PATTERNS OF WOODY PLANT SPECIES DIVERSITY IN LEBANON AS AFFECTED BY CLIMATIC AND SOIL PROPERTIES

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ABSTRACT

Lebanese biodiversity is threatened by tourist and urban development, political instability, over-collection of medicinal and aromatic plants, lack of compliance to the regulations prohibiting over-exploitation from the wild, over-grazing and forest fires. A large number of the native species have unexplored economic potential for either medicinal or ornamental use. One way to preserve these species is by propagation and reintroduction into appropriate habitats. However, this requires an understanding of the species biology and environment. The relationship of nine species to the soil and climatic conditions in eight sites along an altitudinal gradient was studied. Individual species were counted and identified within transects at each site. Climatic data were collected and soil samples were taken and analyzed for soil texture, soil pH, EC, $CaCO_3$, organic matter content and the following nutrients: Ca, Mn, Na, Fe, P, K, Cu, Mg, and Zn. Each ecosystem had a unique environment that could be described using the first two factors (70.3 % of variation) in a Factor Analysis of the six most important variables. Some species' densities were affected by soil conditions (the first factor) while climatic conditions (the second factor) explained the densities of other species. Recommendations are made for the in-situ and ex-situ preservations of the nine species and their ecosystems.

Keywords: Mediterranean ecosystems, woody species diversity, soil properties, climatic characteristics, diversity indices, factor analysis, Lebanon

INTRODUCTION

Since the Lebanese flora was last described by Mouterde (1966; 1970), the natural vegetation has experienced habitat fragmentation and destruction, due to tourist activities, overgrazing, rapid urban expansion, overexploitation of natural resources, and the impact of successive wars. However, an increased abandonment of agriculture in some zones, particularly on the steeper terraced slopes of the coastal valleys, has allowed native vegetation to re-establish in areas that had been under continuous cultivation for centuries. United Nations Environment Program (1996) estimated the number of vascular plant species in Lebanon at 3,761. A large number of Lebanese tree species have unexplored economic potential as either ornamental or medicinal plants. Therefore, there is a need to identify those species with economic potential and understand the environmental factors that affect their growth. In addition, this process will contribute to reintroduction programs especially for endangered plants, where species are planted in the native or semi-natural habitats within their historical range (The World Conservation Union, 1998).

There are diverse climatic zones in Lebanon reflecting the large diversity of plant species. The Lower Mediterranean or Thermomediterranean zone (0-500 m altitude) is characterized by the presence of endemic genera such as *Ceratonia, Pistacia, Pinus*, and *Myrthus*; the Euremediterranean zone (500-1000 m altitude) is characterized by *Quercus, Pinus*, and *Cupressus;* the Supramediterranean zone (1000-1600 m altitude) is characterized by *Quercus, Ostrya, Fraxinus, Halimium,* and *Pinus*; the Mediterranean mountain zone (1500-1800 m altitude) is characterized by *Cedrus*, *Abies, Juniperus, Quercus,* and *Berberis*; while the harsh Oromediterranean zone (over 2000 m altitude) is characterized by *Juniperus, Rhamnus, Berberis, Pyrus*, *Prunus, Daphne,* and *Cotoneaster*. In the Pre-steppe Mediterranean zone (900-2400 m altitude), located at the east side of Mount Lebanon and north side of Anti-Lebanon in the Northern part of the country, mainly *Quercus* and *Juniperus* species dominate.

The selection of the species in this study was based on their threat category and the importance of the genera in the international market as landscape ornamental trees.

Quercus coccifera (L.) is threatened by continuous harvest for fire wood, overgrazing [which is affecting the species natural regeneration], fires and the expansion of cultivated areas (United Nations Environment Program, 1996). *Quercus cerris* (L.) is threatened by grazing, all year long fodder collection and habitat loss due to construction of residential properties.

Juniperus excelsa (M.B.) is threatened by grazing and fire wood collection. Natural regeneration is almost non-existent because of very low seed numbers from the cones, and their low seed quality. *Acer syriacum* (Boin. and Gaill.) needs to be conserved through reintroduction to the wild. Its wood is commonly cut and used for firewood and in cabinet making.

Malus trilobata (Schneid.) is endemic to Lebanon (Mouterde 1966) and is reported to be comparatively rare and ornamentally very distinct (Hillier & Sons, 1973). Its leaves are maple-like, and have an attractive yellow to red color in autumn.

Cercis siliquastrum (L.) is an important landscape tree because of ornamental qualities due to its heart shaped leaves and pink flowers (United Nations Environment Program, 1996).

Ostrya carpinifolia (Scop.), *Styrax officinalis* (L.) and *Sorbus torminalis* (Crantz.) are understory trees, with known ornamental characteristics (Anon, 1999). *S. officinalis* produces bell-shaped white flowers while *S. torminalis* leaves turn deep red color in the fall. *O. carpinifolia* has a distinctive growth habit and produces attractive creamy colored flowers in spring time.

