper model seem relevant. The rate of dead wood, which is often abundant in old forest stages favourable to corticolous and cavernicolous species, the density of trees and the variability of distances between trees have a positive effect on the presence of the species (Laiolo 2002, Leitao *et al*. 2022).

The large size of the branches constitutes an obstacle hindering access to cortical insectivorous species including Short-toed Treecreeper (Benyacoub 1993, Delahaye 2006). This is reflected in the cedar forest by the negative effect of the variability of the diameters and heights of the trees, the total crown area and the standard deviation of the crown areas. In Ardennes oak-beech forest, the old, high forest is particularly suitable for the species (Delahaye 2006). The relatively low mobility and specialized foraging behaviour of this species may explain its dependence on large trees (Dondina *et al.* 2015). In fact, large trees are likely to contain a high density of arthropods and offer good microhabitats, which lead to low mobility of the species (Osiejuk 1996). In mature oak forests in northwestern Tunisia, the occurrence of Short-toed Treecreeper increased with forest area at the local scale and decreased with the amount of low scrub at the landscape scale (Touihri *et al.* 2017).

The European Robin is negatively influenced by anthropization and general cover, and positively by the average crown height and the variability of crown surfaces. Indeed, the heterogeneity of the environment is favourable to the species (Ferry & Frochot 1970, Marion & Frochot 2001). In the pine forest of El Kala, the species tends to achieve its maximum abundance in the undergrowth of forests where the cover and the height of the trees are significant (Benyacoub 1993). In the oak groves of Burgundy, the European Robin has a slight preference for the intermediate stages of young high forest (Ferry & Frochot 1970, 1974, 1987). The same observation was made by Marion and Frochot (2001) in the ecological succession of the Douglas fir in Morvan. In the Ardennes oak forest, the European Robin does not appear in classes with a gardened and irregular stage (where all diameter classes are well represented) (Delahaye 2006). In Norwagian spruce plantation forests, it was positively associated with the amount of fresh deadwood (Velova *et al.* 2021).

Logistic regression is a recommended statistical tool for analyzing binary data. It has been used to model the probability of occurrence of many species (Tobalske & Tobalske 1999, Zimmermann & Kienast 1999, Villard & Guénette 2005, Dendup *et al.* 2021). By the logistic regression, we have identified the explanatory variables responsible for the presence/absence of the bird species. The results show that the modelled species react differently to different environmental factors. Indeed, birds respond equally well to the composition and structure of the habitat (Fleishman *et al.* 2003, Jentsch *et al.* 2008, Jayapal *et al.* 2009, Holmes 2011), but in a different way (Imhoff 1997, Laiolo 2002, Walker 2008). Depending on the microclimate, vegetation structure and availability of food resources, each natural habitat provides a different environment for birds (Rotenberry 1985, Deppe & Rotenberry 2008, Arya & Gopi 2021).

The role of birds in the elaboration and development of biodiversity conservation strategies is well established (Arinaitwe *et al.* 2007, Brooks *et al.* 2008, Rodrigues & Tristao da Cunha 2012). The semi-quantitative progressive frequency sampling method proved to be very practical given the topographic conditions of the forest habitats studied (cedar forests). The principle of the modelling approach is to relate the occurrences of a species to certain environmental descriptors associated with the observation plots. We therefore necessarily model the realized niche of the species, starting from the observation that its observed distribution is already the result of possible biotic constraints restricting its fundamental niche (Guisan 2003).

Our results suggest that cedar forest provides potentially suitable habitat for many bird species. The birds with high indicator value as well as the key factors impacting their distribution are identified. The bird species considered in our study showed remarkably different responses to forest characteristics. Forest managers must be able to anticipate the impact of their management actions in order to contribute to the conservation of bird diversity. To do this, we propose to incorporate into cedar forest guidelines the result derived from the models applied to Common Firecrest, Short-toed Treecreeper and European Robin, because of their high indicator values.

Overall, the results of the models are in favor of the diversification of management practices favoring heterogeneous habitats with different levels of tree density, variability in diameter and height classes of trees, and a considerable amount of dead wood.

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