Synecological approach of novelty responses in bird assemblage inhabiting Atlas cedar afforestation (*Cedrus atlantica*(Endl.) G. Manetti ex Carrière) of Mount M'Cid, Northeastern Algeria

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Abstract

The degradation of Algerian forests caused by repeated fires, pests, diseases, and illegal cutting has led to significant losses in the natural heritage. Afforestation activities play a crucial role in restoring the degraded ecosystem, but the ecological characteristics of the forests are often overlooked when selecting single or multiple native or exotic coniferous species for afforestation. This study used a multivariate synecological approach (such as, Redundancy Canonical Analysis, a variation partitioning approach based on partial RDA and multivariate regression tree with indicator species) to analyze the relative contributions of environmental factors in forest bird community assembly in Atlas cedar stand afforestations. The survey used the point count method to observe the spatial distribution of breeding forest birds across the wooded landscape with respect to habitat predictors, summarizing woodland physiognomy and landscape-scale variables. A total of 47 forest bird species were observed, and the used multivariate synecological analysis has identified three major patterns of relationships among breeding birds and afforested area: the first was related to changes in tree structure during growth, the second was associated with the height of the grass layer, and the third was the gradient of height elevation.

1. Introduction

The Mediterranean forests are recognised for their high species diversity, making them a crucial component of terrestrial ecosystems (Yurkov et al., 2016). However, sustaining biodiversity in Algerian forestry poses a unique challenge (Djema & Messaoudène, 2009). In Algeria, forests cover 4.1 million hectares, which amounts to 11% of the northern land area of the country and includes tellian and steppic landscapes. Maquis and shrublands cover 46% of the total surface, accounting for 1,902,000 hectares, while cork oak stands and pine forests cover the largest area with 1,111,000 hectares (Chouahda & Benyacoub, 2014), followed by 717,000 hectares of afforestation for degraded landscape protection. However, the Algerian forests have faced intensive degradation due to several factors over the years (Djema & Messaoudène, 2009). The effects of drought, population growth, and inadequate forest management have led to forest deteriotion, with fires, pests, diseases, and illegal wood cuting contributing to significant losses of forest resources (Bardadi et al., 2021; Touhami et al., 2020). The degradation of Atlas cedar forests in Algeria, including those in the Aurès mountains and the National Parks of Theniet el Had, Djurdjura, and Chréa, is a particular concern for Algerian foresters and biology researchers (Djema & Messaoudène, 2009). According to Bentouati and Bariteau (2006) and Boudy (1955), Atlas cedar woodlands have lost between 30% and 60% of their original area.

Cedrus atlantica (Endl.) G. Manetti ex Carrière is an endemic pine tree species to the Atlas Mountains of Morocco and Algeria and is classified as an endangered species (Thomas, 2013). It can be found in scattered stands at elevations of 1000 to 2500 m a.s.l., where its distribution is mainly influenced by climatic and orographic traits (Camarero et al., 2021; Quézel, 1998; Slimani, 2014;). In Algeria, over the past decade, native vegetation has been removed or destroyed for various reasons, leading to a disturbance of the delicate balance between soil, vegetation, and water in natural environments (García-

Ruiz et al., 2013; Malagnoux et al., 2008). This has resulted in significant soil loss and the disappearance of various plant species, especially in sensitive landscapes with semi-arid and arid climatic conditions due to incorrect land use with deforestation and erosion (Benabderrahmane & Chenchouni, 2010; Malagnoux et al., 2008; Martínez-Valderrama et al., 2018). Afforestation activities can help re-equilibrate the degraded ecosystem and reduce the effects of global disasters and erosion (Hu et al., 2021; Romero-Díaz et al., 2010). However, the ecological characteristics of afforested ecosystems have not been given enough consideration when discussing the impact of afforestation with single or multiple native or exotic coniferous species (Bremer & Farley, 2010; Brockerhoff et al., 2008; Pommerening & Murphy, 2004; Scarascia-Mugnozza et al., 2000).

The aim of afforestation is not only to optimize economic and conservation values of biological diversity in wooded lands, but also to promote the intrinsic values of biological and cultural diversity in the Algerian region (Chenchouni, 2019; Djema & Messaoudène, 2009). The preservation of both biological and cultural diversity in the region is widely recognized as essential for the sustainable use of biological resources. Among the pine species suitable for afforestation in the Algerian region's mountain ecosystems, Atlas cedar appears to be one of the most promising due to its ecological adaptability and quality of standing trees (Beghami et al., 2012; Mhirit, 1999). In Souk Ahras, this noble species has been introduced in afforestation in Mount M'Cid. However, despite its importance as an ecosystem for biodiversity, this wooded area has not received much scientific research. It was forested in during the 1970s and completed in the 1980s for forest purposes (DGF, 2005). Forest loss and fragmentation have been extensive in Mount M'Cid, where intensive land use and human disturbances have resulted in a remarkable gradient, with major trends related to fires, agricultural expansion, and intensive grazing by domestic animals contributing to vegetation loss.

According to many studies, wooded landscapes have the potential to provide suitable habitat for a wide variety of native forest plants, animals, and fungi, as well as support diverse native shrublands (Brockerhoff et al., 2008; Carnus et al., 2006; Yue et al., 2020). Preserved landscapes managed in a traditional way often maintain a significant level of biological diversity (Bergmeier et al., 2010). The loss and replacement of such ecosystems for afforestation efforts may have negative impacts on forest organisms and interfere with biodiversity conservation goals (Byambadorj et al., 2021; Cao et al., 2011). In order to promote sustainable forestry, Kumar et al. (2020) suggest managing transformed forest landscapes to reinforce and support a diverse array of biodiversity. While suitable indicator species have been used to study the responses of biodiversity to different management practices in forest ecosystems, their reliability remains uncertain (Lindenmayer et al., 2000). Among the wildlife resources associated with forest areas, birds are of utmost importance and are considered good indicators of biodiversity (Egwumah et al., 2017; Mekonen, 2017; Padoa-Schioppa et al., 2006). According to Blondel (1999), conifer habitats, such as the Atlas cedar woodlands, may attract many times the number of birds than adjacent landscapes.

Studies have shown that forest habitat structure strongly influences bird assemblage composition, with changes in habitat structure leading to changes in bird communities (Ameztegui et al., 2018; Rebbah et al., 2019; Menaa et al., 2016; Menaa, 2017; Vélová et al., 2021). These associations have been investigated at various spatial scales and within different habitat types. The availability of resources, predicted by habitat diversity and composition, is the primary determinant of bird occupation, while vegetation composition is the secondary determinant (Bellatreche, 1994; Benyakoub, 1993; Holmes & Robinson, 1981; Robinson & Holms, 1984; Rotenberry, 1985; Wiens & Rotenberry, 1981; Cody, 1985; MacArthur & MacArthur, 1961; MacArthur, 1964; Wiens, 1989). Forest stand features such as foliage volume (Buchanan et al., 1999), tree age (Sallabanks et al., 2006), plant productivity (Cody, 1981), structure of the shrub stratum (Díaz, 2006; Reid et al., 2004), size and configuration of loss habitats, connectivity (Henderson et al., 1985), edge effects (McGarigal & McComb, 1995; Turner et al., 2001), vegetation succession and landscape management of coniferous trees (Sweeney et al., 2010), all affect avian assemblages. However, there is still little known about these factors and their influence on bird assemblages in the southern Mediterranean basin, which is crucial for successful forest ecosystem management. Synecological models are adopted to compare bird communities and reconstruct potential habitat maps based on the presence or relative abundance of bird assemblages, allowing for the association of differences in representation with particular habitat composition and structure (Liira et al., 2019; Louys & Meijaard, 2010; Reed, 1997; Sandrock et al., 2007).

This study represents the first formal investigation using a synecological methodology to explore the environmental drivers contributing to the assembly of forest bird communities in afforested Atlas cedar stands. As breeding bird communities are often indicative of forest habitat integrity and have specific habitat requirements, we employed three complementary methods to examine these communities. Firstly, we employed Redundancy Canonical Analysis (RDA) to characterize the environmental patterns of forest bird species occurrence and to identify the most significant environmental gradients and avian species groups with coherent habitat requirements. This approach allowed us to differentiate patterns resulting from species distribution and their habitat predictors. Secondly, we used a variation partitioning approach based on partial RDA to investigate the relative impacts of Atlas cedar wood physiognomy (vegetation structure) and spatial variables (topography) on bird community composition. Lastly, we combined two methods, Multivariate Regression Tree (MRT) and indicator species, to determine if discriminant species exhibited differential responses to community assembly drivers.

Essentially, we intend to answer on a stand scale the following question: which key parameters account for the occurrence of breeding bird species associated with Atlas cedar afforestation? We believe that this knowledge is crucial, on conservation planning, to determine forward management indicators for the establishment of rehabilitation measures in forest stands.

2. Material and methods

2.1. Study area

The study was conducted in the Mount M'Cid (36°23'56.46" N, 8°03'24.84" E, 1406m a.s.l.), a siliceous massif of Numidian sandstones situated on the northern Medjerda Mountains in the Souk Ahras region of Northeastern Algeria. The study area covers 270 ha and has an average slope ranging from 10–30%. It is located approximately 25 km southeast of the town of Souk Ahras and within the northwest of Ouled Driss municipality (Fig. 1). The mean annual rainfall in this area ranges from 800 to 900 mm, and the average temperature is between 15.1°C and 16.5°C. The yearly climatic patterns are influenced by the Mediterranean and show maximum rainfall in December and January, with mild drought in July. In 1974, the forest administration (DGF, 2005) planted *C. atlantica* (Endl.) Carr. on 150 ha, arranged in lines following the hillside ditches. During the 80s, a second planting was carried out on 15 ha, which was forested in a simple hole (DGF, 2005).

2.2. Bird censuses

Birds were counted through a point-counting method or IPA (Indexes Ponctuels d'Abondance) method (Blondel et al., 1970; Bibby et al., 2000), which included two bird census periods (Drapeau et al., 1999) encompassing the entire 2019 and 2020 breeding seasons. The census periods took place once between mid-March and mid-April for early breeders, and once between mid-May and mid-June for species that arrived later, to maximize the possibility of recording as many breeding bird species as possible. The counting procedure involved a count of all birds seen or heard within a fixed radius of 100 meters during a 15-minute interval. Overflying birds that did not land in trees or on the ground were excluded from the numerical analysis to avoid uncertainty about their residency in the study area (Bibby et al., 2000). The censuses were conducted within four hours of sunrise, during which vocal activities of diurnal birds typically begin (Frochot & Roché, 1990), and only during favorable weather conditions (no rain or strong winds [less than 20 kph]. All point counts were performed by the same two well-trained observers (M., M & M.C., M) to limit the effect of observer errors. Twenty point count stations were established randomly across the study area to attempt to sample the entire range of habitats present and the full gradient of elevations. Each station was placed at least 250 meters apart to avoid counting any bird more than once because species with the most powerful voice can be heard up to 250 meters away (Foucès, 1995). The highest number of individuals of each bird species recorded during any of the two visits was used, as these figures are closer to the real number of individuals and species present in each plot (Sánchez et al., 2012). Note that point counts do not provide absolute densities but rather relative abundances.

2.3. Environmental predictors sampling

In each bird surveying station the following habitat descriptors were sampled. The environmental features were collected after each round of point counts. We georeferenced the census plots (gps coordinates were transformed into coordinates in the Lambert system: latitude (lat) and longitude (long)) with a portable GPS (GARMIN, GPS MAP 64s) and determined their i) elevation (alt). We also estimated the topographical variable ii) slope (slp).

The structure of vegetation was quantified by measuring: the height of mean iii) tree stratum (HT), iv) shrub layer (hSh) and v) grass cover (hHr); (HT) and (hSh) were measured directly with a hypsometer, we used the ocular estimate method to measure (hHr). vi) The tree diameter at breast height (D) (a tape measure was used), (D) recorded (approximately 1.3m) of a tree above ground and includes the bark. We estimated vii) density of tree stratum (DT). (DT) per 100 m^2 assessed by counting the number of trees (> 2 m height) within one meter on each side of two 50 m transects from the center of each point sampling. viii) Density of shrub layer (dSh) and ix) grass cover (hHr) per 100 m2 were measured as frequencies (percentages) obtained from theme specific layers of the topographic map 1:25 000 of Algeria.