This study compared the vegetation characteristics of the nine dominant tree ecosystems in Lebanon (*Acer syriacum*, *Cercis siliquastrum*, *Malus trilobata*, *Sorbus torminalis, Ostrya carpinifolia*, *Styrax officinalis*, *Quercus coccifera*, *Quercus cerris, Juniperus excelsa*). The environmental and soil characteristics explaining the distribution of the nine tree species of interest were also studied. That each ecosystem has a unique set of climate and soil conditions that predicts which ecosystem will exist, is hypothesized.

MATERIALS AND METHODS

Sites

Eight sites along an altitudinal gradient were selected because they harbor species of interest and have relatively minimal disturbance levels compared to other sites in Lebanon (Table 1).

Information about the historical locations (cities and towns) of these tree species across Lebanon, as well as their blooming period was gathered from local floras (Post & Dinsmore, 1933; Mouterde, 1966; 1970). Field visits were conducted in October 2003 and May 2004 to determine the current distribution and local species density.

Within each site, five 50 x 4 m (200 m^2) transects were randomly placed, and their locations recorded for subsequent measurement. Within each transect all individual trees and shrubs were counted and identified. The latitude, longitude and altitude were recorded using a Global Positioning System (eTrex Vista® C model, GARMIN manufacturer). Mean annual temperature and average annual rainfall data were obtained from the closest weather stations to the eight sites (personal communication, Dr. Riad El Solh Al-Khoudary, Beirut International Airport). Wind speed and solar radiation data were not included in the analysis since they were available for only three sites.

Measurements

Soil samples were collected from three soil profiles within transects at seven sites. Soil samples were unavailable from the "Fnaideq" site. Soil was sampled using cores (5 cm diameter) to an average depth of 30 cm and sent to the American University of Beirut for the analysis of soil texture, soil pH, $CaCO_3$, organic matter percent, electrical conductivity (EC), and nutrient content: Ca, Mn, Na, K, Mg, Zn, Cu, Fe, and P. Soil pH and EC were extracted at a ratio of 1:2.5 soil: water and read in pH and EC meters. Exchangeable Na and K were extracted by 1N ammonium acetate and read by a flame photometer (model AFP100, Biotech Engineering Management Co. Ltd., UK). Exchangeable Ca and Mg were extracted by 1N ammonium acetate and read in a double beam atomic absorption spectrophotometer (GBC 902, GBS Scientific Equipment, Australia). Available P was extracted by sodium bicarbonate, color development according to Watanabe & Olsen (1965). Absorbance was read using a spectrophotometer (AQUAMATE, Thermo Electron Corporation, USA). Fe, Zn, Cu, Mn were extracted by DTPA-TEA according to Lindsay & Norvell (1978). The reading was done using an atomic absorption (GBC 902 Double Beam Atomic Absorption Spectrophotometer). Soil texture was determined by the Bouyoucos Hydrometer Method. Soil organic matter was determined by dry digestion at 350°C, and soil calcium carbonate content by acid neutralization.

Measurements (per transect)

Tree diameter at breast height (DBH) was recorded for species more than 1 m tall. The basal area (BA) was derived from the DBH using the formula BA = π (DBH/2)^2. The basal area of woody species that were less than 1 m height was calculated by assuming the DBH = 2.5 cm (1 in).

All woody taxa encountered in these transects were botanically identified. Voucher specimens were collected from each species at each site and identified and deposited in the Herbarium at Ohio State University, USA and at the American University of Beirut (personal communication, Elsa Sattout).

Recorded tree and shrub species were sorted into three categories: deciduous, evergreen angiosperm, or conifer. The data were coded before processing: A. syr., C. sil., J. exc., M. tril., O. carp., Q. cer., Q. coc., S. tor., and S. off. referring to the studied species respectively (*Acer syriacum, Cercis siliquastrum*, *Juniperus excelsa, Malus trilobata*, *Ostrya carpinifolia, Quercus cerris, Quercus coccifera, Sorbus torminalis, Styrax officinalis)*, OC (other coniferous), OE (other evergreen), and OD (other deciduous). Trees (T), shrubs (S), and sub-shrub (SS) species within the three latter categories of OC, OE and OD were recorded. The term "Other" in the codes was used to distinguish the targeted nine species from the other native woody species found at the study sites.

Calculations and statistical analysis

Two measures of diversity were calculated: Shannon's and Simpson's indices. The Shannon's index of diversity was calculated as: SHDI = 1- $\sum p_i * \ln p_i$, where p_i the proportional abundance or the basal area of the *i*th species. The Simpson index was calculated as: SIDI = 1- $\sum p_i * p_i$. Thus, two values for every diversity index for every site were provided; one based on species' basal areas and another based on species' densities.

