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Climate and vegetation structure determine plant diversity in *Quercus ilex* woodlands along an aridity and human-use gradient in Northern Algeria

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ABSTRACT

We studied the influence of environmental factors relating to climate, soil and vegetation cover on total species richness, species richness of different life-forms and species composition of plant communities occurring in *Quercus ilex* woodlands, across a 450-km long transect in Northern Algeria constituting a gradient of aridity and human use. We sampled vegetation and collected environmental data in 81 10 m × 10 m plots in five zones representing the largest *Q. ilex* woodlands throughout the study area, analysing them within an a priori hypothesis framework with the use of Path Analysis. Changes in plant diversity were mainly influenced by environmental factors related to precipitation and temperature regimes, as well as by total plant cover. In particular, changes in species composition were determined by factors associated with the temperature regime through their influence on both woody and annual herbaceous plant richness, and by factors related to the precipitation regime through their influence on perennial herbaceous plant richness, likely due to the differential tolerances of these functional groups to cold and water stress. Our results emphasize the importance of differences in environmental adaptability of the most important life-forms with regard to explaining compositional change (beta diversity) along aridity gradients, and the mediator role of total plant cover in relation to the effects of soil conditions on plant diversity.

Introduction

Explaining the relationships between diversity of vascular plant communities and environmental factors across broad-scale geographical gradients is of particular interest for ecological research (Pausas and Austin, 2001). There has been an increasing amount of studies on this topic over the last few decades (Ferrer-Castán and Vetaas, 2005; Vetaas and Ferrer-Castán, 2008; Field et al., 2009), a fact that might help to assess the main processes determining the assemblage of plant communities (Lortie et al., 2004), and the prevalence of negative (i.e. intra- and inter-specific competition) and positive (i.e. facilitation) interactions thereupon (Bertness and Callaway, 1994). These studies are often linked to applied issues such as land management and predictions related to climate change (Whittaker et al., 2007).

Plant diversity presents different components and can be measured in different ways, but it is usually expressed as species richness at a given location – alpha diversity) and as the rate of compositional change along habitat gradients – beta diversity) (Purvis

and Hector, 2000; Rey-Benayas and Scheiner, 2002). Over any large region, vascular plant diversity is primarily governed by abiotic factors associated with climate, in particular to the water (precipitation) and energy (temperature) regimes (O'Brien, 2006). Factors related to the precipitation regime are the strongest predictors of plant diversity patterns in the warm temperate zones of the world (Hawkins et al., 2003), in Southern Europe (Whittaker et al., 2007), and along shorter environmental gradients in Mediterranean-climate areas (Kutiel et al., 2000). In areas where water is a limiting factor, plant diversity is also determined by factors relating to the temperature regime, showing a decrease with higher temperatures (Whittaker et al., 2007). Changes in plant diversity are also affected by edaphic conditions such as soil fertility (Cowling et al., 1996), texture and moisture (Rey-Benayas and Scheiner, 2002). Abiotic factors related to climate and soil that determine changes in plant diversity across environmental gradients are usually closely inter-related (Purvis and Hector, 2000; Pausas and Austin, 2001). Thus, soil fertility is affected by precipitation and temperature (Sarah, 2004) and by soil moisture and texture (Sardans and Peñuelas, 2007), whereas soil moisture is strongly influenced by precipitation, temperature and soil texture (Rey-Benayas et al., 2004).

Changes in vascular plant diversity are also affected by biotic factors associated with vegetation structure, such as total plant cover, which can be considered as a correlate for interactions between woody and herbaceous plants (North et al., 2005). In

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the Mediterranean-climate regions of the world total plant cover may enhance recruitment of annual herbaceous plants by alleviating water and irradiance stress in the understory (Adkinson and Gleeson, 2004). Total plant cover commonly shows strong and positive relationships with plant diversity and depends on precipitation and temperature (Torras et al., 2008). In Mediterranean regions it is also limited by soil texture (Le Houérou, 2001), moisture and fertility (Moreno-de-las-Heras et al., 2009). Total plant cover plays also an important role in mediating relationships between soil conditions and plant diversity (Ehrenfeld et al., 2005), and can be greatly determined by human activities such as wood extraction and grazing by domestic herbivores (De Bello et al., 2005).

Since relationships between vascular plant diversity and ecosystem processes depend to a great extent on the presence and dominance of different functional groups (Chapin, 2003; Berendse, 2005; Lavorel et al., 2007), relationships between plant diversity and environment across broad-scale geographical gradients are easier to interpret if changes in species richness of functional types are considered, and plant growth or their life forms are commonly used for this purpose (Pausas and Austin, 2001). Woody and herbaceous species are characterized by different kinds of adaptations to water limitation and consequently, they show differential responses to regional variations in precipitation (Kadmon and Danin, 1999). Woody plants, with their deep-reaching and extensive root systems, make use of the water stored in deeper soil layers (Lu et al., 2006). Based on this, in the Mediterranean basin they may even appear in relatively dry areas (Bonet and Pausas, 2004), and changes in species richness of this life form across environmental gradients are determined by factors related to the temperature regime rather than to precipitation (Field et al., 2005; Whittaker et al., 2007; Vetaas and Ferrer-Castán, 2008). Conversely, herbaceous plants can only utilize the transient water stored in the topsoil, synchronic with spatial (i.e. topography and texture) and temporal (i.e. precipitation) pulses (Lu et al., 2006). Their presence in a specific area is most often highly dependent on soil conditions, in particular soil moisture (Sher et al., 2004; North et al., 2005). In semi-arid areas, annual herbaceous plant richness commonly exhibits a large spatial and temporal variability, although it usually shows an increase in places where total plant cover is higher (Holzapfel et al., 2006).

The effects of climatic factors upon changes in species richness and composition of vascular plants along broad-scale geographical gradients have been widely evaluated (Rey-Benayas and Scheiner, 2002; Vetaas and Ferrer-Castán, 2008). The same applies to the effects of abiotic factors related to soil conditions upon changes in total plant richness (Maestre, 2004) and in richness of the main functional types (Kadmon and Danin, 1999; Kutiel et al., 2000; Lu et al., 2006) at regional scales. There is, however, a lack of studies focusing both on abiotic and biotic factors as determinants of changes in species richness and composition and on the plant richness of major life-forms, considering the interrelations between factors (Lortie et al., 2004).

In this study, we analyze the influence of environmental factors on plant diversity of holm-oak (*Quercus ilex* sp. *rotundifolia*, L.) woodlands along an aridity gradient overlaying a human-use gradient in Northern Algeria. We focused on this area because it includes a smooth biome transition between Mediterranean and arid climatic conditions and because biome transition zones are the areas most sensitive to directional changes in climate (di Castri et al., 1988). As *Q. ilex* woodland constitutes the most widely distributed vegetation type across the study area, it enables comparisons among relatively distant sites. We aim to explain the relative importance of factors related to the precipitation and temperature regimes, soil conditions and total plant cover with regard to determining changes in total species richness and composition, and species richness of woody, perennial herbaceous and annual

herbaceous plants, and we attempt to assess how these factors interrelate. Specifically, we hypothesized that: (i) Changes in total plant richness and species composition will be primarily determined by factors associated with the precipitation and temperature regimes, respectively. (ii) Changes in woody plant richness will be mainly determined by factors related to the temperature regime, whereas changes in herbaceous plant richness will be determined principally by factors related to the precipitation regime. In particular, annuals will be positively affected by soil moisture and by total plant cover. (iii) Factors related to soil conditions will determine changes in total plant richness and species composition through their effects on total plant cover. Verification of these predictions will provide clues to the processes determining plant diversity across areas representing the transition between humid and semi-arid Mediterranean climate conditions, and in relation to plausible changes in the Mediterranean plant communities of Northern Africa under regional predictions of climate change.

Materials and methods

Study area

The study was conducted along a latitudinal transect in Northern Algeria (36° 36′–34° N and 2°–3° 37′ E), which is 450 km long and encompasses the transition between Mediterranean and arid climate conditions (Fig. 1). In this area, *Q. ilex* woodlands occur mostly on steep and northern-oriented slopes within a broad altitudinal range (300–2200 m.a.s.l), but they have a clear preference for higher altitudes in the southernmost areas (Dahmani-Megrerouche, 2002). As many other types of vegetation in Northern Africa, they are suffering from increasingly intense and frequent human-induced disturbances such as firewood extraction and grazing (Vogiatzakis et al., 2006).

Along this transect we selected the largest areas of *Q. ilex* woodlands, which were grouped into five zones, namely Blida, Miliana, Berrouaghia, Teniet-el-Had and Aflou. These zones presented a broad array of climatic conditions within the Mediterranean domain (Table 1 and Fig. 1) as well as different intensities of human use (Table 2). Blida and Miliana show mostly sub-humid/warm climatic conditions with some humid/warm locations. They differ in human-use intensity, which is greater in Miliana than in Blida because of the higher cattle and livestock load. Of the five zones, Blida comprises the largest area of *Quercus ilex* woodlands. Berrouaghia and Teniet-el-Had show sub-humid/cold and dry/cold climatic conditions, respectively. Both zones present a higher livestock load than Blida and Miliana. Berrouaghia also harbours the largest human population in the study region. Aflou exhibits very dry/cold climatic conditions and has the largest livestock load. The Aflou *Quercus ilex* woodlands cover the smallest area of the five investigated zones. In general terms, heading south along the transect, precipitation and mean minimum temperatures decreases and livestock load increases.

Field sampling

We sampled a total of 81 10 m × 10 m plots. The number of plots per zone (28 in Blida, 9 in Miliana, 18 in Berrouaghia, 11 in Theniet-el-Had and 15 in Aflou) referred to the total area occupied by *Quercus ilex* woodlands (Table 2). Miliana was an exception, as proportionately fewer plots were surveyed due to the fact that access was restricted to much of the *Q. ilex* woodland in this zone. Field sampling was performed in spring (April–May). We sampled most plots in 1990, but five were sampled in 1991 (all in Blida) and 15 (ten in Blida and five in Miliana) in 1999, due to security problems. In each plot, we collected data on the number of species
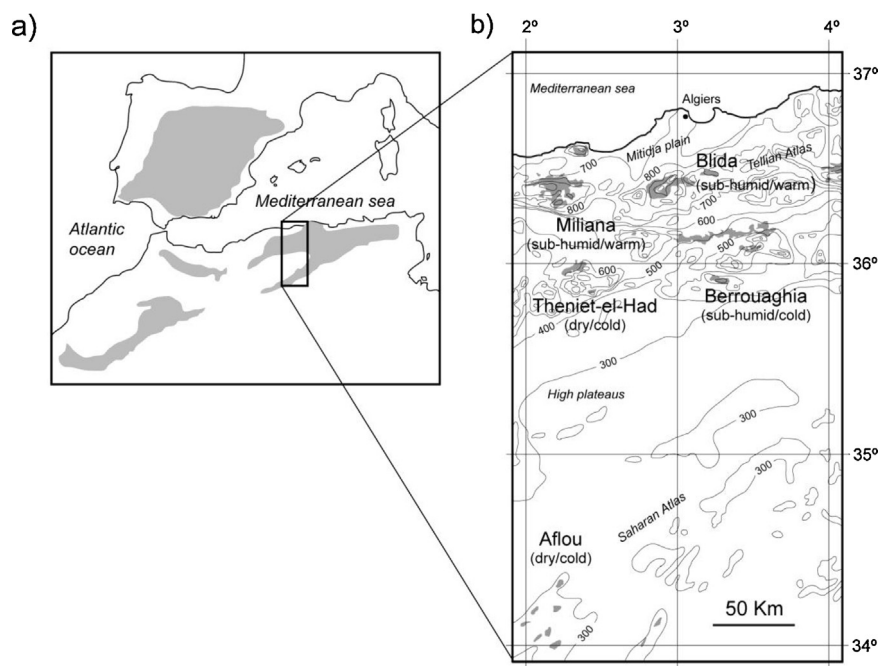
Fig. 1. (a) Location of the study area showing the potential distribution area of *Quercus ilex* sp. *rotundifolia* (in grey). (b) Detailed map of the aridity gradient considered in the study showing isohyets of mean annual precipitation (mm) – in black, areas occupied by *Q. ilex* sp. *rotundifolia* woodlands – in grey, and locations of the five sampling zones selected, namely Blida and Miliana (sub-humid/warm), Berrouaghia (sub-humid/cold), Theniet-el-Had (dry/cold) and Aflou (very dry/cold).

and species composition. All species were classified according to three relevant life-forms: woody, perennial herbaceous and annual herbaceous plants.