2.4. Multivariate synecological approach

The developed framework was based on the study of the habitat selection by various bird species of Atals cedar afforestation of Mount M'Cid and on the construction of multivariate synecological models. The study of the selection and modelisation of the habitat for bird communities on a local scale was based on an accurate habitat characteristic in forested landscape of Atals cedar stands. The study of the bird communities led to specify which species were indicators of the quality of wooded landscape of Mount M'Cid, and also to understand how the diversity and the composition of the bird communities were affected by the stand structure (Fig. 2).

There are many methods for defining potential habitat factors. Three methods could translate linear environmental responses: canonical analysis, variation partitioning and classification tree.

All of the above methods use bird species abundance data for which they compare the values of the environmental variables. Moreover, bird data were Hellinger transformed (spe.hel) (Legendre & Gallagher, 2001) prior to the application of multivariate synecological approach. It expresses abundances as the square-root of their relative abundance at each site. As in our case, we used the following statistical analyzes:

2.4.1. Redundancy Analysis(RDA)

Redundancy Analysis (RDA) is an analytical tool used to analyze multiresponse data by modeling the effect of standardized explanatory variables (X) on a centered response matrix (Y) (Legendre & Gallagher, 2001). RDA is a direct extension of gradient analysis techniques (Jongman et al., 1995) and involves an ordination of Y to obtain ordination vectors that are linear combinations of the variables in X. In RDA, ordination axes are computed from a Principal Component Analysis (PCA) of a matrix of fitted values Yfit, which is calculated by fitting the Y variables to X by multivariate linear regression (ter Braak & Smilauer, 1998; Jongman et al., 1995). The "best model" for RDA is obtained by selecting the most significant explanatory variables using forward selection with the ordiR2step() function of the vegan package (Oksanen et al., 2013). RDA involves two computational steps, in which the significance of the F-statistic tests related to all explanatory variables is analyzed using permutation tests. Then, the explanatory variable with the lowest Akaike Information Criterion (AIC) is selected for inclusion in the "best model". The canonical axes obtained from RDA are interpreted as complex environmental gradients in the analysis of community composition. The strength of the canonical relationship between Y and X is measured by the coefficient of R^2, which calculates the proportion of the variation of Y explained by the variables in X. Additionally, the adjusted R^2 is used to reduce the risk of including insignificant variables into the model.

2.4.2. Partial RDA (p.RDA)

The method of partial canonical ordination was employed to determine the extent to which environmental and spatial variables (or sets of variables) contribute to variations in community composition. This is a valuable multivariate technique that serves as a counterpart to partial linear regression, and enables the assessment of the impact of environmental variables on species composition while accounting for the effect of other habitat descriptors that are of no interest. It is also used to isolate the effect of a single explanatory variable, control for well-known linear effects, or analyze related samples (Legendre et al., 2005). This technique is a modified version of RDA in which the response variables Y (bird species abundance assemblages) are associated with a set of explanatory variables X (physiognomy variables), in the presence of additional explanatory variables (spatial variables) called covariables, and thus the linear effect of physiognomy variables on bird species abundance composition are adjusted for the effects of spatial variables. In the first step of this method, an RDA of the W covariables on the Y response variables is conducted. The residuals of this RDA are then extracted to produce a matrix Yres|W containing the Y variables in which the effect of W covariables was removed. The partial RDA is ultimately computed by performing RDA of X on Yres|W (Legendre & Legendre, 2012). All statistics presented earlier for RDA can be used for partial RDA as well.

2.4.3. Variation partitioning by p. RDA

Variation partitioning is a multivariate ecological analysis technique that combines RDA and p.RDA to divide the variation of a response variable (bird species abundance) into two explanatory data sets: physiognomy and spatial variables. The results of this analysis are commonly presented in Venn diagrams, which show the proportion of explained variance by each subset of the variables. The Venn diagrams can be generated using the plot() function in the vegan package (Oksanen et al., 2013). In our study, we used two explanatory data sets X and W, and the total variation of Y was partitioned as depicted in Fig. 3. The a + b + c fraction represents the variance explained by the two data sets when performing an RDA of the response data Y by X and W. The unexplained variance by the two datasets is shown as fraction d. Fraction a represents the variance explained by the X data set only, which was calculated using a partial RDA of the response data Y by X and W. Fraction c represents the variance explained by the W data set only, which was computed using a partial RDA of Y by W and X. The remaining variance, b, is calculated as the difference between [a + b] + [b + c] and [a + b + c]. To perform the variation partitioning analysis, we used the varpart() function in the vegan package (Oksanen et al., 2013).

2.4.4. Multivariate regression tree (MRT) and descriminant species

Multivariate regression tree (MRT) is a clustering technique that extends the univariate regression tree approach to partition a matrix of quantitative response data (i.e., bird species abundance) by a matrix of explanatory variables (i.e., environmental descriptors) that constrain where to rank the data. By minimizing the within-group sums of squared distances to the group mean, MRT identifies clusters of similar samples in terms of species composition based on environmental value thresholds. This approach produces a tree model with both continuous and categorical predictors, which can reveal local structures and interactions among variables and high-order relationships. The optimal number of splits in the tree is determined by cross-validation. The function mvpart() from the mvpart package calculates both the partition and cross-validation. The final regression tree groups are further analyzed using the indicator species analysis performed by the function indval() from the labdsv package to determine significant associations between taxa and the regression tree groups. Dufrêne & Legendre (1997) recommend selecting either the model with the minimum cross-validated error or the most complex tree within one standard error of the best predictive tree, and here, the best predictive tree with the minimum cross-validated error was selected.

All analyses were performed using the computer language R, version 3.1.2 (R Core Team, 2014)

3. Results

3.1. General Results

A total of 47 forest bird species from 20 families were recorded during the two survey rounds (40 IPA partials) of 2019 and 2020 at the 20 sites of Atlas cedar stands, of which 39 species have been qualified for further synecology analysis (Table 1). The major contribution to the forest bird community in the Atlas cedar woodland of Mount M'Cid was from the family of *Musicapidae* and *Sylviidae*, each represented by seven species and six species respectively, and subsequently by *Accipitridae* (four species), *Fringillidae* (four species). Other families were represented only by 1–2 species (e.g. Emberizidae, *Corvidae* and *Phylloscopidae*). Common forest birds belonged to the families *Fringilidae*, *Paridae* and *Musicapidae*. The most common detected species in Mount M'Cid, were predominantly passerines, with Common Chaffinch (*Fringilla coelebs*) (30.5 pairs) the most frequent species followed by European Robin (*Erithacus rubecula*) (27 pairs) and Eurasian Blue Tit (*Cyanistes teneriffae*) (24 pairs) (Table 1).

Species of conservation concern comprised 32% of all bird community across the forest landscape according to Algerian Red List (2012): Short-toed Snake- Eagle (*Circaetus gallicus*), Eurasian Sparrowhawk (*Accipiter nisus*), Black Kite (*Milvus migrans migrans*), Atlas Long-Legged Buzzard (*Buteo rufinus cirtensis*), Common Kestrel (*Falco tinnunculus*), Peregrine Falcon (*Falco peregrinus*), European Bee-eater (*Merops apiaster*), European Roller (*Coracias garrulus*), Eurasian Jay (*Garrulus glandarius*), Moussier's Redstart (*Phoenicurus moussieri*), European Serin (*Serinus serinus*), Common Firecrest (*Regulus ignicapilla*), Eurasian Wryneck (*Jynx torquilla*), Great Spotted Woodpecker (*Dendrocopos major numidus*), Maghreb Green Woodpecker (*Picus vaillantii*), and from the 47 species recorded during this study, only one is classified as. Vulnerable (IUCN Red List, 2021): European Turtle Dove (*Streptopelia turtur*). In this respect, nine are endemic to the Maghreb and/or to North Africa: Atlas Long-Legged Buzzard, Black Kite, Coal Tit (*Periparus ater ledouci*), African Blue Tit, Northern Raven (*Corvus corax tingitanus*), African Stonechat (*Saxicola torquatus*), European Greenfinch (*Chloris chloris voosi*), Great Spotted Woodpecker, Maghreb Green Woodpecker.

3.2. RDA: Bird assemblages and afforestation feature relationships

In the RDA, the proportion of variance (constrained inertia) of the avian assemblages of Mount M'Cid explained by the predictor parameters [formula = spe.hel ~ alt + slp + D + HT + DT + hSh + dSh + hHr + dHr] was 59.69%, while the unexplained variance of Y (unconstrained inertia) was 40.04%. Through a forward selection procedure, significant explanatory variables were selected, including tree diameter at breast height (AIC= -16.825, $F_{1,999}$ = 1.9399, $p < 0.05$), height of grass cover (AIC= -16.866, $F_{1,999}$ = 1.7187, $p < 0.05$) and elevation (AIC= -16.664, $F_{1,999}$ = 1.9195, $p < 0.05$). These three variables retained by the forward selection were then paced in a new data frame to perform new RDA. The constraining variables (tree diameter at breast height, height of grass cover and elevation) now explain 26.76% of the variance in forest bird species with an adjusted R^2 equal to 0. 1303.

In the RDA analysis that only included significant variables, the associations with these variables were found to be highly significant (ANOVA.model: $F_{3,999}$ = 1.9486, $p < 0.001$), as were the two constrained axes (ANOVA.RDA1: $F_{10,999}$ = 2.7427, $p < 0.01$, ANOVA.RDA2: $F_{10,999}$ = 1.8134, $p < 0.05$), and therefore we interpreted only the two axes on the triplots. These canonical axes accounted for 27.82% of the total variance of the data, with the first axis alone explaining 16%. However, these were unadjusted values. Taking into account R^2adj = 0.1303, the percentages of accumulated constrained eigenvalues showed that the first axis alone explains 12.56% variance, and the two first 20.86% variance.

In the ordination (Fig. 4), the triplots indicated that bird community in the studied forest landscape displayed a distinct environmental pattern in the ordination analysis. The first two axes of the reciprocal averaging analysis revealed that tree diameter at breast height, elevation, and height of grass cover were important factors influencing the distribution of the sites (point counts) (Fig. 4). The scaling 2 triplot opposed the northern and southren sides of Mount M'Cid along the first axis. The scaling 1 triplot showed four groups of forest bird species correlated with different sets of explanatory variables: Common Cuckoo (*Cuculus canorus*), Eurasian Blackbird (*Turdus merula*), European Robin, Maghreb Green Woodpecker, Common Firecrest, European Greenfinch, Garden Warbler (*Sylvia borin*), Short-toed Treecreeper (*Certhia brachydactyla*), European Serin were found in the first half of the sites, and were correlated with high tree diameter at breast height. Moussier's Redstart, Western Bonelli's Warbler (*Phylloscopus bonelli*), Spotted Flycatcher (*Muscicapa striata*), Northern Raven, Cirl Bunting (*Emberiza cirlus*), and Common Linnet (*Linaria cannabina*), on the opposite, were related to sites characterized by low tree diameter at breast height.

The scaling 2 triplot indicated also that the ordination axis 2 (negative loading) was a gradient of height elevation. Common Chaffinch, Woodlark (*Lullula arborea*), Moussier's Redstart, (MUST) Spotted Flycatcher, Blue Rock Thrush (*Monticola solitarius)*, Eurasian Jay, Great Spotted Woodpecker, Calandra Lark (*Melanocorypha calandra*), African Blue Tit and House Sparrow (*Passer domesticus)* were oriented close to this vector. In contrast, axis 2 (positive loading) was a gradient of height of grass cover where

Northern Wren (*Troglodytes troglodytes*), African Stonechat (*Saxicola rubicola*), Common Nightingale (*Luscinia megarhynchos*), Western Subalpine Warbler (*Curruca iberiae)*, Eurasian Blackcap (*Sylvia atricapilla)*, European Turtle Dove, Eurasian Shylarck (*Alauda arvensis*), Sardinian Warbler *Curruca melanocephala*, Iberian Chiffchaff (*Phylloscopus ibericus*), Great Tit (*Parus major*) were clustered along to this.

Some other species had intermediate positions in the triplots, suggesting that they were associated with moderate values of the environmental variables. Their projections on the axes were generally shorter compared to those of the species located at the extremes, indicating that they were either present over most portions of the Atlas cedar afforestation or related to intermediate ecological parameters.

3.3. Partial RDA: Bird assemblages and afforestation feature relationships, holding topography constant

Partial redundancy analysis (p.RDA) was conducted to assess the impact of environmental factors on bird community composition while controlling for the influence of other explanatory variables. The p.RDA was performed between forest birds and the two sets of explanatory variables: the structure of vegetation [formula = spe.hel ~ D + HT + DT + hSh + dSh + hHr + dHr], partialling out the effect of topography [Condition (lat + long + alt + slp)].