A total of 17 variables were recorded for each study site. These were classified into three subgroups: soil physical characteristics [% sand, % clay, % organic matter, electrical conductivity (EC) (mS/cm), pH], soil chemical characteristics [% $CaCO_3$, and ppm of Ca, Mn, Na, K, Mg, Zn, Cu, Fe, and P] and environmental characteristics [altitude, mean annual temperature, and average annual rainfall]. The matrix of Pearson correlation coefficients of the linear relationship between these 17 variables, the average density per 200 m^2 of every species and the diversity indices (calculated for the number of woody species or their basal area) were calculated using PROC CORR of SAS (The SAS System for Windows Release 8.02, SAS Inst. Inc., Cary NC). Six variables were selected for subsequent analysis: two represented environmental variables (mean annual temperature and altitude), two represented soil physical properties (soil organic matter and soil pH) and two represented soil nutrient status (soil Fe concentration and percent $CaCO_3$). These soil and climatic variables were selected because they had the highest correlation coefficients (R^2) relative to the average R^2 of the data matrix described above.

Factor analysis was performed using the six variables using PROC FACTOR of SAS. The analysis was customized using Method=PRIN, and "Varimax' pre-rotations and rotations to enhance the interpretation of the factor component structure. The first three factors were used for subsequent analysis since these accounted for 87 % of the information of the six variables. Factor analysis scores derived from the factor components were plotted against the density of each species.

RESULTS

Description of the study sites is provided in Table 1.

Soil analysis

All soil pH readings exceeded 7.2, except for Mazraat Mazra'at Kfarzebian with a pH of 6.41 (Table 2). Altitude varied from 35 m (Nahr Damour) to 1695 m (Beshwat) and the mean annual rainfall ranged from 410 mm (Beshwat) to 1170 mm (Ayn w Zayn, Batloun and Kfarnabrakh). Sites also varied in their soil physical and chemical properties (Table 2).

Every variable in Table 3 had some influence (positive or negative) on the distribution and density of plant species but only relationships with $R^2 > 20\%$ were shown in Table 3. To narrow the selection since six variables had to be chosen for the statistical analysis, Pearson correlation coefficients between these variables were used. The matrix showed a high negative correlation between pH and Mn (-0.68); rainfall and Fe were negatively correlated (-0.68), K and Fe (0.78) were positively correlated; K and clay were positively correlated (0.92), $CaCO_3$ was correlated with pH. Iron, Ca and K are also correlated with other variables so their effect is already incorporated in the analysis. $CaCO_3$ and organic matter percent in the soil were not significantly correlated with other variables and thus have unique information describing the occurrence of the species. The aim was to select two environmental variables, two soil physical characteristics and two soil chemical characteristic. The variables, average annual temperature, altitude, pH, organic matter percent in the soil, $CaCO_3$, and Fe concentration were then chosen for the SAS factor analysis. The first three eigenvalues that resulted from the analysis accounted for 87 % of the information provided by the six variables (Table 5). Factor 1 was mainly weighted by soil pH (-0.80), soil $CaCO_3$ content (-0.86) and Fe concentration (0.82); Factor 2 was weighted by the climatic variables (-0.97 for mean annual temperature and 0.72 for altitude), while Factor 3 was mainly weighted by soil organic matter content (0.98).

Diversity indices

The average total number of woody species (trees and shrubs) per 200 m^2 varied between sites: 36 in Beshwat, 59 in Ehden, 96 in Nahr Damour, 106 in Mazra'at Kfarzebian, 110 in Kfarnabrakh, 133 in Batloun, and 232 in Ayn w Zayn, (data not shown).

Shannon and Simpson diversity indices calculated from the number of species were higher than those calculated from the species basal area. Based on basal area calculations, Shannon's diversity index ranged from 1.02 (Beshwat) to 2.12 (Mazra'at Kfarzebian), while Simpson's index ranged from 0.04 (Beshwat) to 0.64 (Kfarnabrakh and Ayn w Zayn) (Table 4). Based on the species number calculations, Shannon's diversity index ranged from 1.96 (Ayn w Zayn) to 2.86 (Nahr Damour), while Simpson's index ranged from 0.48 (Ayn w Zayn) to 0.81 (Nahr Damour) (Table 4).

TABLE 1

Description of the Study Sites Selected along the Altitudinal Gradient in Lebanon