For each plot, we recorded data on environmental factors with a direct impact on physiological processes and which thus limit the spatial distribution of the plants (Pausas and Austin, 2001). We

obtained climate data from records of the nearest meteorological stations (Table 1): mean annual precipitation (hereafter MAP, mm), mean quotient of monthly precipitation and mean minimum temperature of the coldest month (hereafter MTC, °C). We obtained soil data by taking three 20-cm deep soil cores in each plot; the cores were mixed into a single composite soil sample that was

Table 1
Climatic conditions of the five zones considered in the present study (Aflou, Berrouaghia, Theniet-el-Had, Miliana and Blida), according to records from the nearest meteorological stations. Data were provided by the *Office National de la Météorologie* (Algiers).

Zone	Aflou	Berrouaghia	Theniet-el-Had			Miliana	Blida			
Meteorological station	Aflou	Berrouaghia	Bir Ghbalou	Theniet- el-Had	Bordj el emir Abdelkader	Miliana	Blida	Lac Mouzaia	Camp des Chênes	Chréa
Latitude	34°7′ N	36°8′ N	36°16′ N	35°52′ N	35°52′ N	36°19′ N	36°28′ N	36°22′ N	36°22′ N	36°2′ N
Longitude	2°6′ E	2°55′ E	3°35′ E	2°1′ E	2°16′ E	2°14′ E	2°50′ E	2°41′ E	2°47′ E	2°53′ E
Elevation (m.a.s.l.)	1406	925	642	1160	1050	750	267	1270	941	1550
Time of measurement (years)	1965–95	1965–95	1968–95	1968–95	1972–95	1960–95	1960–95	1960–95	1970–95	1960–95
Number of plots	15	18	7[a]	11[a]	4[a]	9	2[b]	17[b]	12[b]	9[b]
Mean annual precipitation (MAP) (mm)	340	593	542	620	520	950	950	930	990	1380
Quotient of monthly precipitation; monthly SD/monthly mean precipitation (mm)	0.355	0.608	0.555	0.537	0.540	0.715	0.543	0.680	0.829	0.647
Mean summer rainfall (mm)	48	24	35	38	47	36	47	37	18	70
Mean annual number of days of precipitation	66	60	59	72	81	98	NA	88	NA	NA
Mean annual temperature (MAT) (°C)	13.1	14.2	NA	13.5	NA	15.7	18.3	11.7	NA	11
Mean of the minimums of the coldest month (°C)	-1.3	0.6	NA	0.2	NA	4.6	7.3	1.0	NA	0.4
Mean of the maximums of the warmest months (°C)	33.0	34.2	NA	32	NA	31.1	33.6	28.8	NA	26.3
Evapotranspiration (m/year)[c]	0.29	0.47	NA	0.48	NA	0.65	0.68	0.57	NA	0.56

[a] In Theniet-el-Had we used precipitation data from the Bir-Ghbalou and Bordj el emir Abdelkader meteorological stations for 7 and 4 plots, respectively, and temperature data from the Theniet-el-Had meteorological station for all 11 plots.

[b] In Blida, we used precipitation data from the Camp des Chênes meteorological station and temperature data from the Lac Mouzaia meteorological station for 12 plots.

[c] We calculated evapotranspiration with the Coutagne method (Remenieras, 1974): $ET = MAP - \lambda MAP^2$, where $\lambda = 1/(0.8 - 0.14 \times MAT)$. MAP = mean annual precipitation, MAT = mean annual temperature.

Table 2

Area and surrogates of human-use intensity of the five zones considered in the study (Aflou, Berrouaghia, Theniet-el-Had, Miliana and Blida). Data on human population density and density of cows, sheep and goats (numbers/km^2) correspond to the different provinces (Wilayas) in which the five study zones are located, and were obtained from the *Office National des Statistiques* (Algiers). Number of cows and number of sheep and goats are referred to as cattle and livestock load, respectively.

Zone	Aflou	Berrouaghia	Theniet-el-Had	Miliana	Blida
Province (Wilaya)	Laghouat	Médea	Tissemssilt	Ain Defla	Blida
Area of *Quercus ilex* woodlands (ha)	1350	6900	1545	1860	10,500
Human population density (number km^{-2})	6.89	83.66	40.47	108.26	298.04
Density of cows (number km^{-2})	0.80	5.06	4.69	7.13	11.94
Number of sheep (number km^{-2})	52.17	71.74	52.34	36.74	25.95
Number of goats (number km^{-2})	9.61	5.48	1.47	5.07	5.62

analyzed after being dried, crushed and passed through a 2-mm sieve. We measured soil water content at three soil water potential values (Pf2.5, Pf3 and Pf4.2, at 0.33, 1 and 13 bar, respectively) by means of a pressure membrane, before and after drying soil samples in an air oven at 105 °C. Soil fertility variables included soil organic matter (calculated from organic C with Anne's method, i.e. dichromate oxidation; Anne, 1945), total N (calculated by means of Kjeldahl's method), exchangeable Ca, Mg, K and Na (calculated from photometric determinations upon extraction with 1 M ammonium acetate at pH = 7.0), effective cationic exchange capacity (hereafter CEC; calculated with Metson's method; Metson, 1956), percent total and active limestone (calculated after extraction of calcium carbonate with ammonium oxalate), and pH (determined in a 1:2.5 suspension with 1 M KCl). Soil texture variables included clay, silt and sand proportions in each plot, proportions of the most abundant types of clay, namely kaolinite, chlorite and illite, and proportions of fine- and coarse-grained sand. Total plant cover (hereafter TPC, %) was estimated by means of direct visual estimation. Data on topography-related factors such as latitude and longitude, elevation (m.a.s.l), slope (%), and aspect (N, S, W and E) were measured with a GPS and a clinometer. However, we did not include these factors in our analyses because they were surrogates of other important variables affecting plant growth (Pausas and Austin, 2001). Nomenclature of plant species follows Maire (1982) and Castroviejo et al. (2009).

Data analysis

To determine whether there were significant differences in species composition among the five zones, we applied an Analysis of Similarities (ANOSIM) (Clarke, 1993) to the presence-absence (plots x species) matrix, using 99,999 Monte–Carlo permutations. To determine if there were significant differences between zones for all environmental factors considered, we performed one-way ANOVA and post hoc Tukey's tests.

To identify the major gradients of change in species composition and their explanatory environmental factors, we followed a two-step procedure. First, we selected the most independent and meaningful environmental factors by means of a Pearson's product-moment correlation considering all factors and a principal component analysis (PCA) for each group of climatic, soil-moisture, soil-fertility and soil-texture factors separately. As we detected highly correlated factors within these groups of variables (Pearson's r > 0.6), we selected those with the highest factor loadings (> 0.5) on the first PCA axis, in each group of factors. Among the factors associated with temperature regime, soil moisture, fertility and texture, we selected MAP, Pf3, CEC and proportion of sand, respectively (Appendix 1). Secondly, we used a Non-metric Multidimensional Scaling (NMDS) ordination analysis to visualize floristic gradients and interpret them with respect to the environmental factors selected. As changes in species richness and composition among plots can be influenced by their spatial locations (namely elevation and latitude) across the study area, we partitioned the variation of species composition into several components, namely pure

environmental, pure spatial, environmental component of spatial influence and spatial component of environmental influence, through a sequence of analyses (Borcard et al., 1992). We determined the general variance in species composition by performing a detrended correspondence analysis (DCA), and the environmental and spatial components of this variance by performing two canonical correspondence analyses (CCA), constrained by the environmental factors previously selected by the PCA (CCA1) and the spatial data (i.e. latitude, longitude and elevation) (CCA2), respectively. We determined the environmental component of spatial influence and the spatial component of environmental influence by conducting two partial CCA (pCCA), one constrained by the environmental factors and using the best spatial predictors detected in CCA1 as covariables (pCCA1), and the other constrained by the spatial data and using the best environmental predictors detected in the CCA2 as covariables (pCCA2). In all CCA and pCCA analyses, we evaluated the significance of the first ordination axis by performing Monte–Carlo tests with 999 permutations.

To assess the relative importance of the selected environmental factors in determining species composition, total species richness and species richness of life-forms, and to investigate their interrelationships, we used Path Analysis (Shipley, 1997). Path Analysis is a technique especially developed to test a model of relationships among variables (path diagram) which is proposed by the researcher based on a priori knowledge (Malaeb et al., 2000). The results of a Path Analysis yield several goodness-of-fit indices of the overall model, unexplained variances for the "focus" (pure dependent) and "endogenous" (which can act either as independent or dependent) variables and standardized partial regression coefficients for each relationship in the model. Low unexplained variances for the "focus" variable imply that the equations are considering relevant explanatory variables (Iriondo et al., 2003). Each standardized partial regression coefficient has a sign that indicates the direction of the relationship, a magnitude value (0–1) which indicates the degree to which the independent variable directly influences the dependent variable of the analyzed relationship with all other variables held constant, and a significance value that is assessed by means of a multivariate Wald's test (Shipley, 1997).

We considered as focus variables of the tested relationships total plant richness, woody, perennial herbaceous and annual herbaceous plant richness, and species composition. The latter was measured as coordinates of plots in the first dimension of the NMDS. As independent variables, and in order to avoid problems related with the presence of strongly correlated factors (i.e. collinearity; Petraitis et al., 1996), we considered the factors previously selected at the Pearson's product-moment correlation and PCA; mean annual precipitation, soil water content (Pf3), effective cationic exchange capacity, proportion of sand and total plant cover (Appendix 1). We proposed an initial path diagram (Model A: Fig. 2), and in order to make it simpler and improve its goodness-of-fit, we considered alternative path diagrams which sequentially excluded those paths showing the lowest non-significant standardized partial regression coefficients (Petraitis et al., 1996),
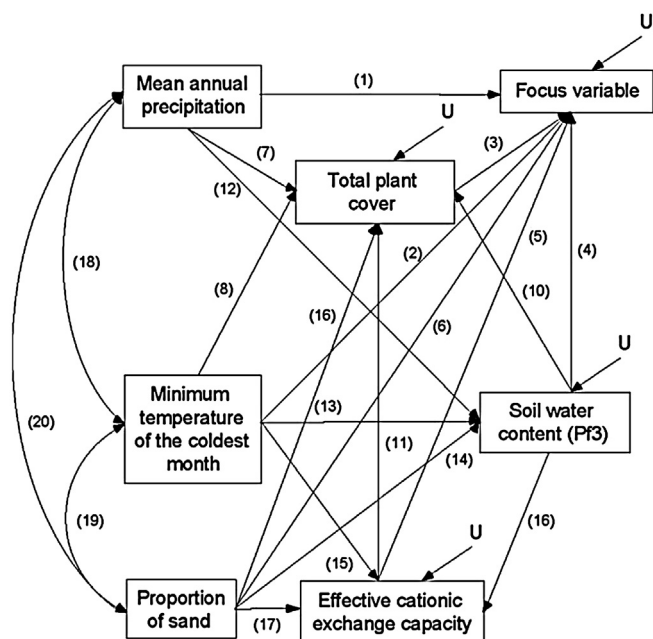
Fig. 2. Path diagram of the *a-prioristic* initial model (Model A) hypothesizing the relationships among each of the focus variables (total species richness, woody, perennial and annual herbaceous plant richness, or species composition), and mean annual precipitation (MAP), mean minimum temperature of the coldest month (MTC), total plant cover (TVC), proportion of sand, soil water content (Pf3) and effective cationic exchange capacity. Relationships, residual correlations and unexplained variances of exogenous variables are depicted by single-headed arrows, double-headed arrows, and arrows not originating at any variable (U), respectively. Numbers match the relationships explained in the main text. According to this model, all focus variables are primarily determined by MAP, MTC, TVC, soil water content (Pf3), effective cationic exchange capacity and proportion of sand (paths 1–6). TVC is, in turn, determined by MAP, MTC, proportion of sand, soil water content (Pf3) and effective cationic exchange capacity (paths 7–11). Soil water content is determined by MAP, MTC and proportion of sand (paths 12–14), and effective cationic exchange capacity is determined by MAP, soil water content and proportion of sand (paths 15–17). Residual correlations between MAP, MTC and proportion of sand are represented by paths 18–20.

and were labelled models B, C, D, E, F and G. In all models, we considered residual correlations between the exogenous variables and unexplained variances for each of the focus variables (Fig. 2). We evaluated the Goodness-of-fit of all models by means of a "Chi-square" test (χ^2 statistic), and calculated the Bentler and Bonnet's normed-fit and Goodness-of-fit indices, NFI and GFI, respectively, which are specially recommended when the number of observations is <100 (Iriondo et al., 2003). A high and non-significant χ^2 statistic and values of NFI and GFI indices > 0.9 indicate an acceptable fit of the models. As we provide sound theoretical justifications for maintaining all the paths represented in the initial model, we only kept any of the alternative models based on the principle of parsimony when their χ^2 values remained relatively low despite their increasingly higher number of degrees-of-freedom (Malaeb et al., 2000).