The aim of this analysis was to determine whether the structure of vegetation could significantly explain the patterns of bird species when controlling for the effect of the topographical gradient. The results showed a significant model (ANOVA.model: $F_{7,999} = 1.6079$, $p < 0.01$) as well as the two first canonical axis: (ANOVA.RDA1: $F_{1,999} = 3.1940$, $p < 0.01$, ANOVA.RDA2: $F_{1,999} = 2.4207$, $p < 0.05$). The structure of vegetation in the Atlas cedar stands explained 44.47% of the variance of bird species composition, topographic covariables explained 23.92% of this variation and the unexplained variation is 31.61%. The adjusted R^2 of this RDA is 21.30%.

The results of this complementry analysis showed also according to the eigenvalues, and their contribution to the variance after removing the contribution of conditioning variables (topographical gradient) that the first two canonical axes explain together 29.16% of the total variance of the data, the first axis alone explaining 16.59%. These are unadjusted values, however. Since R^2adj = 0.2130, the percentages of accumulated constrained eigenvalues show that the first axis alone explains 28.38% variance, and the two first 49.88% variance.

On the triplots of p.RDA (Fig. 5), the explanatory variables showed the same relationships to one another, but some of them (e.g height of mean tree stratum and shrub layer, and density of shrub layer and grass cover) are less important to explain the bird community structure, as shown by their shorter vectors. This may be due to the fact that these variables are well correlated with the position within Mount M'Cid, and therefore their apparent effect on the bird community may have been spurious and has been removed by the analysis, which controlled for the effect of the topographical variables. The scaling 2 triplot showed also that the sites are not as cleanly ordered by their sides in Mount M'Cid.

This indicates that the vegetation structure variables did not necessarily follow that order and that the bird community responds significantly to the vegetation structure constraints irrespective of their locations within the mountain.

3.4. Variation partitioning based on p.RDA: Independent and joint contribution of afforestation bird communities predictors

The variation partitioning analysis was utilized to investigate the relative impact of various habitat factors while controlling for covariables that could have similar effects on the bird species data matrix. In this study, we conducted the variation partitioning to partition the variation of bird species composition between two sets of explanatory variables: vegetation structure and topographic descriptors.

According to the results of the variation partitioning analysis, both sets of explanatory variables were found to contribute to the explanation of the bird species assemblages of the wooded stands of Mount M'Cid.The unique contribution of the vegetation structure variables (left circle, R^2adj = 0.213) is much larger than that of topography (right circle, R^2adj = 0.065). The variation did not explained jointly by the two sets, (R^2adj has been ignored) is considered as null (Fig. 6).

This indicated that vegetation structure and topographic variables were not intercorrelated (Table 2). This is a good reason to do not make an effort towards parsimony, and to do not combine variation partitioning with forward selection.

3.5. MRT and descriminant species: Environmental predictors of afforestation bird communities

Our findings revealed several performance metrics of the model, including the residual error: 30.2%, the cross-validated error: 1.44, and the standard error: 0.138. The tree structure had only four leaves separated by three node. These nodes splited the data into two groups at the threshold of tree diameter at breast height value of 26.54cm, into two groups at the threshold of grass cover height value of 2.5cm, and into two groups at the threshold of elevation value of 1337m (Fig. 4).

Each leaf is characterized by a small barplot showing the abundances of the species, its number of sites and its relative error. We have compare this tree with the four group solution, as suggested by the CVRE criterion.

The main discriminant species of the first split (node) were Northern Wren and Western Bonelli's Warbler that contributed highly to the right leaf, they were the most indicative species of the sites with height (> = 26.54cm) (Table 4).

The second split (node) was primarily distinguished by Woodlark, Spotted Flycatcher and Common Chaffinch were the main discriminant species of the second split (node) where Spotted Flycatcher and

Common Chaffinch contributed highly to the right leaf, and Woodlark was the most indicative species of the sites with lower grass cover (< 2.5cm). In the third split (node), European Robin et Eurasian Blackbird significantly contributed to the right leaf, they were the most indicative species of the sites with height elevation (> = 1337m).

4. Discussion

4.1. Scaling and methodological aspects

Living systems exhibit a hierarchical structure, where the processes that drive biodiversity operate on distinct time and space scales at each level of the hierarchy (O'Neill et al., 1986). Therefore, it is crucial to accurately determine the scale at which the study was conducted and to formulate pertinent questions that align with this scale. This is because scientific findings are closely linked to the scale of the study (Wiens, 1989).

Our findings support the idea that bird communities respond in complex ways to diverse structural and compositional characteristics of forest habitats (Batáry et al., 2006). The identification of these effects is contingent on the scale of perception, and comparisons between studies should take this into account.

Our research focused on investigating the spatial aspects of bird-habitat relationships by conducting a survey during the breeding season. Our results represent an analysis at the local scale, specifically within individual forest stands. Micro-habitat factors, such as local habitat characteristics, were found to be the most significant contributors to explaining the variability of bird communities compared to broader spatial scales (Fuller, 2012). Likewise, Morrison et al. (2012) discovered that regression models that incorporate local habitat descriptors achieve higher correct prediction rates for forest bird species occurrences than models constructed using broader scale environmental variables. This does not imply that variables at a larger scale are unimportant, but rather emphasizes the importance of initially identifying the most relevant local habitat factors in habitat selection before moving on to broader scales to refine prediction models.

The conventional approach to understanding forest bird-habitat relationships and quantifying habitat requirements involves estimating local habitat indices based on knowledge of the ideal range of environmental descriptors for the targeted bird species (Angelstam et al., 2004). Multivariate synecological analysis has recently become a widely used method for describing the relationships between a dependent variable (such as bird species abundance) and independent variables (such as habitat predictors). This statistical tool, which is commonly used for habitat selection, enables the representation of different bird species' preferences for various explanatory variables at different spatial scales (Campos-Silva & Piratelli, 2021; Hortal & Lobo, 2006; Randler & Bogner, 2009).

This method takes into account the interaction of environmental characteristics and identifies how bird species respond to the cumulative effect of multiple environmental descriptors.

This approach is particularly useful for analyzing bird-habitat relationships as it considers the intercorrelation structure of habitat features. In recent years, the use of statistical methods, such as multivariate synecological analysis, to model species distribution and habitat requirements has increased, with a wide range of statistical analyses being applied (e.g. Canedoli et al., 2018; Melles, 2005; Redolfi De Zan et al., 2014; Xu et al., 2018). In this study, various synecological methods, such as RDA, p.RDA, variation partitioning, and MRT, were employed to model habitat requirements and species distribution.

4.2. Atals cedar forest governs bird community composition

Our results indicated that the bird assemblages composition at the local scale breeding the Atlas cedar afforestation were characterized by a some common dominant species, namely Common Chaffinch, European Robin and Eurasian Blue Tit. These ubiquitous birds are generalist species of wooded areas and natural forests, with broad geographical ranges and high population sizes in Algeria (Menaa et al., 2016 ; Messouni & Boubaker, 2015, Rebbah et al., 2019). They were of little conservation concern in the North African context (IUCN Red List, 2021). These birds are also adaptable to small forest patches (Diaz et al. 1998; Razola & Rey Benayas 2009), such as those corresponding to the investigated afforestation in this study. However, about 32% of Ceadr forest bird species occurring in this afforested area are “protected” (JORDAP, 2012), only one is considered as “Vulnerable” (IUCN Red List, 2021), and nine are endemic to the Maghreb and/or to North Africa (de Balsac & Mayaud, 1962; Etchecopar & Hüe, 1964; Howard & Moore, 1991). The presence of these protected, vulnerable and endemic bird species confirms the importance of the Atlas cedar woodland of Mount M’Cid as a key habitat for the conservation of rare and endemic avifauna.

The most abundant species at Mount M’Cid is Common Chaffinch, which was par excellence, the forest bird in North Africa and temperate Europe (Dronneau, 2007; Menaa, 2016, Rebbah et al., 2019). As demonstrated by Muller (1985), this sparrow is the most commonly found species in all types of forests, including hardwoods, conifers or mixed stands.

The avifauna in this Mediterranean region is largely dominated by species of early successional forest stages, which limits the possibility of colonization by pure coniferous woodland species. Bird forest specialists of Mediterranean coniferous woodlands that require more mature and larger forest patches, (Diaz et al. 1998; Santos et al., 2006), such as Coal Tit, Great Tit, African Blue Tit, Short-toed Treecreeper, Common Firecrest or Great Spotted Woodpecker, were recorded in this plantation. This highlighted the suitability of these afforested landscapes for forest avifauna in the region, while also emphasizing the importance of considering the biogeographic context when designing rehabilitation measures through afforestation (Suárez-Seoane et al., 2002). Furthermore, conflicts can arise if single services of ecological restoration such as the long-term storage of carbon by tree plantations, are targeted without taking into account regional biodiversity (Bullock et al., 2011).

4.3. Relationships between bird species occurrence at local scale and effect of vegetation structure

Birds are often used to study the effects of afforestation and to develop effective conservation strategies (Sánchez-Oliver et al., 2014). However, to fully understand the relationship between local environmental factors and avian species, it is important to consider the interrelations between them (Canedoli et al., 2018) where local habitat descriptors play a crucial role in determining habitat suitability and the connectivity of forest ecosystems for species distribution (Beninde et al., 2015; MacFaden & Capen, 2002). This study focused on the afforestation of Mount M'Cid and analyzed the habitat features that have been identified as key determinants of intra-forest biodiversity variation.

The study also observed the importance of these habitat characteristics across three different gradients within the forest ecosystem, which has implications for the development of conservation and habitat management measures for avian species in Atlas cedar woodlands. These measures could also benefit other populations in neighboring regions. Finally, the study emphasized the importance of using multivariate synecological approaches to analyze data from Mount M'Cid and other independent research, making the recommendations more broadly applicable to forest landscapes.

The bird community composition in the study area was of great interest as it supported our hypothesis that the vegetation structure plays a crucial role in driving bird species. The observed bird community is clearly influenced by the vegetation structure in the Atlas cedar plantation. The findings are in agreement with the idea that the vegetation structure was positively correlated with aspects of forest bird species that rely on forest resources during the breeding season, which is a critical factor in determining the bird community species composition at the local scale (MacFaden & Capen, 2002; Sánchez-Oliver et al., 2014).

In particular, our analysis showed that the diameter of trees at breast height was the key factor influencing the bird community composition in the afforested area. This result is consistent with previous studies conducted by several authors (Gutzat & Dormann, 2018; Politi et al., 2009; Zarnowitz & Manuwal, 1985), which indicate that larger trees with greater diameters provide important ecological benefits for bird species. These trees offer a suitable nesting habitat for different bird species, regardless of their dependence on cavities, and are also linked to increased vegetation structure that provides a range of resources for these species, including food, refuges, and nesting sites (Gutzat & Dormann, 2018).

Our results also supported the assertion that sites with larger tree diameters at breast height are crucial in providing suitable habitats for specialized forest bird species, such as Coal Tit, Great Tit, African Blue Tit, Short-toed Treecreeper, Common Firecrest or Great Spotted Woodpecker, as they offer vital resources like food and nesting sites (Jokimäki, 1999). In addition, we highlighted the data for cavity-dependent species. Constructors, such as woodpeckers (e.g. Great Spotted Woodpecker and Maghreb Green Woodpecker), play an important ecological role by creating nesting sites in creating nesting sites that can be used by secondary cavity-exploiters (e.g. Short-toed Treecreeper, Great Tit *Parus major* and African

Blue Tit) (Gutzat & Dormann, 2018; Politi et al., 2009; Tomasevic & Marzluff 2017). Furthermore, the current study emphasizes the necessity of preserving these essential resources in wooded stands, not only for the constructors themselves but also for other exploiters like the secondary cavity nesters.

The significance of large trees for biodiversity has been widely recognized. In this study we aimed to identify the species that are most indicative of sites with the presence of large trees, which have high diameter. Results showed that only two species had a significant contribution, namely Northern Wren and Western Bonelli's Warbler. The latter is known to be highly specialized in open and dry forests. Palomino and Carrascal (2006) suggested that a denser, older, and higher tree canopy can increase foliage height diversity, which in turn, positively affects species richness and diversity by providing nesting and foraging opportunities for several woodland species, including the Short-toed Treecreeper, European Robin, and Northern Wren.