Site	Elevation (m)	Latitude (N)	Longitude (E)	Description
Beshwat	1694.8	34° 12 07.6	036° 08 05.5	Habitat on the highest peaks of the western chains of Mount Lebanon. It overruns to the east side of Mount Lebanon. Open canopy where species such as *Juniperus*, *Rhamnus, Berberis, Pyrus*, *Prunus, Astragalus, Daphne,* and *Cotoneaster* survive harsh environment (very dry and hot weather in summer and snowy and cold in winter). Overgrazing is the main type of disturbance.
Nahr Damour	34.8	33° 42 01.1	035° 29 06.7	Steep, north facing slope facing the Mediterranean Sea to the south; dense canopy with little understory (very few herbaceous plants). Mostly, closed canopy of *Acer*, *Cercis, Laurus*, *Quercus*, *Pistachia,* and ***Nerium.*** Highly erosive and calcareous gravel soil.
Kfarnabrakh	867.33	33° 41 56.0	035° 37 04.3	Open area on the west side of Mount Lebanon. Dominant species are *Quercus*, *Pistachia*, *Cercis*, *Sarcopotereum*, *Spartium*, *Caclycotome*, and *Prunus*. Few hundred meters away from a minor human disturbance
Ayn w Zayn	1054.6	33° 40 54.8	035° 37 06.1	Open area in the west side of Mount Lebanon running south and parallel to Beirut. Very rocky and calcareous habitat on old abandoned terraces. Dominant species are *Quercus*, *Pistachia*, *Juniperus*, *Sarcopotereum*, *Spartium*, *Daucus*, and *Prunus*. Grazing and cutting trees are the major types of disturbance.
Batloun	1045.8	33° 40 57.6	035° 38 06.2	Open area in the west side of Mount Lebanon running south parallel to Beirut. Very calcareous and rocky habitat. Residential construction is underway in the surrounding areas. Dominant species are *Quercus*, *Juniperus*, *Cercis*, *Sarcopotereum*, *Cistus*, and *Calycotome*.
Ehden	1365	34° 18 58.8	035° 58 51.8	National reserve on the north east side of Mount Lebanon. A protected area with closed canopy forest dominated by *Pinus brutia*. Understory species include *Juniperus*, *Styrax*, *Sorbus*, *Cercis, Fraxinus*, *Malus*, and ***Pistachia.***
Mazra'at Kfarzebian	1471	33° 59 49.2	035° 47 17.3	Habitat on the west side of Mount Lebanon running north parallel to Beirut. Closed canopy largely dominated by *Quercus cerris* leaving some space for other *Quercus sp.*, *Juniperus*, *Coronilla, Fumana* and *Rhododendron*. Types of disturbance: grazing, sand excavation.

TABLE 2

Mean Annual Rainfall and Soil Characteristics (Texture, % Clay, pH, Electrical Conductivity (EC), K, Ca, Mg, P, Fe, Mn, $CaCO_3$ and Soil Organic Matter (OM)) for Seven Sites in Lebanon

Location	Rainfall (mm)	Texture	clay (%)	pH	EC (mS/cm)	K (ppm)	Ca (ppm)	Mg (ppm)	P (ppm)	Fe (ppm)	Mn (ppm)	$CaCO_3$ (%)	OM (%)
Kfarnabrakh	1170	loam	24	7.2	367	340	4101	340	61.5	6.0	18.8	69.6	6.6
Nahr Damour	600	sandy clay loam	26	7.7	187	252	4466	745	1.6	5.1	2.4	50.3	1.3
Beshwat	410	clay	48	7.5	192	720	6062	205	38.7	20.0	12.6	2.5	3.2
Ehden	1000	sandy loam	8	7.8	181	49	2277	145	2.0	4.8	0.5	95.9	1.6
Mazra'at Kfarzebian	1090	loamy sand	8	6.4	103	81	636	95	2.0	10.0	12.6	1.3	2.2
Ayn w Zayn	1170	loam	22	7.4	246	240	3424	1100	2.1	5.0	9.7	28.2	3.1
Batloun	1170	clay loam	33	7.6	188	240	4596	950	1.1	5.1	3.7	26.3	4.0

TABLE 3

Correlation Coefficients between Selected Tree Species, Tree, Shrub and sub Shrub Densities and Climatic and Soil Characteristics in Eight Geographical Locations across Lebanon

	Altitude	Mean annual temperature	Rainfall	Percent clay	pH	EC	K	Ca	Mg	P	Fe	Mn	$CaCO_3$	OM
A.syr	0.72	0.34	0.24	*	*	*	*	*	*	*	*	*	*	*
C.sil	*	*	*	*	*	*	*	*	0.21	*	*	*	*	0.50
J.exc	0.25	*	0.57	0.56	*	*	0.79	0.36	*	*	0.89	*	0.21	*
M.tril	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
O.carp	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
Q.cer	*	*	*	0.26	0.76	0.33	*	0.57	*	*	*	*	0.23	*
Q.coc	0.78	0.27	*	*	0.24	*	*	*	*	*	*	0.28	*	*
S.tor	*	0.78	*	0.26	*	*	0.20	*	*	*	*	0.29	0.51	*
S.off	0.25	*	*	*	0.49	*	*	*	*	0.22	*	0.72	0.41	0.20
OC (Shrub)	*	0.77	*	0.28	*	*	0.30	*	*	*	*	0.39	0.42	*
OC (Tree)	0.21	*	*	*	0.39	*	*	*	*	*	*	0.55	0.46	0.40
OD (Shrub)	*	*	0.50	*	*	0.53	*	*	*	0.27	0.22	0.25	*	0.50