When necessary, variables were log, square-root, arc-sin or box-cox transformed to achieve normality and linearity assumptions. In simultaneous inference for multiple tests, and in order to avoid type I errors, we applied Rice's sequential correction. We performed the ANOSIM analysis using PRIMER 6.0 (PRIMER-E Ltd., Plymouth, UK). We used the R Community Ecology Package "vegan" (Version 1.6–10. http://cc.oulu.fi/~jarioksa/) for NMDS, DCA, CCA and pCCA analyses and STATISTICA (Data analysis software system 6, Statsoft 2001, Tulsa, Oklahoma, USA) for Pearson's product moment correlations and the PCA. We performed Path Analyses with AMOS 5.0 (Version 7.0; SPSS, Chicago).
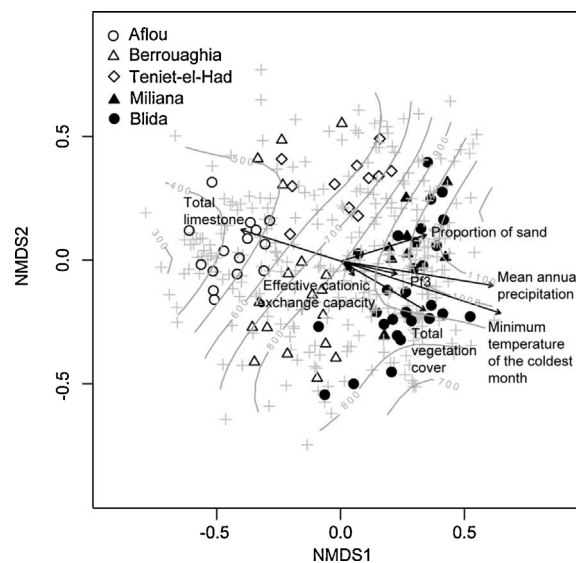
Fig. 3. Non-metric multidimensional scaling ordination of species composition in the 81 plots considered in the study, showing the interpretation of the ordination axes with respect to major environmental factors. Species composition is expressed as coordinates of the sample plots. Symbols (both, full and empty) indicate plots, crosses indicate species and arrows indicate environmental factors. The smoothing surface lines (Oksanen et al., 2010) for mean annual precipitation are shown in grey.

Results

Floristic and environmental characterization of zones

Along the transect we found a total number of 395 plant species; 56 (14.5%) were woody, 123 (31.1%) perennial and 215 (54.4%) annual herbaceous species, respectively (Appendix 2). In general terms the five zones differed in species composition (ANOSIM's $R = 0.5158$, $P < 0.001$). We found the biggest differences between Aflou and Miliana (ANOSIM's $R = 0.91$, $P < 0.001$) and between Aflou and Blida (ANOSIM's $R = 0.76$, $P < 0.001$). One-way ANOVA tests revealed overall significant differences between the five zones in perennial herbaceous and woody plant richness, and in climate (mean annual precipitation, mean minimum temperature of the coldest month and quotient of monthly precipitation), soil fertility (percent total and active limestone, pH), soil texture (proportions of sand, silt, fine- and coarse-grained sand, kaolinite, illite and chlorite), and total plant cover (Appendix 2). According to Tukey's post hoc tests, the plots in Miliana and Blida were significantly different from those in Aflou, Berrouaghia and Theniet-el-Had in terms of woody plant richness, mean annual precipitation, pH, and proportions of sand, silt and illite. The Aflou plots differed significantly from those in Blida with regard to elevation, percentage of total and active limestone, proportions of fine- and coarse-grained sand, and from the plots in Miliana in relation to their values of total plant cover (Appendix 3).

Gradients of species composition

The best two-dimensional solution of the NMDS ordination presented a stress value of 0.26 and showed a sharp differentiation of the five zones along the first dimension (Fig. 3). Changes in species composition along the first NMDS dimension were explained by variations in mean minimum temperature of the coldest month and mean annual precipitation, proportion of sand, total plant cover and soil water content (Pf3), in decreasing order of importance. Changes in species composition along the second NMDS dimension were explained by variation in effective cationic exchange capacity. A large amount of variance remains unexplained by environmental

Table 3
Summary of results of ordination analyses performed for variance partitioning, including: unconstrained (DCA), constrained by environmental factors (CCA1) and spatial data (CCA2), constrained by environmental factors after adjusting by the best predictors among spatial data (pCCA1), and constrained by spatial data after adjusting with the best predictors among the environmental factors (pCCA2). For each analysis, the sum of all eigenvalues (trace), the percentage of variance explained, the degrees of freedom, the F value and the statistical significance of the model (assessed by 999 Monte–Carlo permutations) are shown. Significance levels are denoted by asterisks; * $P < 0.05$ ** $P < 0.001$.

Analysis	Constrained by	Covariables	Trace	% variance explained	df	F
DCA	–	–	1.0328	100	8	–
CCA1	Environmental factors	–	0.8958	13.96	8	1.48**
CCA2	Spatial data	–	0.9595	15.02	3	2.12**
pCCA1	Environmental factors	ELE, LAT	0.6649	13.38	8	1.29**
pCCA2	Spatial factors	MAP, MTC	0.7047	14.47	3	1.58**
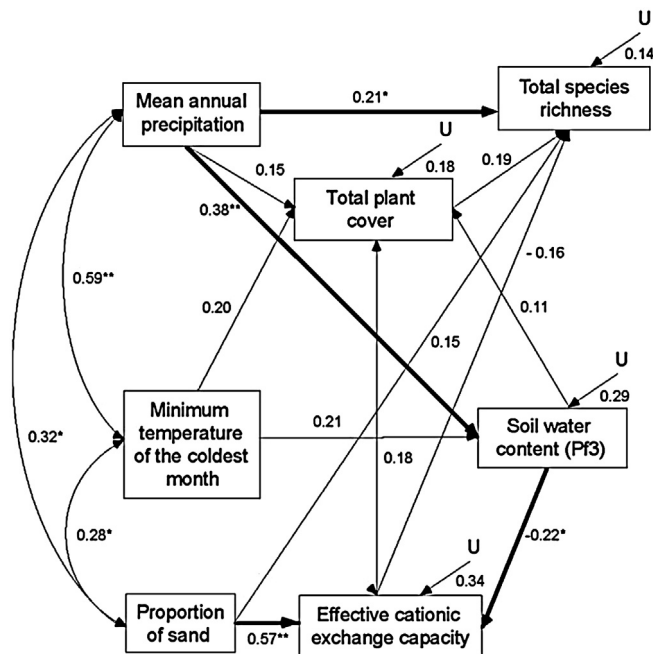
Fig. 4. Solved path diagram for determinants of total species richness (Model E in Table 4). Single-headed arrows depict directional relationships, whereas two-headed arrows depict correlations. Arrows in bold indicate strong and significant relationships. Numbers indicate standardized path coefficients and asterisks denote path coefficients that are significantly different from zero as assessed by multivariate Wald tests; $^*P < 0.05$, $^{**}P < 0.001$.

or spatial factors (Table 3). Spatial factors (CCA2) explained a higher proportion of variance than environmental factors (CCA1), however, the proportion of variance explained by environmental factors (CCA1) was slightly higher than the proportion of variance explained by the environmental component of spatial influence (pCCA1) (Table 3).

Determinants of plant diversity

For the path analysis considering total plant richness as the focus variable, Model E was the best fit for the observed data (Table 4). It revealed a low total unexplained variance ($U = 0.14$) and a positive, strong and significant direct effect of mean annual precipitation on total plant richness (Fig. 4). For path analyses considering woody, perennial herbaceous and annual herbaceous plant richness as the focus variables, Models E, D and E were the best fits of the observed data, respectively (Table 4). They exhibited low total unexplained variances ($U = 0.35$, 0.21 and 0.12, Fig. 5). We determined (i) a positive, strong and significant direct effect of mean minimum temperature of the coldest month on woody plant richness (Fig. 5a); (ii) positive and significant direct effects of similar strength of mean annual precipitation and proportion of sand upon perennial herbaceous plant richness (Fig. 5b); and (iii) significant direct effects

of similar strength of mean minimum temperature of the coldest month (negative) and total plant cover (positive) on annual herbaceous plant richness (Fig. 5c).

For the path analysis considering species composition as the focus variable, Model E was the best fit of the observed data (Table 4). It revealed a high unexplained variance ($U = 0.74$), and positive, strong and significant effects of mean annual precipitation, total plant cover, and particularly mean minimum temperature of the coldest month, on species composition (Fig. 6).

All selected path analysis models showed positive, strong and significant direct effects of mean annual precipitation on soil water content (Pf3) and of proportion of sand on effective cationic exchange capacity, and negative, strong and significant direct effects of soil water content (Pf3) on effective cationic exchange capacity (Figs. 4–6). None of the models showed any significant direct effect of proportion of sand, effective cationic exchange capacity or soil water content (Pf3) upon total plant cover (Figs. 4–6).

Discussion

Total plant richness and species composition

Changes in total species richness and species composition of *Quercus ilex* woodlands along the transect considered in this study were primarily determined by climatic factors related to the precipitation and temperature regimes, namely mean annual precipitation and mean minimum temperature of the coldest month, respectively, a fact which corroborates our initial hypothesis. However, changes in species composition were determined also by total plant cover. The solved path diagram of this focus variable showed stronger relationships than the solved path diagram of total plant richness. These results suggest that species composition, which is more related to beta and taxonomic diversity, reflects processes regulating species coexistence and segregation in space much better than total species richness, which is more closely related to alpha diversity (Purvis and Hector, 2000; Balvanera et al., 2009).

However, the high unexplained variance of the solved path diagram for determinants of species composition indicates that other factors different from those considered in this study may be affecting changes in this variables across the transect considered. This result can be explained by the existence of some differences in the dominant bedrock types in the five zones selected along the study area. In these zones most of the plots are located over limestone, sandstone, schists, quartzites, loam and clay substrates, but the proportion of those located over limestone substrates is higher in Aflou (Ihaddaden, pers. observation). Elevation and latitude influenced species composition of the plots. However, the species variation explained by environmental factors showed a slight decrease (from 14 to 13.4%) when the effects of spatial data were statistically controlled. The potentially confounded effects of spatial parameters and environmental factors on species composition are therefore low.

Table 4
Summary of results of the Path Analysis for determinants of total species richness, woody, perennial and annual herbaceous plant richness and species composition in *Quercus ilex* woodlands in northern Algeria. Model A is the *a-prioristic* model proposed in Fig. 2. Models B, C, D, E, F and G have one, two, three, four, five and six removed paths, respectively. Values of χ^2 (with degrees of freedom and *P*), NFI and GFI statistics from "Chi-square", Bentler and Bonett's normed-fit and the Goodness-of-fit tests are shown. Boldface indicates the models finally selected.

Focus	Model	χ^2	d.f.	*P*	GFI	NFI	RMSEA
Total species richness[a]	Model A	4.70	2	0.095	0.984	0.965	0.130
	Model B	4.81	3	0.186	0.984	0.964	0.087
	Model C	4.81	4	0.307	0.984	0.964	0.051
	Model D	4.82	5	0.438	0.984	0.964	0.000
	Model E	**4.89**	**6**	**0.557**	**0.983**	**0.964**	**0.000**
	Model F	5.727	7	0.572	0.980	0.957	0.000
Woody plant richness[b]	Model A	4.70	2	0.095	0.984	0.970	0.130
	Model B	4.70	3	0.195	0.984	0.970	0.084
	Model C	4.71	4	0.318	0.984	0.970	0.047
	Model D	4.72	5	0.451	0.984	0.970	0.000
	Model E	**4.812**	**6**	**0.568**	**0.983**	**0.969**	**0.000**
	Model F	5.400	7	0.611	0.981	0.966	0.000
	Model G	6.385	8	0.604	0.978	0.959	0.000
Perennial herbaceous plant richness[c]	Model A	4.703	2	0.095	0.984	0.967	0.130
	Model B	4.704	3	0.195	0.984	0.967	0.084
	Model C	4.710	4	0.318	0.984	0.967	0.047
	Model D	**4.733**	**5**	**0.449**	**0.984**	**0.967**	**0.000**
	Model E	5.563	6	0.474	0.981	0.961	0.000
Annual herbaceous plant richness[d]	Model A	4.691	2	0.096	0.984	0.965	0.130
	Model B	4.694	3	0.196	0.984	0.965	0.084
	Model C	4.705	4	0.319	0.984	0.965	0.047
	Model D	4.888	5	0.430	0.983	0.963	0.000
	Model E	**5.026**	**6**	**0.540**	**0.983**	**0.962**	**0.000**
	Model F	5.856	7	0.557	0.980	0.956	0.000
Species composition[e]	Model A	4.703	2	0.095	0.984	0.980	0.130
	Model B	4.704	3	0.195	0.984	0.980	0.084
	Model C	4.710	4	0.318	0.984	0.980	0.047
	Model D	4.792	5	0.442	0.984	0.979	0.000
	Model E	**5.137**	**6**	**0.526**	**0.983**	**0.978**	**0.000**
	Model F	7.501	7	0.379	0.975	0.968	0.030

(a–e) Model A: all relationships (Fig. 2).