Ecological patterns that deviate from those found in natural ecosystems are likely to occur in novel ecosystems, which could result in altered species-habitat relationships. However, given the importance of large trees indicated in previous studies (Mikusiński et al., 2018; Politi et al., 2009), their presence in the studied afforested area would likely further increase species diversity and should be encouraged. Our findings suggest that grass cover height in wooded areas may play a positive role in promoting greater habitat heterogeneity for local fauna. We observed that grass cover height can have distinct effects on community assemblages that are linked to the level of forest ecosystem dependence. As the study area was primarily composed of remnants of native grasslands before the afforestation process on Mount M’Cid, sites with high grass cover may benefit birds that are less dependent on forested habitats by increasing open spaces (e.g. African Stonechat, Eurasian Skylark).

The relationship between bird species distribution and grass cover height in Mount M’Cid was found to be positive, emphasizing the importance of grass cover height. This finding supports previous research that indicates that insectivorous birds that forage in open spaces among trees are among the main groups that benefit from afforestation (Vickery & Gill, 1999). Furthermore, increased grass cover height and density in the spring may provide suitable foraging resources for granivores throughout the season. This assemblage comprises different bird species that have experienced declines in woodland habitats, mostly due to the clearance of preferred open forest areas for pasture and fragmentation of their habitats (Loyn, 2004). Therefore, restoring these habitats may offer a direct benefit to these taxa by providing suitable habitat resources.

Despite these analytical comments, our study indicated that the ecological factors crucial for predicting the habitat characteristics of a given afforestation are of utmost importance. Specifically, small shrub layer, grass cover, and dead leaves were identified as benefiting specialist avian species. In fact, our findings revealed that birds typical of cedar forests were more likely to occur in areas with tall grass cover, including the Spotted Flycatcher and Common Chaffinch, which were the most distinctive species in sites with high grass cover, as well as the Woodlark in sites with low grass cover.

4.4. Vegetation structure and elevation were key factors for bird species community at local scale, but other descriptors might lead to unusual patterns for forest species

Through our analysis of environmental variables at a local scale, we found that vegetation structure played a crucial role in the avian community of Mount M'Cid. Interestingly, elevation was also found to have a negative impact on bird presence within the study area. These findings are consistent with previous research on avian community composition along elevational gradients (Benson et al., 2011; Van Riper III et al., 2002), in which may be explained by the extreme physical environment conditions, as well as the kinds and amounts of resources available for breeding and foraging activities, favored the survival of fewer bird species that have a broad tolerance to climactic variation during the breeding season (Cody, 1981). Furthermore, biophysical conditions become more adverse for some birds at higher elevations, resulting in reduced availability of resources for birds. This reflects differences in forest landscape structure, habitat productivity, vegetation species composition, stand disturbance patterns, other biotic interactions, and available land surface (Benson et al., 2011; Van Riper III et al., 2002).

The analysis of elevation zones revealed only a few species that were significantly different between the zones. Among them, the European Robin and Eurasian Blackbird were found to be more abundant at higher elevations. These species are considered specialist forest birds and are known for their ecological flexibility, which enables them to occupy a wide range of wooded environments. The models developed to examine the cedar forest bird community demonstrated that vegetation structure, including diameter at breast height and grass cover height, along with intrinsic features like elevation, played significant roles in determining the distribution of bird species. However, variables such as longitude, latitude, slope, or tree height at the local scale were found to be relatively insignificant. This reflects the general nature of these variables and does not reduce the importance of the local context in contributing to the bird fauna of each site (Batáry et al., 2006).

4.5. Managment recommandations

Afforestation is a vital tool for biodiversity conservation and ecosystem restoration. However, afforestation programs often fail to consider the needs of avifauna, leading to a loss of biodiversity. Our research findings suggested that it is challenging to generalize the environmental factors that determine forest bird species in the Atlas cedar plantation of Mount M'Cid throughout the year. Therefore, it is difficult to make management recommendations to create a favourable and supportive habitat for avifauna. However, this afforested area provides breeding opportunities for various generalist forest bird species and was perceived as an attractive habitat for most forest species in the region. Additionally, large trees with developed grass cover benefit bird species that are typical of open grassland habitats, including the Eurasian Skylark and African Stonechat. As trimming of Atlas cedar accelerates the development of the timber diameter, a more widespread implementation of this practice could increase overall species density in winter and benefit forest bird species such as the Wood pigeon, which is of interest to hunters, and insectivorous birds such as the Great Tit or African Blue Tit, which have the potential to enhance pest regulation in both tree plantations and surrounding grasslands.

Furthermore, our study also revealed that the distribution of most forest bird species was affected by the elevational gradient in Mount M'Cid. However, there may be other factors that contribute to changes in bird species distribution along this gradient, which were not sufficiently accounted for in our analysis. As such, we suggested that in order to preserve the observed distribution of forest bird species in this wooded landscape, it is important to maintain afforestation activities throughout the entire elevational gradient, rather than solely preserving reserves within particular elevational zones.

5. Conclusion

Overall, this study demonstrated that the diameter at breast height, grass cover height, and elevation are important factors for improving biodiversity in Atlas cedar stands at the local scale in Mount M'Cid. Specifically, diameter at breast height and grass cover height had a strong positive effect on biodiversity, and the afforested area was found to be a suitable habitat for specialized forest bird species. While previous studies have highlighted the importance of large trees in afforested environments (Bremer & Farley, 2010; Brockerhoff et al., 2008), our findings demonstrate that specific practices in forest vegetation management can have unforeseen impacts on specialized forest bird species. However, as noted by Beninde et al. (2015), conservation goals must be clearly defined to determine thresholds for environmental features such as tree diameters or woodland extent. Depending on the conservation objectives, different forest conservation measures may be necessary. Therefore, focused efforts to preserve or enhance biodiversity in afforested areas at various scales can produce the best-fit models (Batáry et al., 2006), and conservation actions that ignore the interactions between broader landscape and local characteristics may fail or produce ineffective results in biodiversity conservation management (Batáry et al., 2006).

Declarations

Data availability statement

Data available on request from the authors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Ameztegui, A., Gil-Tena, A., Faus, J., Piqué, M., Brotons, L., & Camprodon, J. (2018). Bird community response in mountain pine forests of the Pyrenees managed under a shelterwood system. *Forest Ecology and Management*, *407*, 95-105.
2. Angelstam, P., Roberge, J. M., Lõhmus, A., Bergmanis, M., Brazaitis, G., Dönz-Breuss, M., ... & Tryjanowski, P. (2004). Habitat modelling as a tool for spatial conservation: a review of parameters for focal forest birds. *Ecological Bulletins*, *51*, 427-453.
3. Bardadi, A., Souidi, Z., Cohen, M., & Amara, M. (2021). Land Use/Land Cover Changes in the Tlemcen Region (Algeria) and Classification of Fragile Areas. *Sustainability*, *13*(14), 7761.
4. Batáry, P., Báldi, A., & Erdős, S. (2006). Grassland versus non-grassland bird abundance and diversity in managed grasslands: local, landscape and regional scale effects. In *Vertebrate Conservation and Biodiversity* (pp. 45-55). Springer, Dordrecht.
5. Beghami, Y., Kalla, M., Thinon, M., & Benmessaoud, H. (2012). Spatiotemporal dynamics of forest and mountain formations in Aurès area, Algeria. *Journal of Life Sciences*, *6*, 663-669.
6. Bellatreche, M. (1994). *Écologie et biogéographie de l'avifaune forestière nicheuse de la Kabylie des Babors*. (Doctoral dissertation, Université de Dijon). 154p.
7. Benabderrahmane, M. C., & Chenchouni, H. (2010). Assessing environmental sensitivity areas to desertification in Eastern Algeria using Mediterranean desertification and land use “MEDALUS” model. *Int J Sustain Water Environ Syst*, *1*(1), 5-10.
8. Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecology letters*, *18*(6), 581-592.
9. Benson, T. J., Brown, J. D., Anich, N. M., & Bednarz, J. C. (2011). Habitat availability for bottomland hardwood forest birds: the importance of considering elevation. *Journal of Field Ornithology*, *82*(1), 25-31.
10. Bentouati, A., & Bariteau, M. (2006). Réflexions sur le dépérissement du cèdre de l’Atlas des Aurès (Algérie). *Forêt méditerranéenne*, *27*(2), 203-208.
11. Benyacoub, S. (1993). *Écologie de l'avifaune forestière nicheuse de la région d'El-Kala (nord-est algérien).* (Doctoral dissertation, Université de Bourgogne). 287p.
12. Bergmeier, E., Petermann, J., & Schröder, E. (2010). Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. *Biodiversity and Conservation*, *19*(11), 2995-3014.
13. Bibby, C. J., Burgess, N. D., Hill, D. A., & Mustoe, S. (2000). *Bird census techniques.* 2nd edn Academic Press. San Diego, 302p.
14. Blondel, J. (1999). Peuplements d'oiseaux des cédraies méditerranéennes. *Forêt méditerranéenne, 20*(4), 191-197.
15. Blondel, J., Ferry, C., & Frochot, B. (1970). La méthode des indices ponctuels d’abondance (I.P.A.) ou des relevés d’avifaune par “stations d’écoute”. *Alauda*, *38*(1), 55-71.
16. Borcard, D., Gillet, F., & Legendre, P. (2011). *Numerical Ecology with R*. Springer New York. 306p.

17. Bouahmed, A., Vessella, F., Schirone, B., Krouchi, F., & Derridj, A. (2019). Modeling Cedrus atlantica potential distribution in North Africa across time: new putative glacial refugia and future range shifts under climate change. *Regional Environmental Change*, *19*(6), 1667-1682.
18. Boudy, P. (1955). *Economie forestière Nord Africaine*. Tome 4, Edition Larose. 247 p.
19. Breiman, L., Friedman, J.H., Olshen, R.A., & Stone, C.G. (1984). *Classification and Regression Trees*. Wadsworth International Group, Belmont, CA.
20. Bremer, L. L., & Farley, K. A. (2010). Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. *Biodiversity and Conservation*, *19*(14), 3893-3915.
21. Brockerhoff, E. G., Jactel, H., Parrotta, J. A., Quine, C. P., & Sayer, J. (2008). Plantation forests and biodiversity: oxymoron or opportunity?. *Biodiversity and Conservation*, *17*(5), 925-951.
22. Buchanan, T., & Smith, J. L. (1999). Research on the Internet: Validation of a World-Wide Web mediated personality scale. *Behavior Research Methods, Instruments, & Computers*, *31*(4), 565-571.
23. Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., & Rey-Benayas, J. M. (2011). Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in Ecology & Evolution*, *26*(10), 541-549.
24. Byambadorj, S. O., Chiatante, D., Akhmadi, K., Lunten, J., Ochirbat, B., Park, B. B., ... & Nyam-Osor, B. (2021). The effect of different watering regimes and fertilizer addition on the growth of tree species used to afforest the semi-arid steppe of Mongolia. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, *155*(4), 747-758.
25. Camarero, J. J., Sánchez-Salguero, R., Sangüesa-Barreda, G., Lechuga, V., Viñegla, B., Seco, J. I., ... & Linares, J. C. (2021). Drought, axe and goats. More variable and synchronized growth forecasts worsening dieback in Moroccan Atlas cedar forests. *Science of The Total Environment*, *765*, 142752.
26. Campos-Silva, L. A., & Piratelli, A. J. (2021). Vegetation structure drives taxonomic diversity and functional traits of birds in urban private native forest fragments. *Urban Ecosystems*, *24*(2), 375-390.
27. Canedoli, C., Manenti, R., & Padoa-Schioppa, E. (2018). Birds biodiversity in urban and periurban forests: environmental determinants at local and landscape scales. *Urban Ecosystems*, *21*(4), 779-793.
28. Cao, S., Sun, G., Zhang, Z., Chen, L., Feng, Q., Fu, B., ... & Wei, X. (2011). Greening China naturally. *Ambio*, *40*(7), 828-831.
29. Carnus, J. M., Parrotta, J., Brockerhoff, E., Arbez, M., Jactel, H., Kremer, A., ... & Walters, B. (2006). Planted forests and biodiversity. *Journal of Forestry*, *104*(2), 65-77.
30. Chenchouni, H. (2019). Ecological dynamics of the green dam by remote sensing : the case of Moudjbara (Djelfa, central Algeria). *International Journal*, *75*(4/1).
31. Chouahda, S., & Benyacoub, S. (2014). Fire Recurrence Effects on the Resilience Capacity of Cork Oak (*Quercus suber*) Forests in Northeast Algeria. *European Journal of Scientific Research*, *118*(4), 514-522.