	Altitude	Mean annual temperature	Rainfall	Percent clay	pH	EC	K	Ca	Mg	P	Fe	Mn	$CaCO_3$	OM
OD (Tree)	*	*	0.29	0.37	*	*	0.28	0.42	*	0.22	*	*	*	*
OD (sub shrub)	*	*	*	*	0.71	*	*	*	0.61	*	0.34	0.20	0.30	*
OE (shrub)	*	0.20	0.32	*	0.43	*	0.22	0.36	*	*	*	*	0.27	*
OE (Tree)	0.74	*	0.36	*	0.21	*	*	*	*	*	*	0.27	*	*
OE (Sub shrub)	*	*	*	*	*	*	*	0.58	*	*	*		*	**
SHDI (basal area)	0.24	0.39	*	*	*	*	*	*	*	*	0.25	*	*	
SHDI (species)	0.34	*	*	*	0.38	*	*	*	*	*	0.26	0.53	0.39	*
SIDI	0.35	*	0.46	*	*	0.41	*	*	0.40	*	0.65	*	*	*
SIDI (species)	0.24	*	*	*	*	0.26	*	*	*	*	*	0.42	0.27	*
Average R^2	0.41	0.54	0.39	0.32	0.30	0.49	0.31	0.43	0.40	0.33	0.45	0.38	0.37	0.40

* indicates correlation coefficients < 0.20.

Woody species diversity, measured with Shannon's diversity index based on the number of species and that based on the basal area, were negatively correlated with altitude (R^2 = 27-28 %, Fig. 1). Woody species evenness, based on the basal area, measured with Simpson's index, followed a similar pattern (R^2 = 37 %) unlike that calculated based on the number of species that was negligibly affected by increasing altitude (R^2 = 15 %, Fig. 1).

Although both indices identified the same sites as having the least and most diversity, when calculated based on the number of species, there was a larger variation in Shannon's diversity index among sites with increasing altitude than with Simpson's index. The latter showed a minimal variation with increasing altitude (Fig. 1).

TABLE 4

Shannon Diversity Index (SHDI) and Simpson's Diversity (SIDI) Index Calculated Based on the Number of Woody Species *per* Site and the Basal Area of the Woody Species Identified at Each of the Eight Study Sites

Location	SHDI basal area	SIDI basal area	SHDI number of species	SIDI number of species
Beshwat	1.02	0.04	2.06	0.59
Ehden	1.13	0.30	2.74	0.77
Batloun	1.89	0.46	2.57	0.75
Nahr Damour	1.89	0.45	2.86	0.81
Kfarnabrakh	2.08	0.64	2.31	0.65
Ayn w Zayn	1.70	0.64	1.96	0.48
Mazra'at Kfarzebian	2.12	0.27	2.16	0.61

Based on the number of species, Shannon's and Simpson's indices showed a higher correlation with Factor 1 (51 % and 33 % respectively) than with factors 2 and 3 (Fig. 2). On the other hand, based on the basal area, Shannon's index showed the highest correlation with Factor 2 (45 %) compared to factors 1 and 3, while Simpson's index showed the highest correlation with Factor 1 (33 %, Fig. 2).

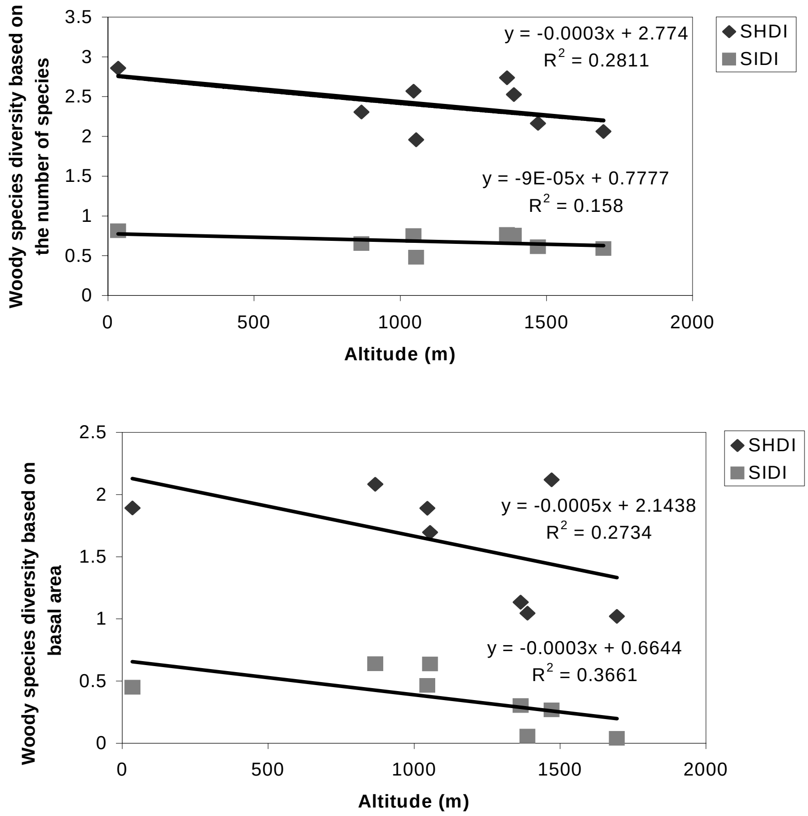


Figure 1. Woody species diversity (average number per 200 m^2) plotted against altitude (m). The upper graph is woody species diversity calculated from the number of species. The bottom graph is woody species diversity calculated from the species basal area.