[a] Model B: without 2; Model C: without 2 and 14; Model D: without 2, 14 and 15; Model E: without 2, 14, 15 and 4.

[b] Model B: without 15; Model C: without 15 and 14; Model D: without 14, 15 and 6; Model E: 15, 14, 6 and 3; Model D: without 15, 14, 6, 3 and 5; Model E: without 15, 14, 6, 3, 5 and 4.

[c] Model B: without 15; Model C: without 15 and 14; Model D: 15, 14 and 4; Model E: without 15, 14, 4 and 10.

[d] Model B: without 14; Model C: without 14 and 15; Model D: without 14, 15 and 6; Model E: without 14, 15, 6 and 1; Model F: without 14, 15, 6, 1 and 10.

[e] Model B: without 15; Model C: without 15 and 14; Model D: without 15, 14 and 5; Model E: without 15, 14, 5 and 6; Model F: without 15, 14, 5, 6 and 4.

Species richness and life-forms

As we hypothesized, changes in woody plant richness were primarily determined by factors related to the temperature regime. The effect of mean minimum temperature of the coldest month on woody plant richness was strong and positive, which resulted from the high woody plant richness seen in the warmest zones of the study area (Blida and Miliana). This may be explained by the low tolerance of many woody plants (particularly trees) to extreme cold temperatures in the Mediterranean climate zones of the world due to limitations to photosynthesis and plant growth (Larcher, 2000). Nonetheless, mean minimum temperature of the coldest month was also the most important factor explaining changes in species composition. These results fit with the predictions of Dahmani-Megrerouche (2002) for *Quercus ilex* woodlands in Northern Algeria and complement recent findings in the mountains of Northern Morocco, which emphasize that changes in species composition along altitudinal gradients are chiefly determined by the differential tolerance of woody plants to cold conditions (Ajbilou et al., 2006). Similarly, our results suggest that changes in species composition along the considered latitudinal transect are closely associated with changes in woody plant richness. Moreover, Miliana and Blida, the zones showing the highest total and woody plant richness values, also receive the greatest amount of rain along the transect studied, which implies that the effects of mean minimum temperature of the coldest month on species composition are

greater where mean annual precipitation is higher (Kadmon and Danin, 1999). Mean annual precipitation has a strong, positive and significant effect on woody plant richness increasing the soil water content (Pf3). It is interesting to note, however, that the calculations render only a weak, negative and non-significant direct effect of soil water content (Pf3) on woody plant richness. This might be explained by the tolerance of many woody species in the region to semi-arid conditions (Bonet and Pausas, 2004).

Changes in perennial herbaceous plant richness were mainly determined by factors associated with the precipitation regime (mean annual precipitation), but not by soil water content (Pf3). Both perennial and annual herbaceous plants use the transient water stored in the topsoil (Lu et al., 2006). Nonetheless, under conditions of high soil water availability, perennials are more competitive than annuals because they have greater root plasticity and root water uptake capacities, which enable them to make more rapid use of the transient water synchronic with precipitation pulses as they are typical for infrequent summer rains (De Lillis et al., 2005). Along the transect considered, the highest values for perennial herbaceous plant richness were observed in Miliana and Blida, the zones with the highest mean annual precipitation, and where summer drought is the shortest and least intense. This has been observed as well in other broad-scale transition biomes, such as the arid and semi-arid grasslands of North America (Hochstrasse et al., 2002) and at the Iberian Peninsula (Clary, 2008) and agrees with predictions by Floret et al. (1990) for Northern Algeria. The
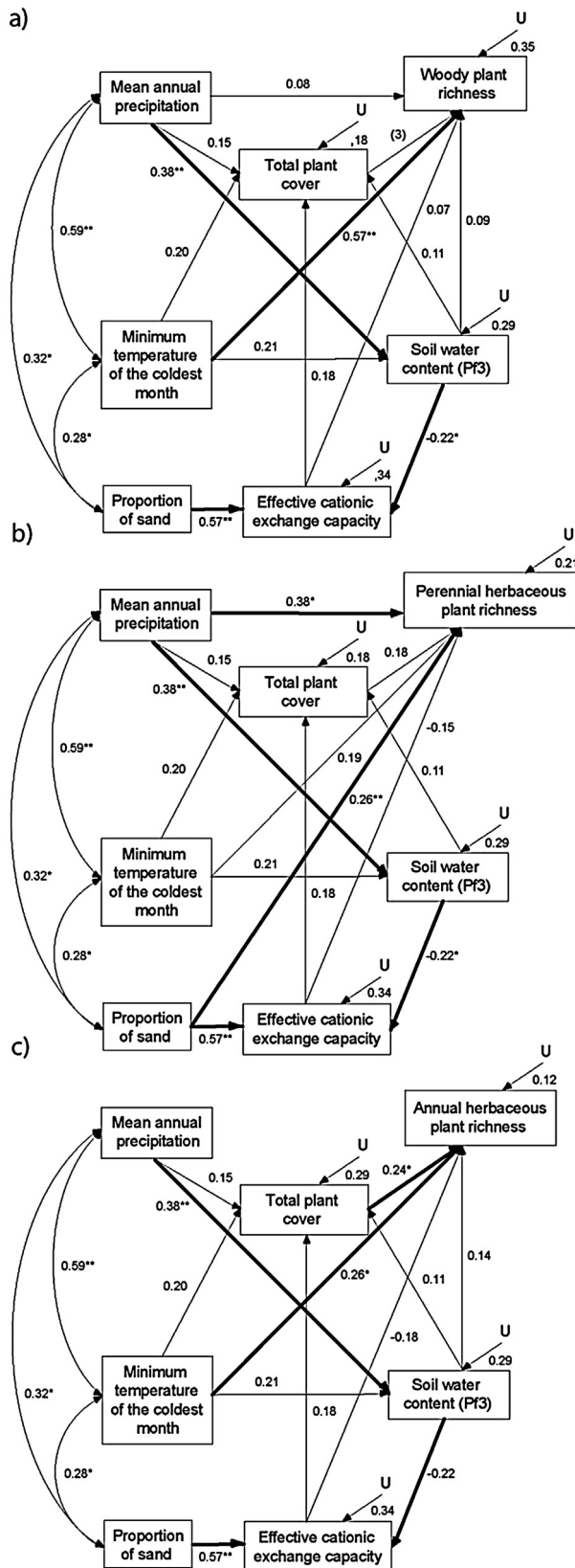
Fig. 5. Solved path diagram for determinants of woody plant richness (a), perennial herbaceous plant richness (b) and annual herbaceous plant richness (c) (Models E, C and E, respectively, Table 4). Single-headed arrows depict relationships, whilst two-headed arrows depict correlations. Arrows in bold indicate strong and significant relationships. Numbers near the paths indicate standardized path coefficients and asterisks denote path coefficients that are significantly different from zero as assessed by multivariate Wald tests; $^*P < 0.05$, $^{**}P < 0.001$.
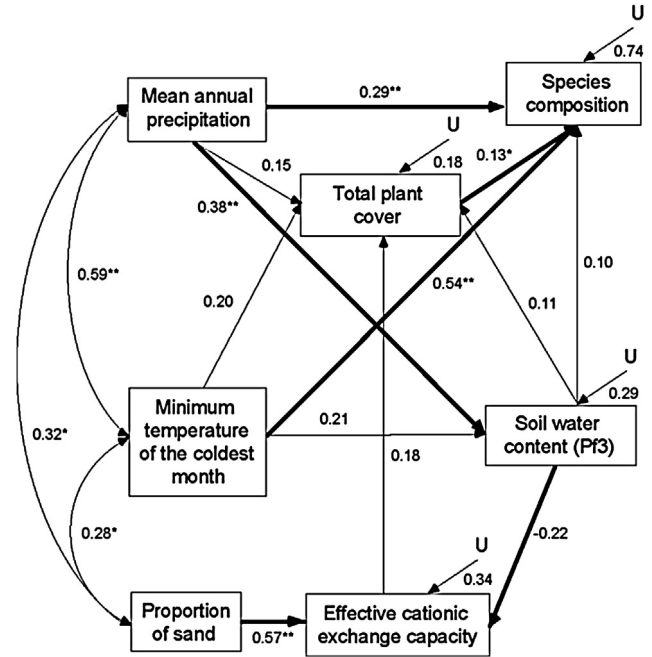
Fig. 6. Solved path diagram for determinants of species composition (Model E in Table 4). Single-headed arrows depict direct relationships, whereas two-headed arrows depict correlations. Arrows in bold indicate strong and significant relationships. Numbers indicate standardized path coefficients and asterisks denote path coefficients that are significantly different from zero as assessed by multivariate Wald tests; $^*P < 0.05$, $^{**}P < 0.001$

strong, positive and significant effect of the proportion of sand on perennial herbaceous plant richness may be explained by the more regular and higher primary productivity of sandy areas than that of finer-textured soils in Northern Africa (Le Houérou, 2001). This effect might also be related with the strong relationship between mean annual precipitation and perennial herbaceous plant richness, as there is more rapid weathering of fine-grained soil particles (i.e. silt and clay) in soils in zones receiving the highest amount of precipitation and in turn, the proportion of sand therein tends to be high (A. Ihaddaden, personal observation).

In contrast to our third hypothesis, changes in annual herbaceous plant richness were primarily affected by mean minimum temperature of the coldest month and total plant cover. The effect of mean minimum temperature of the coldest month on annual herbaceous plant richness was strong but negative, which could be related to the high level of annual herbaceous plant richness in the coldest zones of the transect (i.e. Aflou, Berrouaghia and Theniet-el-Had). Moreover, the strong negative and positive effects of mean minimum temperature of the coldest month on annual herbaceous and woody plant richness, respectively, might be related to the differential tolerance of these life-forms to cold conditions (Bhattarai and Vetaas, 2003). This fact might influence changes in species composition along the transect studied. Furthermore, we found strong, positive and significant effects of total plant cover on annual herbaceous plant richness and species composition, and the most arid (i.e. Aflou) and mesic (i.e. Blida) of our study zones had the highest and lowest annual herbaceous plant richnes, respectively. These results suggest a change in the relative dominance of facilitation and competition between woody and annual herbaceous plants from south to north along the studied transect. This would be in agreement with the *stress gradient hypothesis*, which predicts that negative (i.e. intra- and inter-specific competition) and positive (i.e. facilitation) interactions often prevail in the mildest and the harshest zones of environmental gradients, respectively (Bertness and Callaway, 1994). Similar results have been obtained in studies conducted at

local (Holzapfel et al., 2006) and regional (Armas et al., 2011) scales in the Mediterranean basin. It should also be noted that in Blida, five plots were sampled in 1991 and ten in 1999, and mean annual precipitation in these two years was slightly higher than in 1990 (Office National de la Météorologie, Algiers). Amount and seasonality of precipitation influence seed production, germination and establishment of annual plants in the semi-arid Mediterranean (Sher et al., 2004). Therefore, the higher mean annual precipitation in 1991 and 1999 compared to 1990 could have increased the richness of annual herbaceous plants in Blida, thus biasing our results. However, Blida presents the mildest climate in the transect considered (accounting for the highest mean annual rainfall and the least quotient of monthly precipitation), and the lowest richness of annual species. Thus, it is unlikely that differences in the total amount and intra-annual variations of precipitation between 1990/1991 and 1999 could have strongly affected annual herbaceous plant richness in this zone.