32. Cody, M. L. (1981). Habitat selection in birds: the roles of vegetation structure, competitors, and productivity. *BioScience*, *31*(2), 107-113.
33. Cody, M. L. (Ed.). (1985). *Habitat selection in birds*. Academic press.
34. de Balsac, H. H., & Mayaud, N. (1962). *Les oiseaux du nord-ouest de l'Afrique: distribution géographique, écologie, migrations, reproduction* (Vol. 10). P. Lechevalier.
35. De'ath, G. (2014). mvpart: Multivariate partitioning. R package version 1. 6-2. http://CRAN.R-project.org/package=mvpart
36. De'ath, G. (2002). Multivariate regression trees: a new technique for modeling species–environment relationships. *Ecology*, *83*(4), 1105-1117.
37. De'ath, G., & Fabricius, K. E. (2000). Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology*, *81*(11), 3178-3192.
38. Delahaye, L. (2006). Habitat selection in forest birds and predictive models of species' potential distributions in Ardenne's oak and beech forests: effects of tree composition and forest stand structure.
39. DGF 2005. Programme d'action national sur la lutte contre la désertification. Document interne.
40. Diaz, M., Carbonell, R., Santos, T., & Telleria, J. L. (1998). Breeding bird communities in pine plantations of the Spanish plateaux: biogeography, landscape and vegetation effects. *Journal of Applied Ecology*, *35*(4), 562-574.
41. Díaz, S., Fargione, J., Chapin III, F. S., & Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS biology*, *4*(8), e277.
42. Djema, A., & Messaoudene, M. (2009). The Algerian forest: Current situation and prospects. *Modelling, Valuing and Managing Mediterranean Forest Ecosystems for Non-Timber Goods and Services*, 17.
43. Drapeau, P., Leduc, A., & McNeil, R. (1999). Refining the use of point counts at the scale of individual points in studies of bird-habitat relationships. *Journal of Avian Biology*, *30*, 367-382.
44. Dronneau, C. (2007). Peuplement d'oixeaux nicheurs d'une foret alluviale du rhin (première partie). *Alauda*, *75*(3), 215-226.
45. Dufrêne, M., & Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological monographs*, *67*(3), 345-366.
46. Egwumah, F. A., Egwumah, P. O., & Edet, D. I. (2017). Paramount roles of wild birds as bioindicators of contamination. *Int J Avian & Wildlife Biol*, *2*(6), 00041.
47. Etchecopar, R., & Hue, F. (1964). *Les oiseaux de l'Afrique du Nord*. Boubée, Paris.
48. Foucès, V. (1995). Les comunitats d'helofits i el poblament d'especies de Passeriformes associat a l'illa de Buda. Departament de Medi Ambient (Generalitat de Catalunya), Barcelona, Spain. *Unpublished report*.
49. Frochot, B., & Roché, J. (1990). Suivi de populations d'oiseaux nicheurs par la méthode des indices ponctuels d'abondance (IPA). *Alauda*, *58*(1), 29-35.

50. Fuller, R. J. (Ed.). (2012). *Birds and habitat: relationships in changing landscapes*. Cambridge University Press.
51. García-Ruiz, J. M., Nadal-Romero, E., Lana-Renault, N., & Beguería, S. (2013). Erosion in Mediterranean landscapes: changes and future challenges. *Geomorphology*, *198*, 20-36.
52. Gutzat, F., & Dormann, C. F. (2018). Decaying trees improve nesting opportunities for cavity-nesting birds in temperate and boreal forests: A meta-analysis and implications for retention forestry. *Ecology and Evolution*, *8*(16), 8616-8626.
53. Henderson, M. T., Merriam, G., & Wegner, J. (1985). Patchy environments and species survival: chipmunks in an agricultural mosaic. *Biological Conservation*, *31*(2), 95-105.
54. Holmes, R. T., & Robinson, S. K. (1981). Tree species preferences of foraging insectivorous birds in a northern hardwoods forest. *Oecologia*, *48*(1), 31-35.
55. Hortal, J., & Lobo, J. M. (2006). A synecological framework for systematic conservation planning. *Biodiversity Informatics*, *3*, 16-45.
56. Howard, R., & Moore, A. (1991). *A complete checklist of the birds of the world* (No. Ed. 2). Academic Press Ltd..
57. Hu, S., Jiao, J., Kou, M., Wang, N., García-Fayos, P., & Liu, S. (2021). Quantifying the effects of Robinia pseudoacacia afforestation on plant community structure from a functional perspective: New prospects for management practices on the hilly and gullied Loess Plateau, China. *Science of The Total Environment*, *773*, 144878.
58. IUCN. (2021). *The IUCN Red List of Threatened Species. Version 2021-1*. https://www.iucnredlist.org. Downloaded 12 August 2021.
59. Jokimäki, J. (1999). Occurrence of breeding bird species in urban parks: effects of park structure and broad-scale variables. *Urban Ecosystems*, *3*(1), 21-34.
60. Jongman, R. H. G., ter Braak, C. J. F., & Van Tongeren, O. F. R. (1995). *Data analysis in community and landscape ecology*. Cambridge University Press, Cambridge, United Kingdom.
61. JORADP (2012). Décret exécutif n° 12-235 du 24 mai 2012, fixant la liste des espèces animales non domestiques protégées. *Journal Officiel de la Republique Algérienne Démocratique et Populaire*.
62. Kumar, M., Singh, M. P., Singh, H., Dhakate, P. M., & Ravindranath, N. H. (2020). Forest working plan for the sustainable management of forest and biodiversity in India. *Journal of Sustainable Forestry*, *39*(1), 1-22.
63. Legendre, P., & Gallagher, E. D. (2001). Ecologically meaningful transformations for ordination of species data. *Oecologia*, *129*(2), 271-280.
64. Legendre, P., & Legendre, L. (2012). Multiscale analysis: spatial eigenfunctions. Chapter 14 in: Numerical ecology, 3rd English edition. *Devlopments in Environmental Modelling*, *24*, 859-906.
65. Legendre, P., Borcard, D., & Peres-Neto, P. R. (2005). Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological monographs*, *75*(4), 435-450.

66. Liira, J., Triisberg-Uljas, T., Karofeld, E., Karu, H., & Paal, J. (2019). Does the autecology of core species reflect the synecology of functional groups during the assembly of vegetation in abandoned extracted peatlands?. *Mires & Peat*, *24*(8), 1-14.
67. Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. *Conservation biology*, *14*(4), 941-950.
68. Louys, J., & Meijaard, E. (2010). Palaeoecology of Southeast Asian megafauna-bearing sites from the Pleistocene and a review of environmental changes in the region. *Journal of Biogeography*, *37*(8), 1432-1449.
69. Loyn, R. H. (2004). Research for ecologically sustainable forest management in Victorian eucalypt forests.
70. MacArthur, R. H. (1964). Environmental factors affecting bird species diversity. *The American Naturalist*, *98*(903), 387-397.
71. MacArthur, R. H., & MacArthur, J. W. (1961). On bird species diversity. *Ecology*, *42*(3), 594-598.
72. MacFaden, S. W., & Capen, D. E. (2002). Avian habitat relationships at multiple scales in a New England forest. *Forest Science*, *48*(2), 243-253.
73. Malagnoux, M., Sène, E. H., & Atzmon, N. (2008). Forests, trees and water in arid lands: a delicate balance. *UNASYLVA-FAO-*, *229*, 24.
74. Martínez-Valderrama, J., Ibáñez, J., Del Barrio, G., Alcalá, F. J., Sanjuán, M. E., Ruiz, A., ... & Puigdefábregas, J. (2018). Doomed to collapse: Why Algerian steppe rangelands are overgrazed and some lessons to help land-use transitions. *Science of the Total Environment*, *613*, 1489-1497.
75. McGarigal, K., & McComb, W. C. (1995). Relationships between landscape structure and breeding birds in the Oregon Coast Range. *Ecological monographs*, *65*(3), 235-260.
76. Mekonen, S. (2017). Birds as biodiversity and environmental indicator. *Advances in Life Science and Technology, 60,* 16-22.
77. Melles, S. J. (2005). Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats*, *3*(1), 25-48.
78. Menaa, M., 2017. *Structure et dynamique de l'avifaune nicheuse de la forêt domaniale de Boumezrane (Ain Zana, Souk-Ahras)*. Thèse de Doctorat, Université d'Oum El Bouaghi, pp. 133.
79. Menaa, M., Maazi, M. C., Telailia, S., Saheb, M., Boutabia, L., Chefrour, A., & Houhamdi, M. (2016). Richness and habitat relationships of forest birds in the Zeen Oak woodland (Forest of Boumezrane, Souk-Ahras), Northeastern Algeria. *Pakistan Journal of Zoology*, *48*(4), 1059-1069.
80. Mhirit, O. (1999). Le cèdre de l'Atlas à travers le réseau Silva mediterranea" cèdre". Bilan et perspectives. *Forêt méditerranéenne, 20*(3), 91-100.
81. Mikusiński, G., Bubnicki, J. W., Churski, M., Czeszczewik, D., Walankiewicz, W., & Kuijper, D. P. (2018). Is the impact of loggings in the last primeval lowland forest in Europe underestimated? The conservation issues of Białowieża Forest. *Biological conservation*, *227*, 266-274.

82. Morrison, M. L., Marcot, B., & Mannan, W. (2012). *Wildlife-habitat relationships: concepts and applications*. Island Press.
83. Moussouni, A., & Boubaker, Z. (2015). Diversité des oiseaux de la cédraie du Djurdjura (Est de l'Algérie). *Revue Forestière Française, LXVII*(5), 421-436.
84. Muller, Y. (1985). *L'Avifaune forestière nicheuse des Vosges du Nord: sa place dans le contexte médio-européen.* (Doctoral dissertation, Université de Dijon). 138p.
85. Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'hara, R. B., ... & Oksanen, M. J. (2013). Package 'vegan'. *Community ecology package, version*, *2*(9), 1-295.
86. O'Neill, R. V., Deangelis, D. L., Waide, J. B., Allen, T. F., & Allen, G. E. (1986). *A hierarchical concept of ecosystems* (No. 23). Princeton University Press.
87. Padoa-Schioppa, E., Baietto, M., Massa, R., & Bottoni, L. (2006). Bird communities as bioindicators: The focal species concept in agricultural landscapes. *Ecological indicators*, *6*(1), 83-93.
88. Palomino, D., & Carrascal, L. M. (2006). Urban influence on birds at a regional scale: a case study with the avifauna of northern Madrid province. *Landscape and Urban Planning*, *77*(3), 276-290.
89. Politi, N., Hunter, Jr, M., & Rivera, L. (2009). Nest selection by cavity-nesting birds in subtropical montane forests of the Andes: implications for sustainable forest management. *Biotropica*, *41*(3), 354-360.
90. Pommerening, A., & Murphy, S. T. (2004). A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. *Forestry*, *77*(1), 27-44.
91. Quézel, P. (1998). La végétation des mares transitoires à Isoetes en région méditerranéenne, intérêt patrimonial et conservation. *Ecologia mediterranea*, *24*(2), 111-117.
92. R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria URL http://www.R-project.org/.
93. Randler, C., & Bogner, F. X. (2009). Efficacy of two different instructional methods involving complex ecological content. *International Journal of Science and Mathematics Education*, *7*(2), 315-337.
94. Razola, I., & Rey Benayas, J. M. (2009). Effects of woodland islets introduced in a Mediterranean agricultural landscape on local bird communities. *Web Ecology*, *9*(1), 44-53.
95. Rebbah, A. C., Menaa, M., Telailia, S., Saheb, M., & Maazi, M. C. (2019). Effect of Habitat Types on Breeding Bird Assemblages in the Sidi Reghis Forests (Oum El Bouaghi, North-Eastern Algeria). *Pakistan Journal of Zoology*, *51*(2), 433-447.
96. Redolfi De Zan, L., Battisti, C., & Carpaneto, G. (2014). Bird and beetle assemblages in relict beech forests of central Italy: a multi-taxa approach to assess the importance of dead wood in biodiversity conservation. *Community Ecology*, *15*(2), 235-245.
97. Reed, M. G. (1997). Power relations and community-based tourism planning. *Annals of tourism research*, *24*(3), 566-591.