Species density

Tree density varied between the study sites (Table 6). Tree species varied in the response of density to the three factors. The density of some species had higher correlation with Factor 1 (*S. officinalis, Q. cerris* and *J. excelsa)*; other species were most affected by Factor 2 (*Q. coccifera*, *M. trilobata*, *S. torminalis*, *O. carpinifolia*, and *A. syriacum*), while only *C. siliquastrum* density was affected by Factor 3 (Fig. 3).

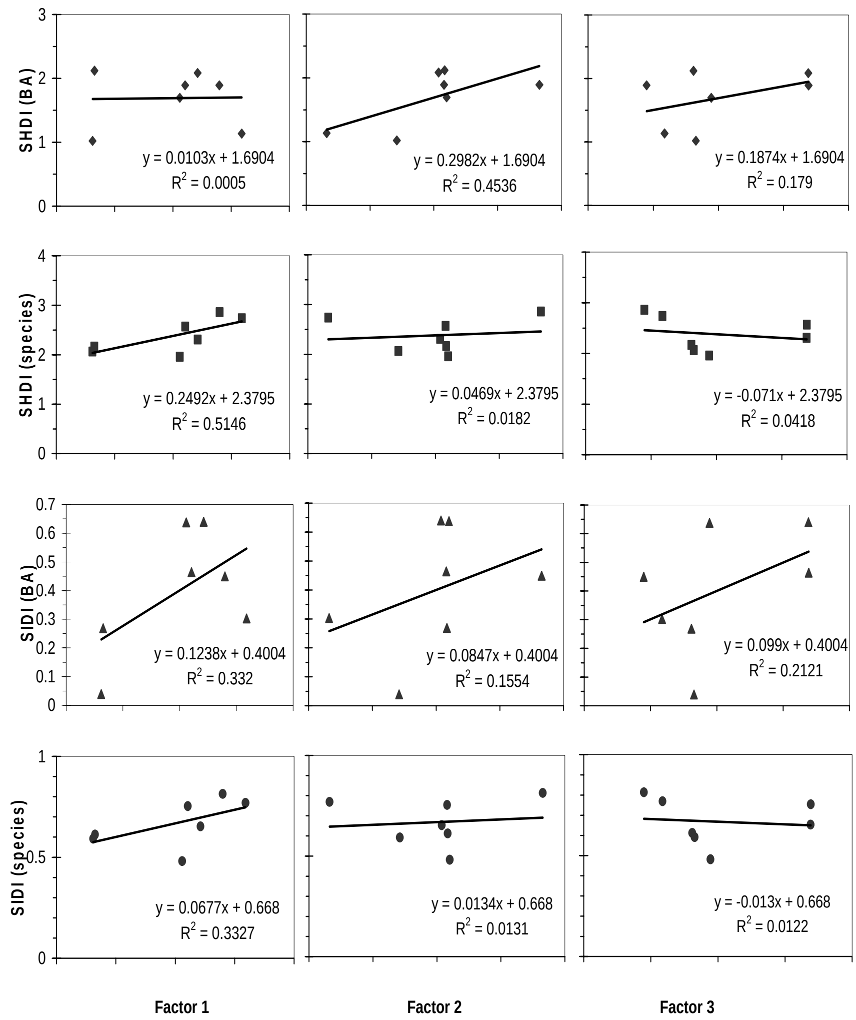
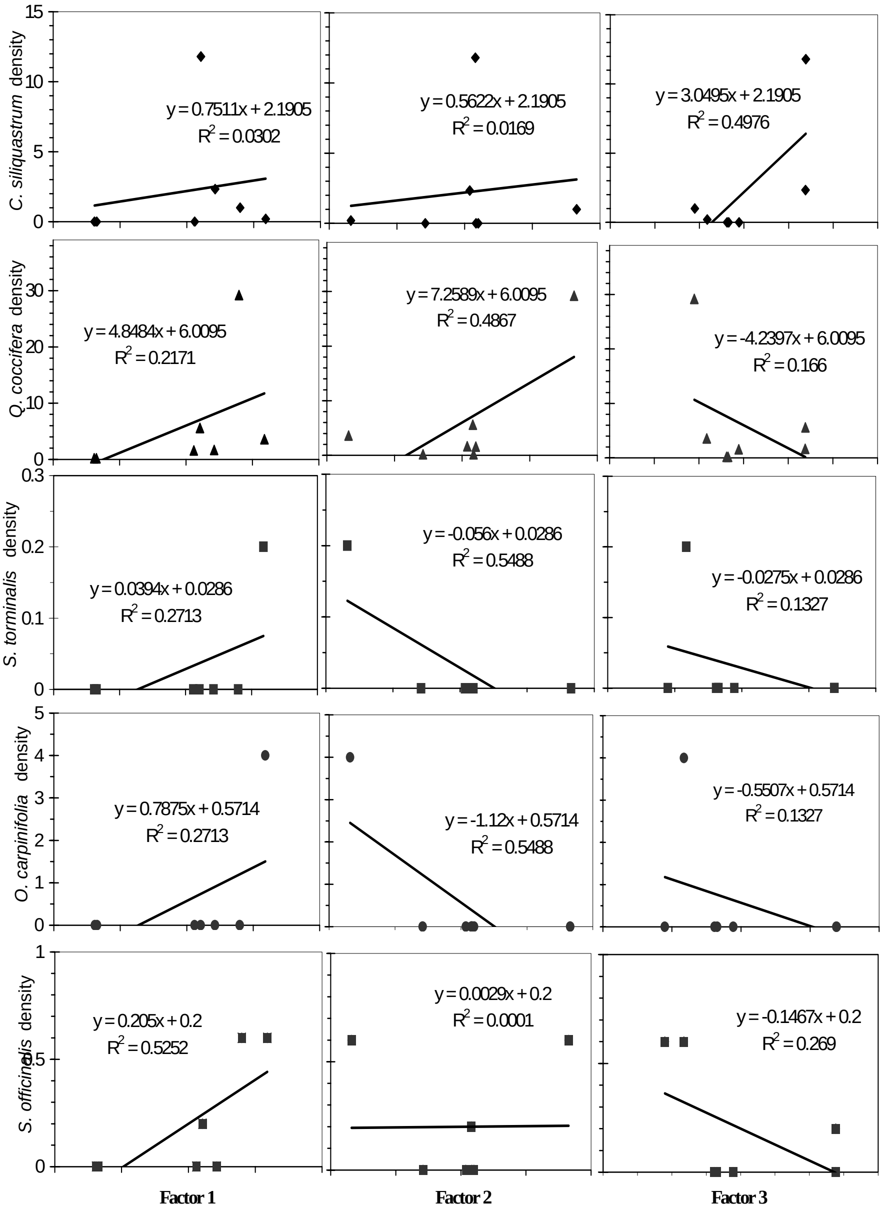