Soil conditions and total plant cover

Proportion of sand and soil water content (Pf3) did not show any direct and significant effect on total plant cover, but indirectly affected this variable through their effects on the capacity for effective cationic exchange. These results contrast with those of García-Fayos and Bochet (2009), who found that, in Mediterranean shrublands, plant species richness was mainly and directly correlated with soil conditions. Our findings point at the important role played by total plant cover as a mediator of the effects of soil conditions on plant diversity (Ehrenfeld et al., 2005). They also suggest that in the Q. ilex woodlands considered in this study, total plant cover has not been depleted beyond irreversible thresholds, a fact that would lead to desertification (see, e.g. Moreno-de-las-Heras et al., 2009). Thus, total plant cover in the investigated zones is strongly and positively related to plant diversity and may be considered a good indicator of ecosystem health (Torras et al., 2008).

Human use

It is also important to point out that, although the history of the effects of human uses was not included at the plot scale and not considered in the analyses, it could be important explaining the high annual herbaceous plant richness in Aflou, Berrouaghia and Theniet-el-Had. This richness in Aflou could be explained by the fact that this zone, which presents a semi-arid climate, bears a high livestock load (Table 2), and establishment and germination of annual herbaceous plants are usually favoured by grazing in semi-arid areas (De Bello et al., 2005). In Berrouaghia and Theniet-el-Had, the high richness of annual herbaceous plants may be explained by the fact that these two areas, which present a mesic climate, also harbour a large human (and mainly rural) population, and their Q. ilex woodlands suffer from intense fuel extraction for domestic use (unpublished observations). In areas of intermediate seasonality, annual herbaceous plants tend to fill open spaces, acting as r-selected ruderals (Clary, 2008). Thus, in these two zones, they could have invaded the areas degraded by intense human use. The presence in Berrouaghia and Theniet-el-Had of species such as *Stipa tenacissima* and *Ampelodesmos mauritanica*, which are often associated with landscape degradation as a result of human-induced disturbance (Le Houérou, 2001; Maestre, 2004), provides additional support for this interpretation. Moreover, along the studied transect, the percentage of annual herbaceous plants (54.4%) was much higher than the percentages of perennial herbaceous (31.1%) and woody (14.5%) plants among the total number of species. This contrasts with findings of Dahmani-Megrerouche (1996), who reported less contrasting percentages for these life forms in Algerian Q. ilex woodlands. Our findings thus highlight a more intense than originally expected (but not irreversible) landscape degradation in the study area.

Implications

Our results provide support for some of the hypotheses put forward in the introduction. They indicate that changes in plant diversity of Q. ilex woodlands in Northern Algeria are mainly influenced by environmental factors related to the precipitation and temperature regimes, and by total plant cover. Climate change predictions for the southern boundary of the Mediterranean basin suggest an increase in mean annual temperature and a reduction of soil water content (Gao and Giorgi, 2008). This, together with the reduction of total plant cover due to human activities (Vogiatzakis et al., 2006; Underwood et al., 2009), may have profound consequences for the vegetation studied. These will include a decrease in total plant richness and in the amount of perennial herbaceous plants, chiefly in the humid and sub-humid zones at the Northern side of the Tell Atlas. Sustainable management of remnant Q. ilex woodlands in Northern Africa is needed to avoid degradation of the vegetation cover and to maintain plant diversity, functional status and provision of ecosystem services. It should be pointed out that, although our approach enabled us to elucidate the main environmental factors driving changes in plant richness across the studied transect, it is unable to elucidate in a causal way the underlying processes, which should be analyzed by experimental approaches (Petraitis et al., 1996).

Acknowledgements

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.flora.2013.03.009.

Appendix 1. Pearson's product-moment correlations among climate, soil moisture, soil fertility, soil texture and vegetation structure (Vs) factors, and factor loadings of each factor on the first PCA axis (80.84, 90.72, 27.42, 27.42% of inertia explained for energy regime, soil water availability, soil fertility, soil texture factors, respectively) (last column). Asterisks indicate, in the first nine columns, strong (r > 0.50) and statistically significant correlations after sequential Rice's correction for multiple tests (P < α′ = 0.001), and in the last column, factor loadings > 0.50.

	Climatic			Soil moisture			Soil fertility										Soil texture								Vs	
	MAP	MTC	QMP	Pf4.2	Pf3	Pf2.5	SOM	N	Ca	Mg	K	Na	CEC	TL	AL	Ph	Clay	Silt	Sand	Kao	Ill	Chl	FGs	CGs	TVC	1stPCA
MAP																										0.90*
MTC	0.59																									0.89*
QMP	0.62*	0.77*																								0.82*
Pf4.2	0.02	0.07	0.01																							−0.95*
Pf3	0.10	0.23	0.12	0.92*																						−0.97*
Pf2.5	0.14	0.28	0.19	0.80*	0.85*																					−0.92*
SOM	0.12	0.14	−0.03	0.72*	0.76*	0.73*																				0.68*
N	0.17	0.21	0.08	0.62*	0.59	0.53	0.64*																			0.77*
Ca	−0.01	−0.03	0.03	0.61*	0.46	0.47	0.39	0.42																		0.80*
Mg	−0.11	−0.01	0.04	0.08	0.06	0.13	0.12	−0.05	−0.09																	0.05
K	−0.29	−0.20	−0.21	−0.11	−0.12	−0.13	−0.15	−0.07	−0.04	−0.10																−0.15
Na	0.08	0.16	0.06	0.04	0.07	0.03	0.04	0.03	−0.05	−0.04	0.04															0.05
CEC	0.02	0.06	0.11	0.66*	0.51	0.44	0.43	0.46	0.92*	0.18	−0.07	0.02														0.85*
TL	−0.31	−0.43	−0.24	−0.05	−0.01	−0.04	0.00	−0.22	−0.07	0.01	−0.02	−0.09	−0.14													−0.38
AL	−0.36	−0.46	−0.26	0.02	0.06	0.00	0.04	−0.21	−0.01	0.09	0.05	−0.11	−0.06	0.94*												−0.33
Ph	−0.64*	−0.48	−0.38	0.08	−0.00	0.01	0.00	−0.07	0.22	0.08	0.23	−0.06	0.15	0.38	0.41											−0.03
Clay	0.18	0.26	0.09	0.25	0.27	0.28	0.24	0.13	0.02	−0.04	−0.05	0.09	0.08	−0.19	−0.15	−0.16										0.16
Silt	0.42	0.45	0.17	0.09	0.16	0.12	0.18	0.32	−0.21	−0.12	−0.04	0.05	−0.17	−0.41	−0.41	−0.41	0.15									0.93*
Sand	0.51	0.44	0.17	0.12	0.17	0.12	0.19	0.33	−0.19	−0.14	−0.09	0.03	−0.15	−0.39	−0.40	−0.47	−0.13	0.94*								0.95*
Kao	−0.24	−0.17	−0.12	−0.13	−0.10	−0.01	0.00	−0.12	0.07	0.15	0.01	−0.13	0.05	0.10	0.12	0.19	−0.09	0.50	0.55							−0.66*
Ill	0.09	0.35	0.15	0.01	0.06	0.06	0.08	0.16	−0.18	−0.02	0.08	0.10	−0.14	−0.33	−0.31	−0.15	0.15	0.75*	−0.22							−0.57*
Chl	0.52	0.30	0.09	0.14	0.17	0.11	0.18	0.30	−0.12	−0.16	−0.15	−0.03	−0.10	−0.24	−0.27	−0.46	0.06	0.67*	0.86*	−0.52	0.01					0.77*
FGs	−0.62*	−0.57	−0.55	−0.24	−0.32	−0.32	−0.21	−0.21	−0.11	0.11	0.23	−0.08	−0.12	0.19	0.23	0.35	−0.16	−0.35	−0.42	0.35	−0.10	−0.42				−0.56*
CGs	0.47	0.43	0.42	−0.25	−0.28	−0.26	−0.16	0.08	−0.16	−0.11	−0.06	0.03	−0.13	−0.42	−0.48	−0.41	−0.15	0.46	0.43	−0.27	0.37	0.28	−0.41			0.58*
TVC	0.33	0.35	0.24	0.32	0.37	0.35	0.24	0.17	0.19	0.02	−0.23	0.02	0.18	−0.34	−0.33	−0.23	0.32	0.27	0.25	−0.06	0.26	0.13	−0.35	−0.00		–

Appendix 2. List of plant species registered in *Quercus ilex* woodlands across a 450-km long transect in Northern Algeria. Life-form: woody (w), annual herbaceous (ann) and perennial herbaceous (per) of each species, and proportion of plots (%) in each zone and in the entire transect in which each species is present, are indicated.

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Acer obtusatum Waldst. & Kit. Ex Willd.	w	0.0	0.0	0.0	0.0	3.6	1.2
Achillea ligustica All.	per	0.0	5.6	0.0	0.0	0.0	1.2
Achillea santolina L.	per	13.3	0.0	0.0	0.0	0.0	2.5
Aegilops triuncialis L.	ann	0.0	33.3	0.0	0.0	3.6	8.6
Ajuga iva (L.) Schrb	per	0.0	16.7	0.0	0.0	3.6	4.9
Alchemila arvensis Scop.	per	0.0	0.0	0.0	11.1	0.0	1.2
Alliaria oficinales Andrz. Ex Bieb	ann	0.0	0.0	0.0	0.0	3.6	1.2
Allium paniculatum L.	per	6.7	0.0	0.0	0.0	0.0	1.2
Allium roseum L.	per	0.0	11.1	0.0	0.0	0.0	2.5
Allium triquetrum L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Alyssum granatense Boiss. & Reuter	ann	66.7	5.6	0.0	0.0	0.0	13.6
Alyssum macrocalyx Coss. & Dur.	ann	20.0	0.0	0.0	0.0	0.0	3.7
Ammoides verticillatum L.	ann	6.7	16.7	45.5	0.0	10.7	14.8
Ampelodesmos mauritanica (Poir.) Durieu & Schinz	per	0.0	11.1	45.5	11.1	35.7	22.2
Anacyclus clavatus (Desf.) Pers.	ann	0.0	33.3	27.3	44.4	32.1	27.2
Anagallis arvensis L.	ann	0.0	5.6	9.1	0.0	7.1	4.9
Anarrhinum pedatum (Desf.)	per	0.0	5.6	0.0	0.0	3.6	2.5
Andryala integrifolia L.	per	0.0	0.0	0.0	11.1	3.6	2.5
Annograma leptophylla (L.) Link	ann	0.0	0.0	0.0	0.0	7.1	2.5
Anthemis pedunculata L.	ann	0.0	5.6	0.0	11.1	28.6	12.3
Anthoxantum odoratum L.	per	0.0	5.6	0.0	0.0	0.0	1.2
Anthyllis tetraphylla L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Anthyllis vulneraria L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Arabis auriculata Lam.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Arabis hirsuta (L.) Scop.	per	0.0	5.6	0.0	0.0	0.0	1.2
Arabis pubescens (Desf.)	ann	0.0	5.6	0.0	0.0	7.1	3.7
Arabis verna (L.) R. Br.	ann	6.7	0.0	0.0	22.2	3.6	4.9
Arbutus unedo L.	w	0.0	0.0	0.0	0.0	21.4	7.4
Argyrolobium zanonii (Turra) P.Ball subsp. *zanonii*	w	0.0	5.6	0.0	11.1	3.6	3.7
Arisarum vulgare Targ. Tozz.	per	0.0	0.0	0.0	33.3	17.9	9.9
Aristolochia altissima Desf.	per	0.0	5.6	0.0	0.0	0.0	1.2
Asparagus acutifolius L.	w	6.7	5.6	18.2	33.3	21.4	16.0
Asparagus officinalis L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Asperula arvensis L.	ann	0.0	5.6	9.1	0.0	0.0	2.5
Asperula hirsuta Desf.	ann	6.7	22.2	0.0	11.1	7.1	9.9
Asperula laevigata L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Asphodelus microcarpus Salzm. & Viv.	per	6.7	11.1	27.3	33.3	3.6	12.3
Asplenium adiantum-nigrum L.	per	0.0	0.0	0.0	22.2	25.0	11.1
Asplenium trichomanes L.	per	0.0	0.0	0.0	0.0	7.1	2.5
Asterolinum linum-stellatum (L.) Duby.	ann	6.7	16.7	27.3	0.0	10.7	12.3
Astragalus incanus L.	per	13.3	0.0	0.0	0.0	0.0	2.5
Astragalus monspessula L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Atractylis cancellata L.	ann	13.3	33.3	0.0	0.0	0.0	9.9
Atractylis gummifera L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Atractylis humilis L.	per	6.7	5.6	0.0	0.0	0.0	2.5
Avena alba Maire	ann	0.0	0.0	0.0	0.0	7.1	2.5
Avena bromoides Gouan (b)	ann	6.7	0.0	0.0	0.0	0.0	1.2