98. Reid, S., Díaz, I. A., Armesto, J. J., & Willson, M. F. (2004). Importance of native bamboo for understory birds in Chilean temperate forests. *The Auk*, *121*(2), 515-525.
99. Roberts, D. W. (2013). labdsv: Ordination and Multivariate Analysis for Ecology. Package Version 1.6-1. *URL: http://cran. r-proje ct. org/web/packa ges/labds v*.
100. Robinson, S. K., & Holmes, R. T. (1984). Effects of plant species and foliage structure on the foraging behavior of forest birds. *The Auk*, *101*(4), 672-684.
101. Romero-Díaz, A., Belmonte-Serrato, F., & Ruiz-Sinoga, J. D. (2010). The geomorphic impact of afforestations on soil erosion in Southeast Spain. *Land Degradation & Development*, *21*(2), 188-195.
102. Rotenberry, J. T. (1985). The role of habitat in avian community composition: physiognomy or floristics?. *Oecologia*, *67*(2), 213-217.
103. Sallabanks, R., Haufler, J. B., & Mehl, C. A. (2006). Influence of forest vegetation structure on avian community composition in west-central Idaho. *Wildlife Society Bulletin*, *34*(4), 1079-1093.
104. Sánchez, S., Javier Cuervo, J., & Moreno, E. (2012). Vegetation structure in beech-fir forests: effects on the avian community. *Revue d'écologie (Terre et Vie), 67*(2), 213-211.
105. Sánchez-Oliver, J. S., Benayas, J. R., & Carrascal, L. M. (2014). Differential effects of local habitat and landscape characteristics on bird communities in Mediterranean afforestations motivated by the EU Common Agrarian Policy. *European Journal of Wildlife Research*, *60*(1), 135-143.
106. Sandrock, O., Kullmer, O., Schrenk, F., Juwayeyi, Y. M., & Bromage, T. G. (2007). Fauna, taphonomy, and ecology of the Plio-Pleistocene Chiwondo Beds, northern Malawi. In *Hominin environments in the East African Pliocene: an assessment of the faunal evidence* (pp. 315-332). Springer, Dordrecht.
107. Santos, T., Tellería, J. L., Díaz, M., & Carbonell, R. (2006). Evaluating the benefits of CAP reforms: can afforestations restore bird diversity in Mediterranean Spain?. *Basic and Applied Ecology*, *7*(6), 483-495.
108. Sbabdji, M., Lambs, L., Haddad, A., & Kadik, B. (2015). Effect of periodic defoliations by Thaumetopoea pityocampa Schiff. on radial growth in cedar woodland in Chréa, Algeria. *Revue d'écologie (Terre et Vie), 70*(4), 371-386.
109. Scarascia-Mugnozza, G., Oswald, H., Piussi, P., & Radoglou, K. (2000). Forests of the Mediterranean region: gaps in knowledge and research needs. *Forest Ecology and management*, *132*(1), 97-109.
110. Schreiber, B., & deCalesta, D. S. (1992). The relationship between cavity-nesting birds and snags on clearcuts in western Oregon. *Forest Ecology and Management*, *50*(3-4), 299-316.
111. Slimani, S., Touchan, R., Derridj, A., Kherchouche, D., & Gutiérrez, E. (2014). Fire history of Atlas cedar (*Cedrus atlantica* Manetti) in Mount Chélia, northern Algeria. *Journal of Arid Environments*, *104*, 116-123.
112. Suárez-Seoane, S., Osborne, P. E., & Alonso, J. C. (2002). Large-scale habitat selection by agricultural steppe birds in Spain: identifying species–habitat responses using generalized additive models. *Journal of Applied Ecology*, *39*(5), 755-771.

113. Sweeney, O. F. M., Wilson, M. W., Irwin, S., Kelly, T. C., & O'Halloran, J. (2010). Breeding bird communities of second-rotation plantations at different stages of the forest cycle. *Bird Study*, *57*(3), 301-314.
114. ter Braak, C. J. F., & Smilauer, P. (1998). *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (Version 4)*. Centre for Biometry.
115. Thomas, P. (2013). *Cedrus atlantica*. *The IUCN Red List of Threatened Species* 2013: e.T42303A2970716. https://dx.doi.org/10.2305/IUCN.UK.20131.RLTS.T42303A2970716.en. Downloaded on 12 August 2021.
116. Tomasevic, J. A., & Marzluff, J. M. (2017). Cavity nesting birds along an urban-wildland gradient: is human facilitation structuring the bird community?. *Urban Ecosystems*, *20*, 435-448.
117. Touhami, I., Chirino, E., Aouinti, H., El Khorchani, A., Elaieb, M. T., Khaldi, A., & Nasr, Z. (2020). Decline and dieback of cork oak (Quercus suber L.) forests in the Mediterranean basin: a case study of Kroumirie, Northwest Tunisia. *Journal of Forestry Research*, *31*(5), 1461-1477.
118. Turner, M. G., Gardner, R. H., O'neill, R. V., & O'Neill, R. V. (2001). *Landscape ecology in theory and practice* (Vol. 401). Springer New York.
119. Van Riper III, C., Van Riper, S. G., & Hansen, W. R. (2002). Epizootiology and effect of avian pox on Hawaiian forest birds. *The Auk*, *119*(4), 929-942.
120. Vélová, L., Véle, A., & Horák, J. (2021). Land use diversity and prey availability structure the bird communities in Norway spruce plantation forests. *Forest Ecology and Management*, *480*, 118657.
121. Vickery, J., & Gill, J. (1999). Managing grassland for wild geese in Britain: a review. *Biological Conservation*, *89*(1), 93-106.
122. Wiens, J. A. (1989). Spatial scaling in ecology. *Functional ecology*, *3*(4), 385-397.
123. Wiens, J. A., & Rotenberry, J. T. (1981). Habitat associations and community structure of birds in shrubsteppe environments. *Ecological monographs*, *51*(1), 21-42.
124. Xu, X., Xie, Y., Qi, K., Luo, Z., & Wang, X. (2018). Detecting the response of bird communities and biodiversity to habitat loss and fragmentation due to urbanization. *Science of the total environment*, *624*, 1561-1576.
125. Yue, L., Juying, J., Bingzhe, T., Binting, C., & Hang, L. (2020). Response of runoff and soil erosion to erosive rainstorm events and vegetation restoration on abandoned slope farmland in the Loess Plateau region, China. *Journal of Hydrology*, *584*, 124694.
126. Yurkov, A. M., Röhl, O., Pontes, A., Carvalho, C., Maldonado, C., & Sampaio, J. P. (2016). Local climatic conditions constrain soil yeast diversity patterns in Mediterranean forests, woodlands and scrub biome. *FEMS yeast research*, *16*(1), 1-11.
127. Zarnowitz, J. E., & Manuwal, D. A. (1985). The effects of forest management on cavity-nesting birds in northwestern Washington. *The Journal of wildlife management*, *49*(1), 255-263.

Tables

Table 1: Bird species/families/orders recorded in Atlas cedar forest during the breeding period of 2019 and 2020.

- P: Protected – UP: Unprotected (according to the National protection status 2012)
- LC: Least Concern – VU: Vulnerable (according to the IUCN Red List status 2021.1)

No. Common English name/ Scientific name	Code	Abundance (pairs)	National protection status 2012	IUCN Red List status 2021.1
Order: Accipitriformes				
Family: Accipitridae				
1. Short-toed Snake- Eagle/ *Circaetus gallicus*	_		P	LC
2. Eurasian Sparrowhawk/ *Accipiter nisus*	_		P	LC
3. Black Kite/ *Milvus migrans migrans*	_		P	LC
4. Atlas Long-Legged Buzzard/ *Buteo rufinus cirtensis*	_		P	LC
Order: Falconiformes				
Family: Falconidae				
5. Common Kestrel/ *Falco tinnunculus*	_		P	LC
6. Peregrine Falcon/ *Falco peregrinus*	_		P	LC
Order: Columbiformes				
Family: Columbidae				
7. European Turtle/ Dove *Streptopelia turtur*	STTU	1	NP	VU
Order: Coraciiformes				
Family : Meropidae				
8. European Bee-eater/ *Merops apiaster*	_		P	LC
Family: Coraciidae				
9. European Roller/ *Coracias garrulus*	COGA	1	P	LC
Order: Cuculiformes				
Family: Cuculidae				
10. Common Cuckoo/ *Cuculus canorus*	CUCA	8	NP	LC
Order: Passeriformes				
Family: Paridae				
11. Coal Tit/ *Periparus ater ledouci*	PEAT	1	NP	LC
12. Great Tit/ *Parus major*	PAMA	1.5	NP	LC
13. African Blue Tit/ *Cyanistes teneriffae*	PACA	23	NP	LC

Family: Alaudidae				
14. Calandra Lark/ *Melanocorypha calandra*	MECA	1	NP	LC
15. Eurasian Skylark/ *Alauda arvensis*	ALAR	1.5	NP	LC
16. Woodlark/ *Lullula arborea*	LUAR	11.5	NP	LC
Family: Emberizidae				
17. Corn Bunting/ *Emberiza calandra*	MICA	1	NP	LC
18. Cirl Bunting/ *Emberiza cirlus*	EMCI	3.5	NP	LC
Family: Sylviidae				
19. Eurasian Blackcap/ *Sylvia atricapilla*	SYAT	2.5	NP	LC
20. Garden Warbler/ *Sylvia borin*	SYBO	1	NP	LC
21. Common Whitethroat/ *Curruca communis*	SYCO	2.5	NP	LC
22. Sardinian Warbler/ *Curruca melanocephala*	SYME	14	NP	LC
23. Western Orphean Warbler/ *Curruca hortensis*	SYHO	1	NP	LC
24. Western Subalpine Warbler/ *Curruca iberiae*	SYCA	2	NP	LC
Family: Corvidae				
25. Eurasian Jay/ *Garrulus glandarius*	GAGL	1.5	P	LC
26. Northern Raven/ *Corvus corax tingitanus*	COCO	3.5	NP	LC
Family: Muscicapidae				
27. Spotted Flycatcher/ *Muscicapa striata*	MUST	9	NP	LC
28. Blue Rock Thrush/ *Monticola solitarius*	MOSO	1	NP	LC
29. Common Nightingale/ *Luscinia megarhynchos*	LUME	2.5	NP	LC
30. European Robin/ *Erithacus rubecula*	ERRU	27	NP	LC
31. Moussier's Redstart/ *Phoenicurus moussieri*	PHMO	16.5	P	LC
32. African Stonechat/ *Saxicola torquatus*	SARU	5	NP	LC
33. Black-eared Wheatear/ *Oenanthe hispanica*	OEHI	0.5	NP	LC
Family: Certhiidae				

34. Short-toed Treecreeper/ *Certhia brachydactyla*	CEBR	8	NP	LC
Family: Fringillidae				
35. Common Linnet/ *Linaria cannabina*	CACA	2	NP	LC
36. Common Chaffinch/ *Fringilla coelebs*	FRCO	36	NP	LC
37. European Serin/ *Serinus serinus*	SESE	3	NP	LC
38. European Greenfinch/ *Chloris chloris voosi*	CACH	16.5	NP	LC
Family: Turdidae				
39. Eurasian Blackbird/ *Turdus merula*	TUME	19	NP	LC
Family: Passeridae				
40. House Sparrow/ *Passer domesticus*	PADO	0.5	NP	LC
Family: Phylloscopidae				
41. Western Bonelli's Warbler/ *Phylloscopus bonelli*	PHBO	11.5	NP	LC
42. Iberian Chiffchaff/ *Phylloscopus ibericus*	PHIB	3.5	NP	LC
Family: Regulidae				
43. Common Firecrest/ *Regulus ignicapilla*	REIG	16.5	NP	LC
Family: Troglodytidae				
44. Northern Wren/ *Troglodytes troglodytes*	TRTR	19	NP	LC
Order: Piciformes				
Family: Picidae				
45. Eurasian Wryneck/ *Jynx torquilla*	JUTO	2	NP	LC
46. Great Spotted Woodpecker/ *Dendrocopos major numidus*	DEMA	2	NP	LC
47. Maghreb Green Woodpecker/ *Picus vaillantii*	PIVA	2	NP	LC

Table 2: Results of ANOVA Tests of significance of all fractions based on their p-value and and values of variation partitioning of a response bird data set Y explained by two datasets X (in the left: vegetation structure) and W (in the right: topography).