Figure 2. Shannon and Simpson's diversity indices (SHDI and SIDI, respectively) calculated either from number of species (species) or basal area (BA), plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively. The X axis values range from -2 to 2 with the tick mark placed after one unit.



C. siliquastrum density
y = 0.7511x + 2.1905
R^2 = 0.0302
y = 0.5622x + 2.1905
R^2 = 0.0169
y = 3.0495x + 2.1905
R^2 = 0.4976
Q. coccifera density
y = 4.8484x + 6.0095
R^2 = 0.2171
y = 7.2589x + 6.0095
R^2 = 0.4867
y = -4.2397x + 6.0095
R^2 = 0.166
S. torminalis density
y = 0.0394x + 0.0286
R^2 = 0.2713
y = -0.056x + 0.0286
R^2 = 0.5488
y = -0.0275x + 0.0286
R^2 = 0.1327
O. carpinifolia density
y = 0.7875x + 0.5714
R^2 = 0.2713
y = -1.12x + 0.5714
R^2 = 0.5488
y = -0.5507x + 0.5714
R^2 = 0.1327
S. officinalis density
y = 0.205x + 0.2
R^2 = 0.5252
y = 0.0029x + 0.2
R^2 = 0.0001
y = -0.1467x + 0.2
R^2 = 0.269
Factor 1
Factor 2
Factor 3