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Avena sp. L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Balancea glaberrima Desf.	ann	0.0	0.0	0.0	0.0	7.1	2.5
Bellis annua L.	ann	0.0	5.6	9.1	0.0	0.0	2.5
Bellis sylvestris L.	per	0.0	16.7	36.4	0.0	7.1	11.1
Biscutella didyma L.	ann	0.0	16.7	27.3	11.1	35.7	21.0
Blackstonia perfoliata (L.) Hudson.	ann	0.0	0.0	0.0	0.0	14.3	4.9
Bombicilaena discolor (Pers.) Laínz	ann	26.7	5.6	27.3	0.0	0.0	9.9
Brachypodium distachyum (L.) P. Beauv.	ann	0.0	44.4	18.2	22.2	10.7	18.5
Brachypodium sylvaticum (Huds.) P. Beauv.	per	0.0	0.0	0.0	0.0	3.6	1.2
Brassica amplexicaulis (Desf.) Pomel	per	0.0	5.6	27.3	11.1	3.6	7.4
Bromus lanceolatus Roth.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Bromus madritensis L.	ann	13.3	11.1	27.3	33.3	7.1	14.8
Bromus rubens L.	ann	53.3	5.6	0.0	0.0	0.0	11.1
Bufonia tenuifolia L.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Bunium sp.L.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Calendula arvensis L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Calycotome spinosa (L.) Link	w	0.0	16.7	18.2	11.1	25.0	16.0
Calystegia sepium (L.) R. Br.	ann	0.0	0.0	0.0	11.1	0.0	1.2
Campanuda dichotoma L.	ann	0.0	0.0	9.1	11.1	0.0	2.5
Cardamine hirsuta L.	ann	0.0	0.0	9.1	0.0	3.6	2.5
Carduncellus pinnatus Desf.	per	0.0	0.0	0.0	0.0	3.6	1.2
Carduncellus sp. L.	per	6.7	0.0	0.0	0.0	0.0	1.2
Carduus getulus Pomel.	ann	0.0	0.0	0.0	0.0	7.1	2.5
Carduus pycnocephalus L.	ann	0.0	0.0	0.0	22.2	3.6	3.7
Carex halleriana Asso	per	0.0	22.2	0.0	11.1	3.6	7.4
Carex sp. L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Carlina involucrata Poir.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Carlina lanata L.	ann	26.7	16.7	9.1	0.0	10.7	13.6
Carthamus lanatus L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Carthamus pectinatus Desf.	per	0.0	0.0	9.1	0.0	0.0	1.2
Catananche arenaria Coss. & Dur.	per	6.7	0.0	0.0	0.0	0.0	1.2
Catananche caerulea L.	per	6.7	0.0	0.0	0.0	0.0	1.2
Catananche caespitosa Desf.	per	0.0	16.7	9.1	0.0	0.0	4.9
Catapodium loliaceum (Huds.) Link	ann	6.7	0.0	18.2	22.2	0.0	6.2
Cedrus atlantica Endl.	w	0.0	0.0	0.0	0.0	3.6	1.2
Centaurea alba L.	per	6.7	0.0	0.0	0.0	0.0	1.2
Centaurea granatensis Boiss. Ex DC.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Centaurea incana Desf.	ann	6.7	5.6	9.1	0.0	0.0	3.7
Centaurea melitensis L.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Centaurea parviflora Desf.	ann	26.7	11.1	9.1	0.0	0.0	8.6
Centaurea pullata L.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Centaurea sp. L.	ann	20.0	0.0	9.1	0.0	0.0	4.9
Centaurium erythraea (Griseb.) Wight	ann	0.0	0.0	0.0	0.0	7.1	2.5
Cephalantera longifolia (L.) Fritsch	ann	0.0	5.6	0.0	0.0	0.0	1.2
Cerastium glomeratum Thuill.	ann	0.0	0.0	27.3	44.4	0.0	8.6
Cerastium pentandrum L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Chenopodium foliosum (Moench) Asch.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Chrysanthemum fontanesii (Boiss., Reut. & sine ref.)	ann	0.0	0.0	0.0	0.0	7.1	2.5
Cirsium echinatum (Desf.) DC.	ann	0.0	0.0	18.2	0.0	0.0	2.5
Cirsium monspessulanum (L.) Hill.	per	0.0	0.0	0.0	0.0	3.6	1.2
Cirsium sp. L.	per	6.7	5.6	0.0	0.0	0.0	2.5
Cistus creticus (Spach.)	w	6.7	0.0	0.0	0.0	14.3	6.2
Cistus monspeliensis L.	w	0.0	0.0	0.0	33.3	14.3	8.6
Cistus salvifolius L.	w	0.0	22.2	0.0	22.2	35.7	19.8
Clematis cirrhosa L.	per	0.0	0.0	0.0	33.3	28.6	13.6
Clematis flammula L.	per	0.0	0.0	0.0	33.3	21.4	11.1
Coleosthepus myconis (L) Reichenb. fil.	ann	0.0	0.0	0.0	11.1	17.9	7.4
Convulvulus cantabrica L.	per	0.0	27.8	0.0	0.0	10.7	9.9
Convulvulus humilis Jacq.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Convulvulus tricolor L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Coronilla scorpioides (L.) Koch	ann	0.0	0.0	18.2	0.0	7.1	4.9
Coronilla valentina L.	w	0.0	0.0	0.0	0.0	14.3	4.9
Crambe filiformis Jacq.	per	0.0	0.0	0.0	0.0	3.6	1.2
Crataegus laciniata Ucria.	w	0.0	0.0	0.0	11.1	0.0	1.2
Crataegus monogyna Jacq.	w	0.0	0.0	0.0	11.1	0.0	1.2
Crataegus oxyacantha L.	w	0.0	0.0	0.0	0.0	3.6	1.2
Crepis vesicaria L.	per	0.0	16.7	0.0	22.2	0.0	6.2
Crucianella angustifolia L.	ann	0.0	16.7	0.0	0.0	0.0	3.7
Cruciata laevipes G. Gaertn	per	0.0	16.7	0.0	0.0	0.0	3.7
Crupina vulgaris Cass.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Cutandia dichotoma (Forssk.) Trab	ann	6.7	0.0	0.0	0.0	0.0	1.2
Cyclamen africanum Boiss. & Reuter	ann	0.0	0.0	0.0	0.0	3.6	1.2
Cynoglossum cheirifolium L.	ann	6.7	0.0	9.1	11.1	3.6	4.9

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Cynosurus elegans Desf.	ann	6.7	0.0	54.5	44.4	21.4	21.0
Cytisus arboreus Desf. DC.	w	0.0	0.0	0.0	11.1	0.0	1.2
Cytisus monspessulanum L.	w	0.0	0.0	0.0	0.0	7.1	2.5
Cytisus villosus Pourr.	w	0.0	0.0	0.0	11.1	32.1	12.3
Dactylis glomerata L.	per	86.7	66.7	36.4	44.4	67.9	64.2
Daphne gnidium L.	w	0.0	0.0	9.1	11.1	14.3	7.4
Daucus carota L.	ann	6.7	5.6	27.3	0.0	21.4	13.6
Daucus crinitus Desf.	per	0.0	0.0	9.1	0.0	0.0	1.2
Dianthus caryophyllus L.	per	13.3	0.0	0.0	0.0	0.0	2.5
Diplotaxis harra (Forssk.) Boiss.	ann	13.3	0.0	0.0	0.0	0.0	2.5
Diplotaxis sp. L.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Diplotaxis virgata (Cav.) DC.	ann	53.3	0.0	0.0	0.0	0.0	9.9
Dittrichia viscosa (L.) W, Greuter	w	0.0	0.0	0.0	0.0	3.6	1.2
Ebenus pinnata Aiton.	per	0.0	0.0	0.0	0.0	3.6	1.2
Echinaria capitata (L.) Desf.	ann	20.0	11.1	0.0	0.0	0.0	6.2
Echinops spinosus L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Elaeoselinum thapsioides (Desf.) M.	per	0.0	5.6	0.0	0.0	0.0	1.2
Ephedra major L.	w	13.3	0.0	0.0	0.0	0.0	2.5
Erica arborea L.	w	0.0	0.0	0.0	11.1	14.3	6.2
Erodium cicutarium L'Her. ex Aiton 1789	ann	6.7	0.0	0.0	0.0	0.0	1.2
Erodium triangulare (Forssk.) Muschl.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Eruca vesicaria (L.) Cav.	ann	6.7	16.7	0.0	0.0	0.0	4.9
Eryngium dichotomum Desf.	per	0.0	16.7	18.2	0.0	0.0	6.2
Eryngium tricuspidatum L.	per	0.0	5.6	18.2	11.1	17.9	11.1
Erysimum bocconei (All.)	per	0.0	0.0	9.1	0.0	0.0	1.2
Erysimum incanum Kunze	ann	6.7	0.0	0.0	0.0	0.0	1.2
Euphorbia cuneifolia Guss.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Euphorbia exigua L.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Euphorbia falcata L.	ann	20.0	11.1	0.0	0.0	3.6	7.4
Euphorbia peplus L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Euphorbia phymatosperma Boiss. & Gaill. Ex Boiss.	ann	0.0	0.0	9.1	11.1	0.0	2.5
Euphorbia sp.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Euphorbia sulcata Lens ex Loisel.	ann	13.3	5.6	0.0	0.0	0.0	3.7
Fedia cornucopiae (L.) Gaertner	ann	0.0	0.0	0.0	0.0	3.6	1.2
Ferula communis L.	per	13.3	5.6	0.0	0.0	17.9	9.9
Festuca atlantica Duval-Jouve in Clauson	per	0.0	0.0	0.0	11.1	7.1	3.7
Festuca trifolra Desf.	per	0.0	0.0	0.0	0.0	7.1	2.5
Filago gallica (L.)	ann	0.0	0.0	0.0	0.0	3.6	1.2
Filago spathulata auct, non Presl.	ann	46.7	0.0	18.2	22.2	10.7	17.3
Fraxinus sp. L.	w	0.0	0.0	0.0	11.1	0.0	1.2
Fumana thymifolia (L.) Spach ex Webb	w	0.0	5.6	0.0	0.0	3.6	2.5
Fumaria capreolata L.	ann	0.0	5.6	0.0	11.1	10.7	6.2
Galactites tomentosa Moench	ann	6.7	5.6	0.0	22.2	10.7	8.6
Galium aparine L.	ann	20.0	0.0	63.6	11.1	35.7	25.9
Galium molugo L.	per	6.7	11.1	0.0	0.0	25.0	12.3
Galium parisiense (L.)	ann	0.0	5.6	0.0	0.0	10.7	4.9
Galium rotundifoli L.	per	0.0	0.0	0.0	11.1	21.4	8.6
Galium sp. L.	per	0.0	5.6	9.1	0.0	0.0	2.5
Galium tunetatum Lam.	per	0.0	11.1	0.0	0.0	3.6	3.7
Gastridium scabrum C. Presl	ann	6.7	0.0	0.0	22.2	0.0	3.7
Gastridium ventricosum (Gouan) Schinz & Thell.	ann	0.0	0.0	0.0	11.1	3.6	2.5
Genista tricuspidata Desf. Subsp. duriaei	w	0.0	22.2	9.1	0.0	32.1	17.3
Geranium lucidum L.	ann	0.0	0.0	9.1	11.1	0.0	2.5
Geranium malvaeflorum Boiss. & Reut.	per	0.0	0.0	9.1	0.0	0.0	1.2
Geranium molle L.	ann	0.0	5.6	18.2	11.1	7.1	7.4
Geranium robertianum L.	ann	0.0	5.6	18.2	44.4	28.6	18.5
Gymnogramma leptophylla (L.) Desv.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Hedypnois cretica (L.) Will.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Helianthemum appeninum (Desf.) Pers	per	0.0	0.0	9.1	0.0	0.0	1.2
Helianthemum cinereum (Cav.) Pers. subsp. rubellum	w	26.7	22.2	0.0	0.0	0.0	9.9
Helianthemum hirtum (L.) Mill.	per	26.7	0.0	0.0	0.0	3.6	6.2
Helianthemum ledifolium (L.) Mill.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Helianthemum virgatum (Desf.) Pers.	per	46.7	5.6	0.0	0.0	0.0	9.9
Helichrysum stoechas (L.) Moench	per	0.0	0.0	0.0	0.0	14.3	4.9
Heliotropium bacciferum Forssk.	per	0.0	5.6	0.0	0.0	0.0	1.2
Herniaria hirsuta L.	ann	66.7	0.0	0.0	0.0	0.0	12.3
Hippocrepis multisiliquum L.	ann	0.0	5.6	9.1	0.0	0.0	2.5
Hippocrepis scabra DC.	per	6.7	0.0	0.0	0.0	0.0	1.2
Hirschfeldia incana (L.) Lagr.-Foss.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Hordeum murinum L.	ann	26.7	0.0	0.0	22.2	0.0	7.4
Hyacinthoides hispanica (Mill.) Chouard ex Rothm.	per	0.0	0.0	0.0	0.0	7.1	2.5
Hyacinthoides sp.	per	0.0	0.0	0.0	0.0	3.6	1.2