Fraction	Df	Var	F	N.Perm	Pr(>F)
[a+c]	7	0.20088	1.6117	999	**0.003 ****
[b+c]	4	0.099142	1.1788	999	0.16
[a+b+c]	11	0.28351	1.5734	999	**0.002 ****
[a]	7	0.18436	1.6079	999	**0.008 ****
[c]	4	0.082624	1.261	999	0.147

Table 3: Discriminant species with MRT results of each node, with its indval and p- values within the Atlas cedar woodlands afforestation of Mount M'Cid.

Species	IndVal	*P*	Split	μ on the left leaf	μ on the right leaf
L.arborea	0.5584384	0.004**	2	0.00	0.777
T.troglodytes	0.3741999	0.042*	1	1.00	0.562
E.rubecula	0.4202632	0.01**	3	1.00	0.787
T.merula	0.3240940	0.030*	3	1.00	0.505
P.bonelli	0.4938115	0.047*	1	1.00	0.709
M.striata	0.5741599	0.005**	2	1.00	0.774
F.coelebs	0.3253555	0.018*	2	1.00	0.452

Figures

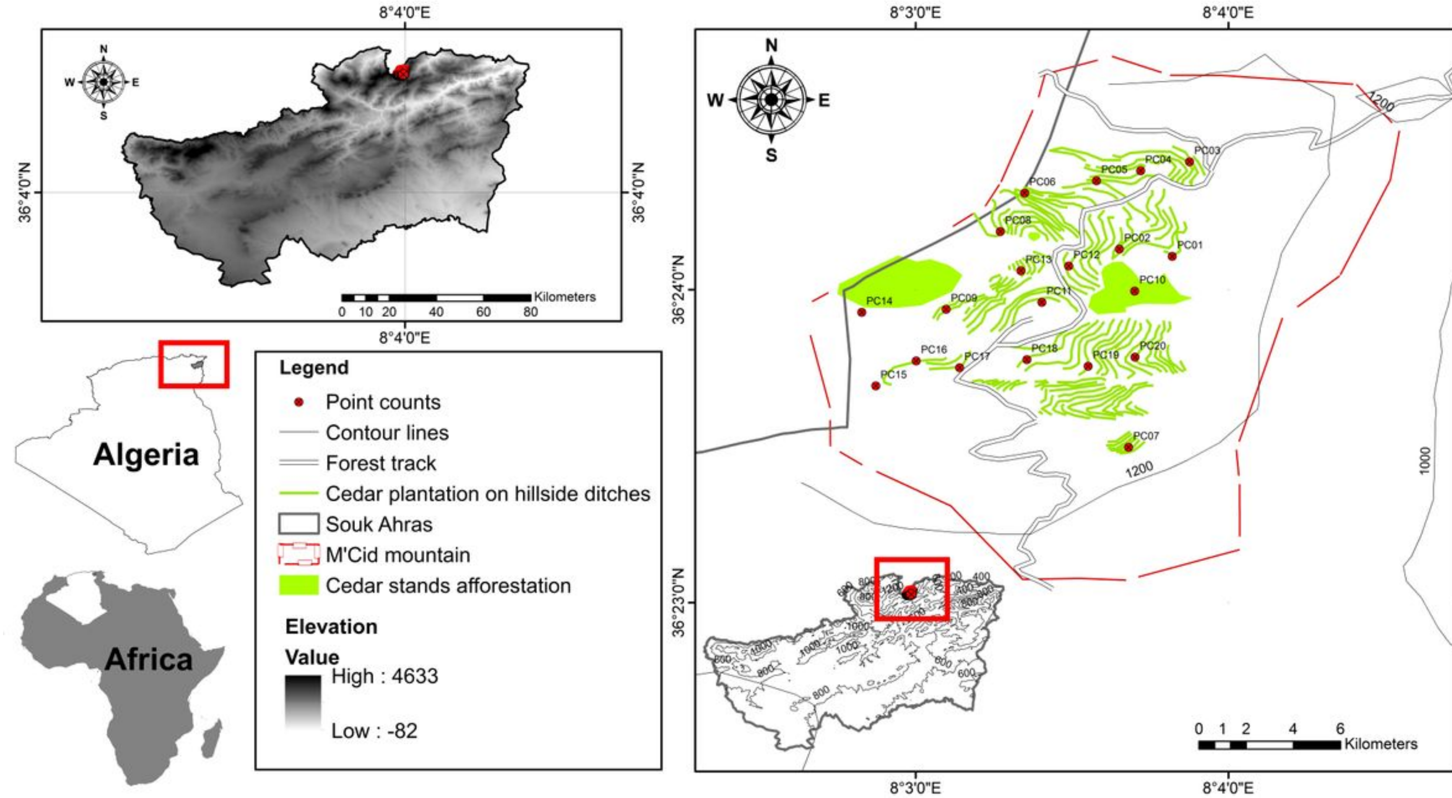

Figure 1

Geographic location of the Atlas cedar afforestation of Mount M’Cid.

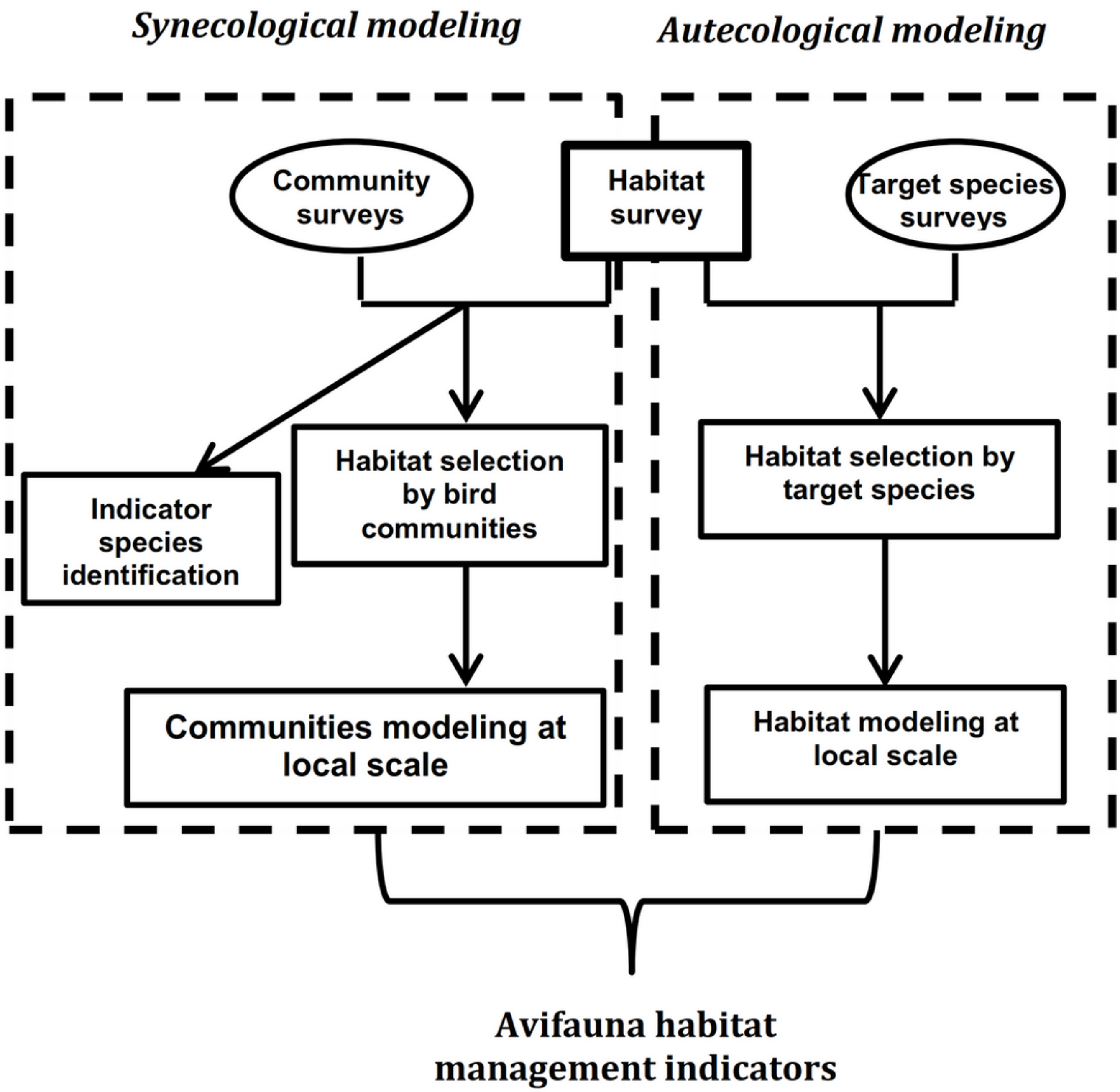

Figure 2

Multivariate synecological framework for modelling environmental responses of forest bird species.

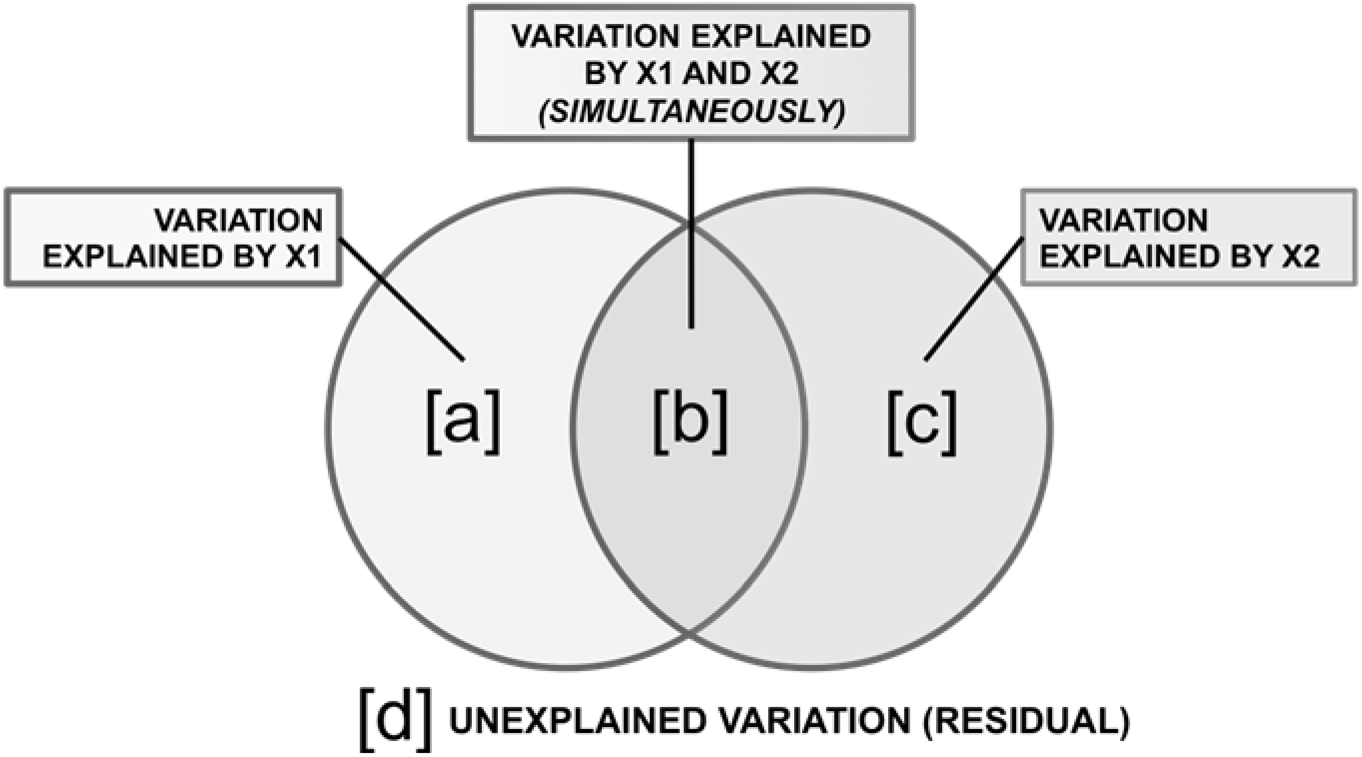

Figure 3

Venn diagram of partition of the variation of a response variable y among two sets of explanatory variables X and W (Legendre & Legendre 2012).

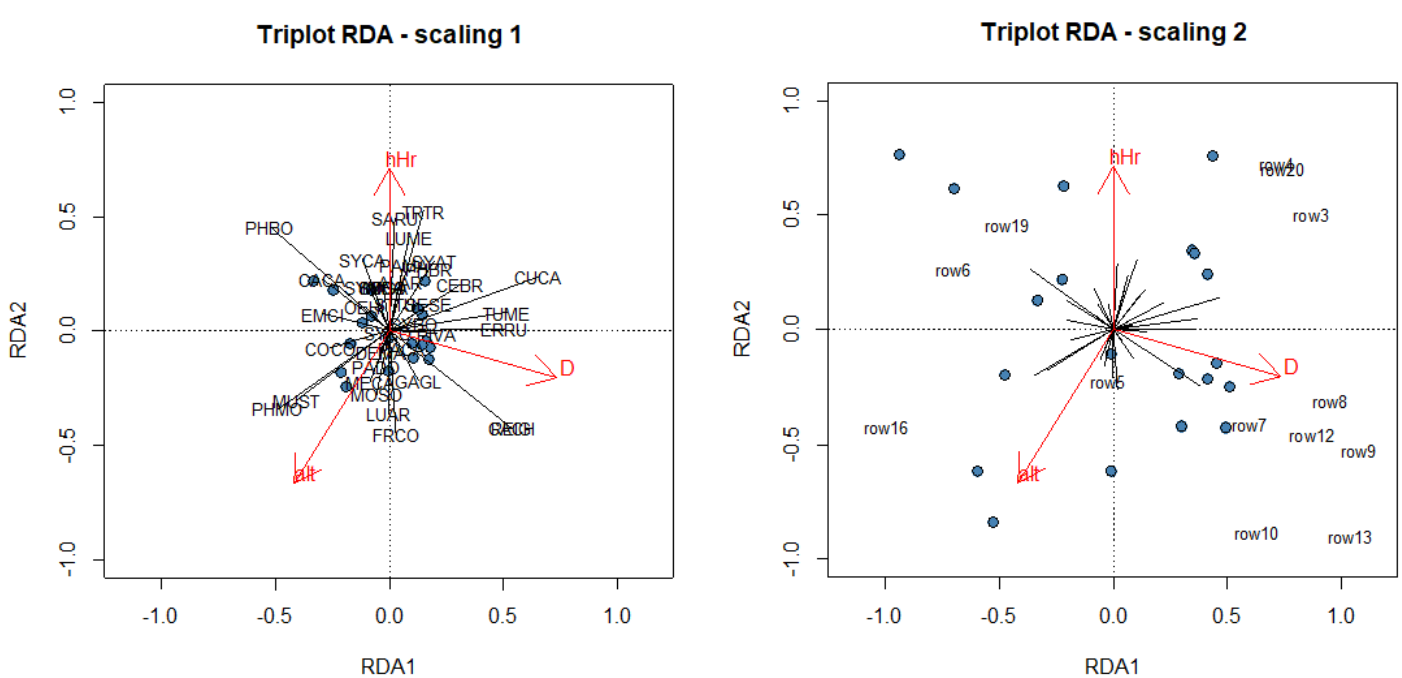

Figure 4

Ordination diagrams of the habitat redundancy analysis of the Hellinger-transformed bird data in the Atlas cedar stands of MountM’Cid (see codes in the table 1). Only species with scores >0.2 are shown.

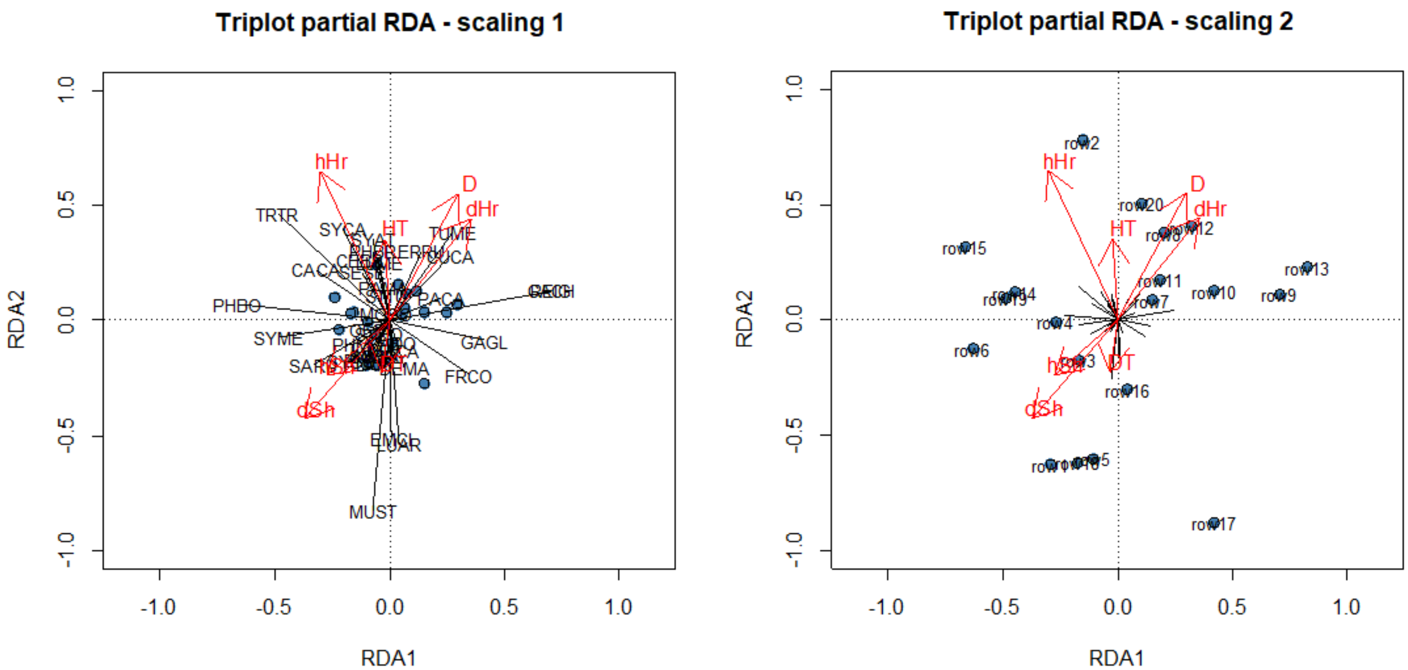

Figure 5

Ordination diagrams of the partial habitat redundancy analysis of the Hellinger-transformed bird data in the Atlas cedar stands of Mount M’Cid (see codes in the table 1). Only species with scores >0.2 are shown.

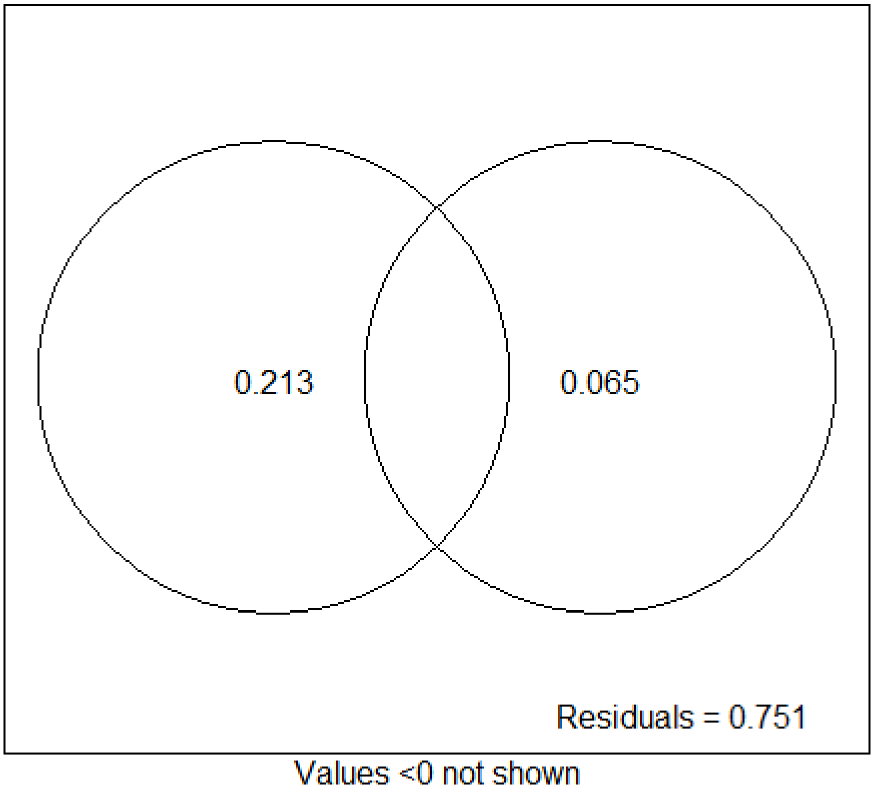

Figure 6

Venn diagram of the variation partitioning of a response bird data set Y explained by two data sets X (in the left: vegetation structure) and W (in the right: topography). The rectangle represents the total sum-of-squares of Y.

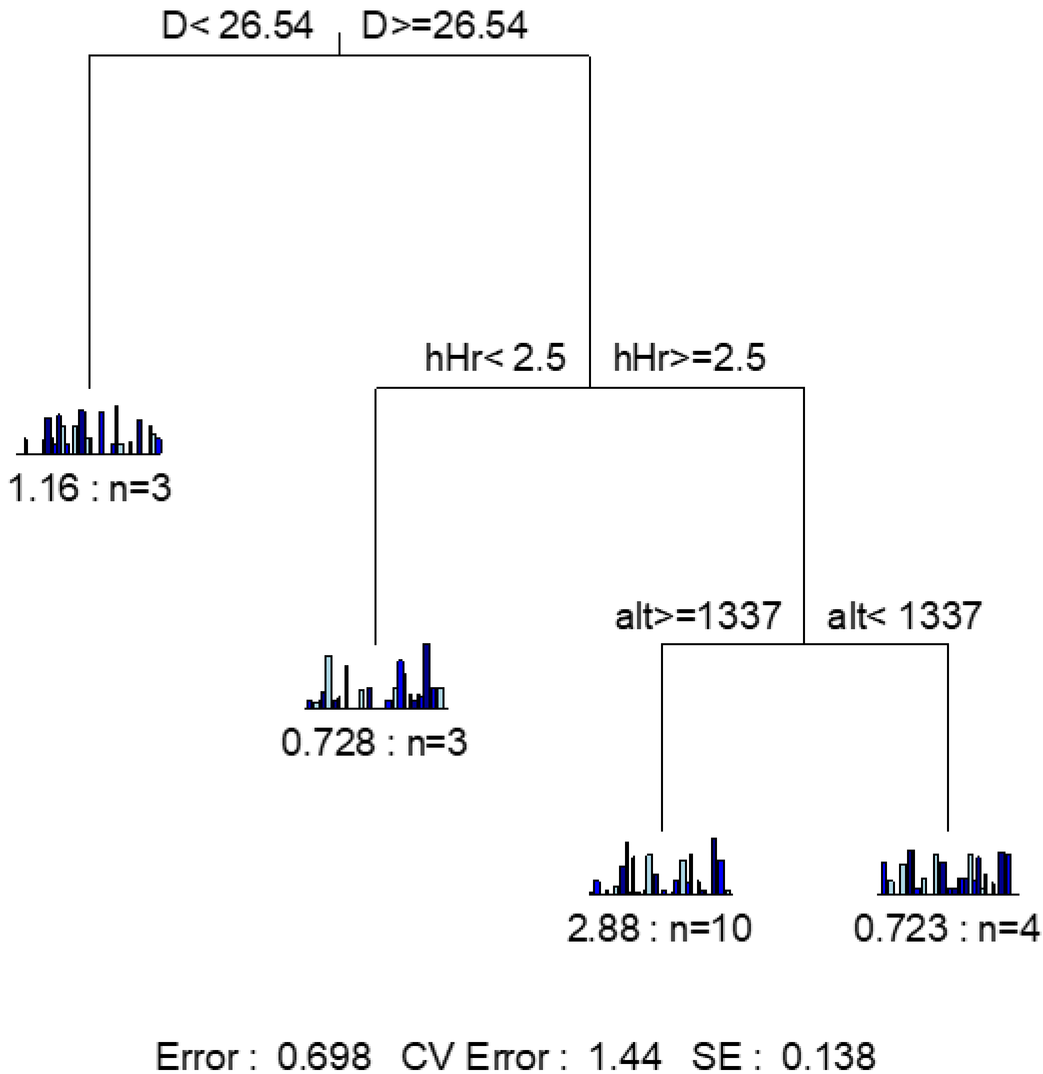

Figure 7

Multivariate regression tree of the bird data matrix explained by their environmental predictors in the Atlas cedar stands of Mount M'Cid.