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Hyoseris radiata L.	per	6.7	5.6	27.3	33.3	25.0	18.5
Hypochoeris achryophorus L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Hypochoeris laevigata (L.) Ces., Pass. & Gibelli	ann	0.0	0.0	0.0	44.4	0.0	4.9
Hypochoeris radicata L.	per	0.0	5.6	0.0	11.1	0.0	2.5
Iberis linifolia L.	per	0.0	5.6	0.0	0.0	0.0	1.2
Jasione montana L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Jasminum fruticans L.	w	13.3	11.1	0.0	0.0	0.0	4.9
Juniperus oxycedrus L.	w	26.7	33.3	18.2	33.3	7.1	21.0
Juniperus phoenicea L.	w	13.3	0.0	0.0	0.0	0.0	2.5
Kentranthus calcitrapa (L.) Duf.	ann	6.7	5.6	18.2	0.0	0.0	4.9
Lactuca seriola L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Lactuca viminea (L.) J. et C. Presl	ann	0.0	5.6	0.0	0.0	0.0	1.2
Lagurus ovatus L.	ann	0.0	5.6	0.0	11.1	25.0	11.1
Lamarckia aurea (L.) Moench	ann	0.0	0.0	0.0	11.1	0.0	1.2
Lamium amplexicaule L.	ann	0.0	0.0	27.3	0.0	0.0	3.7
Lamium flexuosum Ten.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Launaea nudicaulis (L.) Hook.	ann	13.3	0.0	0.0	0.0	0.0	2.5
Lavandula stoechas Lam.	w	0.0	5.6	0.0	22.2	28.6	13.6
Legousia falcata (Ten.) Fritsch.	ann	6.7	0.0	0.0	88.9	21.4	18.5
Leontodon hispanicus Poir. subsp. Hispanicus	ann	6.7	0.0	0.0	0.0	0.0	1.2
Leontodon hispidulus (Delile) Boiss.	ann	13.3	27.8	36.4	55.6	17.9	25.9
Leontodon tuberosus L.	ann	0.0	0.0	27.3	11.1	0.0	4.9
Leontodos sp. L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Leucanthemum paludosum (Poiret)	ann	0.0	0.0	18.2	0.0	7.1	4.9
Leuzea confiera (L.) DC.	per	20.0	22.2	0.0	0.0	0.0	8.6
Linaria reflexa (L.) Desf.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Linaria simples DC.	ann	13.3	0.0	18.2	0.0	0.0	4.9
Linum corymbiferum L.	per	0.0	5.6	0.0	0.0	0.0	1.2
Linum sp. L.	per	0.0	0.0	0.0	0.0	7.1	2.5
Linum strictum L.	ann	0.0	16.7	0.0	0.0	0.0	3.7
Linum trigynum L.	ann	0.0	5.6	0.0	0.0	21.4	8.6
Linum usitatissimum L.	per	0.0	0.0	0.0	11.1	0.0	1.2
Lithospermum apulum L. Vahl.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Lithospermum arvense L.	ann	6.7	0.0	9.1	0.0	0.0	2.5
Lobularia maritima (L.) Desv.	per	20.0	0.0	9.1	11.1	0.0	6.2
Lolium rigidum Gaud.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Lonicera implexa Ait.	w	0.0	11.1	0.0	0.0	14.3	7.4
Lotus creticus L.	per	6.7	0.0	9.1	0.0	0.0	2.5
Lotus creticus.co (Boiss.) Briquet subsp. collinus	per	6.7	5.6	9.1	11.1	0.0	4.9
Malope malachoides L.	per	0.0	5.6	0.0	0.0	0.0	1.2
Mantisalca salmantica (L.) Briq. & Cavill.	per	0.0	5.6	0.0	0.0	0.0	1.2
Matthiola fruticulosa (Loefl. ex L.) Maire	per	0.0	11.1	0.0	0.0	0.0	2.5
Medicago hispida Gaertn.	ann	0.0	0.0	27.3	0.0	0.0	3.7
Medicago lupulina L.	ann	0.0	0.0	0.0	0.0	7.1	2.5
Medicago minima (L.) L.	ann	20.0	0.0	9.1	0.0	0.0	4.9
Medicago orbicularis (L.) Bartal.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Medicago secundiflora Durand	ann	6.7	0.0	0.0	0.0	0.0	1.2
Medicago sp. L.	ann	6.7	0.0	0.0	11.1	7.1	4.9
Melandrium album (Mill.) Garke.	per	0.0	0.0	0.0	0.0	3.6	1.2
Melilotus indica (L.) All.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Melilotus sp. L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Mercurialis annua L.	ann	0.0	0.0	0.0	33.3	7.1	6.2
Minuartia campestres L.	ann	46.7	0.0	0.0	0.0	0.0	8.6
Minuartia geniculata (Poiret) F.N. Williams	per	6.7	0.0	0.0	0.0	0.0	1.2
Minuartia hybrida (Vill.) Schischkin	ann	0.0	5.6	9.1	0.0	0.0	2.5
Minuartia tenuifolia (L.) non Martius	ann	6.7	0.0	0.0	0.0	0.0	1.2
Moehringia trinervia (L.) Clairv.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Myosotis ramosissima Rochel ex Schult.	ann	0.0	0.0	18.2	0.0	0.0	2.5
Olea europaea L.	w	0.0	0.0	0.0	33.3	3.6	4.9
Onobrychis caput-galli (L.) Lam.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Ononis mitissima L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Ononis natrix L.	per	0.0	11.1	9.1	0.0	0.0	3.7
Ononis pusilla L.	per	0.0	0.0	9.1	0.0	0.0	1.2
Onopordum arenarium (Desf.) Pomel.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Onopordum macracanthum Schousboe	ann	6.7	0.0	0.0	0.0	0.0	1.2
Onopordum sp. L.	ann	6.7	11.1	0.0	0.0	0.0	3.7
Orchis coriophora L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Origanum floribundum Munby	w	0.0	11.1	9.1	55.6	17.9	16.0
Ornithogallum umbellatum L.	per	0.0	5.6	9.1	0.0	3.6	3.7
Orobanche crenata Forskk.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Pallenis spinosa (L.) Cass.	ann	13.3	22.2	18.2	11.1	10.7	14.8
Papaver rhoeas L.	ann	20.0	5.6	27.3	0.0	3.6	9.9
Paronychia argentea Lam.	ann	13.3	11.1	0.0	0.0	0.0	4.9
Paronychia capitata (L.) Lam.	per	20.0	11.1	0.0	0.0	0.0	6.2
Petrorhagia illyrica (L.) Ball et Heyw.	ann	0.0	0.0	0.0	11.1	3.6	2.5

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Phagnalon saxatile (L.) Cass.	per	0.0	0.0	0.0	11.1	3.6	2.5
Phlomis bovei Noë	w	0.0	0.0	0.0	11.1	0.0	1.2
Phillyrea angustifolia L.	w	6.7	27.8	0.0	55.6	14.3	18.5
Phillyrea latifolia L. (syn. *P. media*)	w	0.0	0.0	0.0	0.0	6.7	1.2
Picris duriaei Schultz Bip. ex Batt.	ann	0.0	5.6	9.1	0.0	7.1	4.9
Picris echioides L.	ann	0.0	5.6	9.1	0.0	0.0	2.5
Pinus halepensis Mill.	w	0.0	0.0	0.0	0.0	7.1	2.5
Pistacia lentiscus L.	w	0.0	5.6	0.0	55.6	21.4	14.8
Plantago albicans L.	per	13.3	0.0	0.0	0.0	0.0	2.5
Plantago coronopus L.	ann	0.0	5.6	0.0	0.0	7.1	3.7
Plantago lagopus L.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Plantago psyllium L.	ann	26.7	5.6	0.0	0.0	0.0	6.2
Plantago serraria L.	per	0.0	11.1	0.0	0.0	3.6	3.7
Plantago sp. L.	ann	0.0	0.0	0.0	0.0	7.1	2.5
Polycarpon tetraphyllum L.	ann	6.7	16.7	0.0	11.1	0.0	6.2
Polycnemum fontanesii DR. & Moc.	w	33.3	0.0	0.0	0.0	0.0	6.2
Polygala nicaeensis Risso ex W.D.J. Koch	per	0.0	5.6	0.0	0.0	10.7	4.9
Prasium majus L.	w	0.0	0.0	0.0	0.0	10.7	3.7
Prunas insititia L.	w	0.0	0.0	0.0	11.1	3.6	2.5
Psychine styloda Desf.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Pteridium aquilinum (L.) Kunth	per	0.0	0.0	0.0	0.0	3.6	1.2
Pulicaria odora (L.) Rchb.	per	0.0	5.6	0.0	22.2	21.4	11.1
Quercus ilex L.	w	46.7	50.0	54.5	88.9	75.0	63.0
Quercus suber L.	w	0.0	0.0	0.0	11.1	0.0	1.2
Ranunculus bulbosus L.	per	0.0	0.0	18.2	0.0	3.6	3.7
Ranunculus paludosus Poir.	per	0.0	0.0	0.0	0.0	10.7	3.7
Ranunculus spicatus Desf.	per	0.0	0.0	0.0	0.0	3.6	1.2
Reichardia picrioides (L.) Roth	per	6.7	0.0	0.0	0.0	3.6	2.5
Reseda alba L.	per	6.7	11.1	9.1	0.0	0.0	4.9
Rhamnus alaternus L.	w	0.0	5.6	0.0	0.0	7.1	3.7
Roemeria hybrida (L.) DC.	ann	13.3	0.0	0.0	0.0	0.0	2.5
Rosa canina L.	w	0.0	0.0	0.0	0.0	7.1	2.5
Rosa sempervivens L.	w	0.0	0.0	9.1	11.1	14.3	7.4
Rosa sp. L.	w	0.0	0.0	0.0	0.0	7.1	2.5
Rosmarinus officinalis L.	w	6.7	0.0	0.0	0.0	0.0	1.2
Rosmarinus tourneforti Noe.	w	13.3	0.0	0.0	0.0	0.0	2.5
Rubia peregrina L.	w	0.0	0.0	0.0	11.1	42.9	16.0
Rubus ulmifolius Schott	w	0.0	0.0	0.0	22.2	32.1	13.6
Rumex bucephalophorus L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Rumex tuberosus L.	ann	0.0	0.0	0.0	11.1	0.0	1.2
Ruscus aculeatus L.	w	0.0	0.0	0.0	0.0	3.6	1.2
Salix sp. L.	w	0.0	0.0	0.0	11.1	0.0	1.2
Salvia verbenaca L.	per	6.7	5.6	0.0	0.0	0.0	2.5
Sanguisorba minor Scop	ann	0.0	33.3	0.0	11.1	10.7	12.3
Sanguisorba sp. L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Satureja graeca Sibth.	per	0.0	0.0	0.0	22.2	25.0	11.1
Satureja vulgaris (L.) Fritsch	per	0.0	0.0	0.0	22.2	32.1	13.6
Scabiosa stellata L.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Scandix australis L.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Schismus barbatus (L.) Tell.	ann	26.7	0.0	0.0	0.0	0.0	4.9
Scleropoda rigida (L.) Griseb.	ann	20.0	0.0	9.1	33.3	10.7	12.3
Scolymus grandiflorus Desf.	per	0.0	5.6	0.0	0.0	0.0	1.2
Scolymus hispanicus L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Scorpiurus muricatus L.	ann	0.0	0.0	18.2	0.0	0.0	2.5
Sedum album L.	per	0.0	5.6	0.0	0.0	0.0	1.2
Sedum caeruleum L.	ann	0.0	22.2	0.0	11.1	0.0	6.2
Sedum pubescens Vahl.	ann	0.0	0.0	9.1	11.1	0.0	2.5
Sedum sediforme Jacq. Pau	per	0.0	16.7	9.1	0.0	0.0	4.9
Sedum villosum L.	per	0.0	0.0	0.0	11.1	3.6	2.5
Selaginella denticulata (L.) Spring	per	0.0	0.0	0.0	11.1	0.0	1.2
Senecio leucanthemifolius Poir.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Senecio sp. L.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Senecio vulgaris L.	ann	0.0	5.6	0.0	33.3	7.1	7.4
Sherardia arvensis L.	ann	0.0	11.1	45.5	44.4	28.6	23.5
Silene atlantica Coss. & Dur.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Silene coelirosa (L.) Godr.	ann	0.0	0.0	0.0	0.0	10.7	3.7
Silene colorata Poir.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Silene disticha Willd.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Silene imbricada Desf.	ann	0.0	11.1	9.1	0.0	0.0	3.7
Silene nocturna L.	ann	13.3	0.0	0.0	0.0	0.0	2.5
Silene pseudo-atocion Desf.	ann	0.0	0.0	0.0	0.0	14.3	4.9
Silene rubella L.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Silene secundiflora Otth	ann	0.0	5.6	0.0	0.0	3.6	2.5
Silene sp. L.	ann	0.0	5.6	9.1	0.0	10.7	6.2
Silene tridentata Desf.	ann	6.7	11.1	0.0	11.1	3.6	6.2
Silene vulgaris (Moench) Garcke	per	0.0	11.1	0.0	33.3	0.0	6.2
Sinapis arvensis L.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Sinapis pubescens L.	per	0.0	0.0	0.0	11.1	3.6	2.5
Sisymbrium officinale (L.) Scop.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Sisymbrium torulosum Desf.	ann	13.3	0.0	0.0	0.0	0.0	2.5
Smilax aspera L.	w	0.0	0.0	0.0	11.1	32.1	12.3
Smyrnium olusatrum L.	per	0.0	0.0	0.0	11.1	3.6	2.5
Sonchus oleraceus L.	ann	6.7	27.8	18.2	22.2	7.1	14.8
Sonchus tenerrimus L.	per	0.0	5.6	0.0	0.0	0.0	1.2

Species	Life-form	Zone					
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida	Transect
Stachys ocymastrum (L.) Briq.	ann	0.0	0.0	0.0	22.2	7.1	4.9
Stellaria media (L.) Vill.	ann	0.0	0.0	18.2	22.2	25.0	13.6
Stipa capensis Thunb.	ann	0.0	5.6	0.0	0.0	0.0	1.2
Stipa tenacísima L.	per	46.7	5.6	0.0	0.0	0.0	9.9
Tamus communis L.	per	0.0	0.0	0.0	33.3	21.4	11.1
Tetraclinis articulata (Vahl) Mast.	w	0.0	0.0	0.0	11.1	0.0	1.2
Teucrium chamaedrys L.	per	0.0	0.0	0.0	22.2	3.6	3.7
Teucrium flavium L.	per	0.0	0.0	0.0	0.0	3.6	1.2
Teucrium polium L.	per	20.0	16.7	9.1	0.0	0.0	8.6
Teucrium pseudochamaepitys L.	per	0.0	22.2	0.0	0.0	10.7	8.6
Teucrium pseudosscorodonia Desf.	per	0.0	0.0	0.0	11.1	42.9	16.0
Thapsia garganica L.	per	0.0	0.0	9.1	0.0	3.6	2.5
Thapsia villosa L.	per	6.7	0.0	18.2	0.0	3.6	4.9
Theligonum cynocrambe L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Thlaspi perfoliatum L.	ann	6.7	11.1	54.5	0.0	7.1	13.6
Thymus fontanessii Boiss. & Reut.	w	0.0	11.1	0.0	0.0	0.0	2.5
Thymus hirtus Willd.	w	46.7	61.1	36.4	0.0	10.7	30.9
Torilis arvensis (Hudson) Link	ann	26.7	5.6	72.7	55.6	3.6	23.5
Torilis nodosa (L.) Gaertner	ann	0.0	5.6	0.0	22.2	7.1	6.2
Trifolium angustifolium L.	ann	0.0	5.6	9.1	0.0	3.6	3.7
Trifolium campestre Schreb. In Sturm	ann	0.0	0.0	0.0	22.2	14.3	7.4
Trifolium glomeratum L.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Trifolium ligusticum Balb. Ex Loisel.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Trifolium scabrum L.	ann	0.0	11.1	0.0	0.0	0.0	2.5
Trifolium sp. L.	ann	0.0	0.0	9.1	11.1	3.6	3.7
Trifolium stellatum L.	ann	0.0	0.0	9.1	0.0	0.0	1.2
Trigonella polycerata L.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Trisetaria flavescens (L.)	ann	6.7	0.0	0.0	0.0	3.6	2.5
Tuberaria guttata (L.) Raf.	ann	0.0	0.0	0.0	11.1	0.0	1.2
Umbilicus veneris (Salisb.) Dandy	per	0.0	0.0	0.0	33.3	14.3	8.6
Urospermum picroides (L.) Scop. Ex F.W. Schmidt	ann	0.0	0.0	0.0	11.1	7.1	3.7
Urtica membranacea Poir.	ann	0.0	0.0	0.0	11.1	0.0	1.2
Valerianella coronata (L.) DC in Lam. & DC	ann	6.7	0.0	27.3	0.0	0.0	4.9
Valerianella morisoni DC.	ann	0.0	0.0	9.1	0.0	3.6	2.5
Veronica arvensis L.	ann	6.7	0.0	18.2	11.1	0.0	4.9
Viburnum tinus L.	w	0.0	0.0	0.0	0.0	7.1	2.5
Vicia tetrasperma (L.) Schreb	ann	0.0	5.6	0.0	0.0	0.0	1.2
Viola munbyana Boiss. et Reut.	per	0.0	0.0	0.0	0.0	7.1	2.5
Viola odorata L.	per	0.0	0.0	0.0	0.0	14.3	4.9
Viola sylvestris (Lamk) Rchb.	ann	0.0	0.0	0.0	0.0	3.6	1.2
Xanthium strumarium L.	ann	46.7	0.0	0.0	0.0	0.0	8.6
Xeranthemum inapertum (L.) Mill.	ann	6.7	0.0	0.0	0.0	0.0	1.2
Zizyphora hispanica L.	ann	46.7	0.0	9.1	0.0	0.0	9.9

Appendix 3. Mean and standard error of total species richness, woody, perennial and annual herbaceous plant richness, and environmental factors, at the five zones considered in this study. Asterisks indicate the statistical significance of each factor in the one-way ANOVA test with $^{**}P < 0.001$ and $^{*}P < 0.05$. Values within rows followed by the same superscript capital letters are not significantly different at $P < 0.05$ according to Tukey's post hoc tests.

		Zone				
		Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida
Variables	TR	19.9 ± 1.84	18.72 ± 2.13	19.54 ± 1.80	25.44 ± 2.99	24.00 ± 1.82
	WR**	$3.73^A \pm 0.44$	$4.11^A \pm 0.41$	$2.90^A \pm 0.44$	$7.00^B \pm 0.88$	$7.42^B \pm 0.59$
	PHR*	4.66 ± 0.92	5.27 ± 0.84	4.18 ± 0.58	6.11 ± 0.98	7.78 ± 0.81
	AHR	11.46 ± 1.2	9.33 ± 1.55	12.45 ± 1.36	12.33 ± 1.87	8.78 ± 0.99
Topography factors	ELE**	$1385^A \pm 21.86$	$1076^B \pm 41.63$	$1042^{BC} \pm 38.83$	$945.0^B \pm 64.29$	$872.1^C \pm 53.31$
	LAT**	34.20 ± 0.02	36.12 ± 0.01	35.86 ± 0.01	$36.36^A \pm 0.02$	$36.40^A \pm 0.01$
	LON	$2.16^A \pm 0.01$	3.33 ± 0.06	$2.13^A \pm 0.02$	$2.21^A \pm 0.02$	2.83 ± 0.02
Climatic factors	MAP**	336.7 ± 5.46	716.9 ± 29.21	552.2 ± 21.26	$1047^A \pm 32.11$	$951.9^A \pm 41.27$
	MTC**	-1.22 ± 0.01	0.01 ± 0.17^A	$0.675^A \pm 0.16$	3.833 ± 0.26	2.753 ± 0.20
	QMP**	0.35 ± 0.00	$0.60^A \pm 0.00$	$0.53^A \pm 0.00$	$0.71^C \pm 0.00$	$0.68^B \pm 0.02$
Soil moisture factors	Pf 4.2	16.64 ± 1.70	18.01 ± 1.36	15.79 ± 0.83	17.59 ± 2.32	17.81 ± 1.24
	Pf 3	22.20 ± 2.07	23.44 ± 1.33	21.24 ± 0.59	26.14 ± 2.33	24.91 ± 1.37
	Pf 2.5	25.06 ± 2.12	30.26 ± 1.52	26.23 ± 0.86	32.73 ± 3.00	29.75 ± 1.67
Soil fertility factors	SOM*	$7.46^A \pm 0.88$	$7.82^A \pm 0.49$	$5.005^A \pm 0.61$	$10.24^B \pm 1.97$	$8.180^B \pm 0.81$
	N	0.36 ± 0.03	0.39 ± 0.03	0.317 ± 0.02	0.500 ± 0.08	0.434 ± 0.04
	Ca	16.79 ± 2.06	22.14 ± 1.84	22.14 ± 2.19	17.91 ± 2.67	18.62 ± 1.75
	Mg	2.82 ± 0.58	2.92 ± 0.79	0.909 ± 0.45	1.778 ± 0.52	2.419 ± 0.40
	K	0.50 ± 0.08	0.33 ± 0.04	0.405 ± 0.05	0.327 ± 0.08	0.332 ± 0.03
	Na	2.00 ± 0.27	1.70 ± 0.11	2.323 ± 0.31	2.280 ± 0.34	2.216 ± 0.14
	CEC	22.05 ± 2.19	27.01 ± 1.82	25.78 ± 2.33	24.17 ± 2.71	24.98 ± 1.71

			Zone				
			Aflou	Berrouaghia	Teniet-el-Had	Miliana	Blida
TL**		19.9^{A} ± 3.45	25.30^{A} ± 5.30	4.202^{B} ± 1.51	2.711^{BC} ± 1.88	3.802^{C} ± 1.41	
	AL**		9.93^{A} ± 1.36	11.39^{A} ± 2.11	2.182^{B} ± 0.96	1.444^{BC} ± 1.12	2.054^{C} ± 0.78
	Ph**		7.71^{A} ± 0.05	7.47^{A} ± 0.03	7.532^{A} ± 0.08	6.831^{B} ± 0.22	6.915^{B} ± 0.12
Soil texture factors	Clay		20.53 ± 1.52	24.67 ± 2.47	20.73 ± 2.24	31.00 ± 5.18	26.86 ± 3.08
	Silt**		43.00^{A} ± 2.00	32.22^{A} ± 2.84	40.00^{A} ± 3.75	67.22^{B} ± 6.19	58.93^{B} ± 4.03
	Sand**		43.80^{A} ± 2.75	33.11^{A} ± 3.08	40.91^{A} ± 3.98	78.89^{B} ± 10.92	74.82^{B} ± 6.47
	Kao**		13.33^{A} ± 0.63	15.56^{A} ± 1.27	15.00^{A} ± 3.16	16.67^{A} ± 5.40	5.357^{B} ± 1.28
	Ill**		40.33^{AB} ± 2.04	31.11^{AB} ± 2.70	39.00^{AB} ± 3.74	55.56^{A} ± 5.17	43.03^{A} ± 3.13
	Chl**		2.66^{A} ± 0.83	1.11^{A} ± 0.65	0.909^{A} ± 0.91	11.67^{B} ± 5.89	15.89^{B} ± 3.10
	FGs**		1.51^{A} ± 0.02	1.24^{AB} ± 0.06	1.33^{B} ± 0.04	1.17^{BC} ± 0.04	0.93^{C} ± 0.04
	CGs**		0.93^{A} ± 0.08	0.93^{A} ± 0.07	1.06^{AB} ± 0.06	1.30^{BC} ± 0.09	1.36^{C} ± 0.05
Vegetation structure factors	TVC*		54.66^{A} ± 5.40	63.61^{AB} ± 4.66	59.54^{AB} ± 2.38	79.44^{B} ± 6.89	69.28^{AB} ± 3.48

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