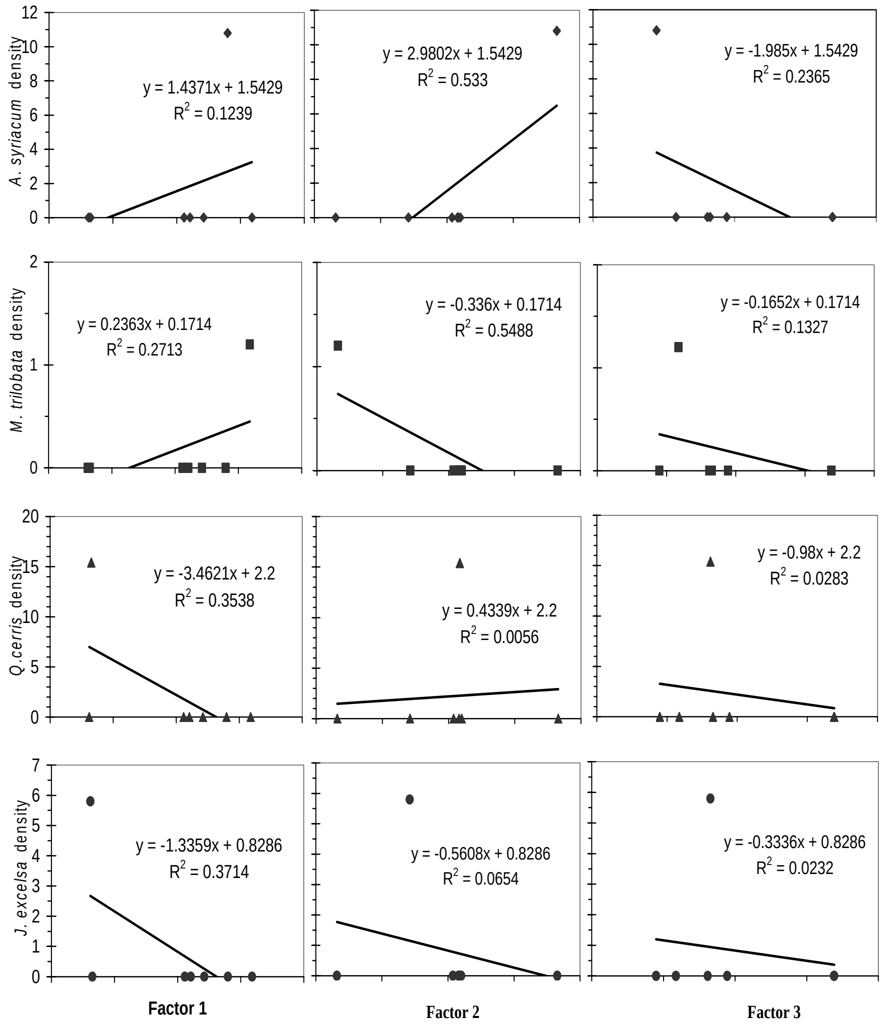


Figure 3. Tree species density (from top to bottom: *C. siliquastrum, Q. coccifera, S. torminalis, O. carpinifolia, S. officinalis, A. syriacum, M. trilobata, Q. cerris* and *J. excelsa*) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively. The X axis values range from -2 to 2 with the tick mark placed after one unit.

The correlations between *S. officinalis, Q. cerris and J. excelsa* with Factor 1 were 52, 35 and 37 %, respectively. *Quercus coccifera* density was better correlated with Factor 2 ($R^2 = 0.49$) than with Factors 1 and 3 ($R^2 = 0.22$ and 0.17, respectively). *Sorbus torminalis*, *M. trilobata* and *O. carpinifolia* showed the same correlations with factors 1, 2 and 3 ($R^2 = 0.27$, 0.55 and 0.13, respectively, Fig. 3). *A. syriacum* was better correlated with Factor 2 than Factors 1 and 3 ($R^2 = 0.53$ vs 0.12 and 0.24, respectively, Fig. 3). *A. syriacum* density was negatively correlated with altitude ($R^2 = 0.72$) and with rainfall ($R^2 = 0.24$) but positively correlated with mean annual temperature ($R^2 = 0.34$, data not shown). *Cercis siliquastrum* had low correlations with both Factors 1 and 2 (Fig. 3). Among all 17 variables, *C. siliquastrum* was best correlated with soil Mg content ($R^2 = 0.21$) and soil organic matter content ($R^2 = 0.51$).

TABLE 5

Eigenvalues of the Correlation Matrix That Resulted from PROC FACTOR of SAS

	Factor 1	Factor 2	Factor 3
Eigenvalue	2.5627	1.6572	1.0206
Cumulative	0.4271	0.7033	0.8734
Mean temperature	0.2127	-0.9728	-0.0435
Altitude	0.6692	0.7194	0.1329
OM	0.0037	-0.1108	0.9852
pH	-0.8056	0.1118	-0.0739
$CaCO_3$	-0.8632	0.3740	0.016
Fe	0.8219	0.1689	-0.1571

Evergreen shrub density and evergreen tree density had higher correlations with Factor 2 ($R^2 = 0.17$ and 0.57, respectively, Figs. 4 and 5) than Factors 1 and 3. Conifer tree density was better correlated with Factor 1 than Factors 2 and 3 ($R^2 = 0.47$ vs 0.001 and 0.44, respectively, Fig. 4) unlike conifer shrub density which was better correlated with Factor 2 than Factors 1 and 3 ($R^2 = 0.52$ vs 0.27 and 0.07, respectively, Fig. 5). The density of deciduous trees was poorly correlated with Factors 1, 2 and 3 ($R^2 < 0.10$, Fig. 4). Deciduous shrub density was better correlated with Factor 3 than Factors 1 and 2 ($R^2 = 0.61$ vs 0.08 and 0.0009, respectively, Fig. 5). Low correlation was observed between the evergreen sub-shrub category and the three Factors, whereas the deciduous sub-shrub category was better correlated with Factor 3 than Factors 1 and 2 ($R^2 = 0.26$ vs 0.08 and 0.02, respectively, Fig. 5).

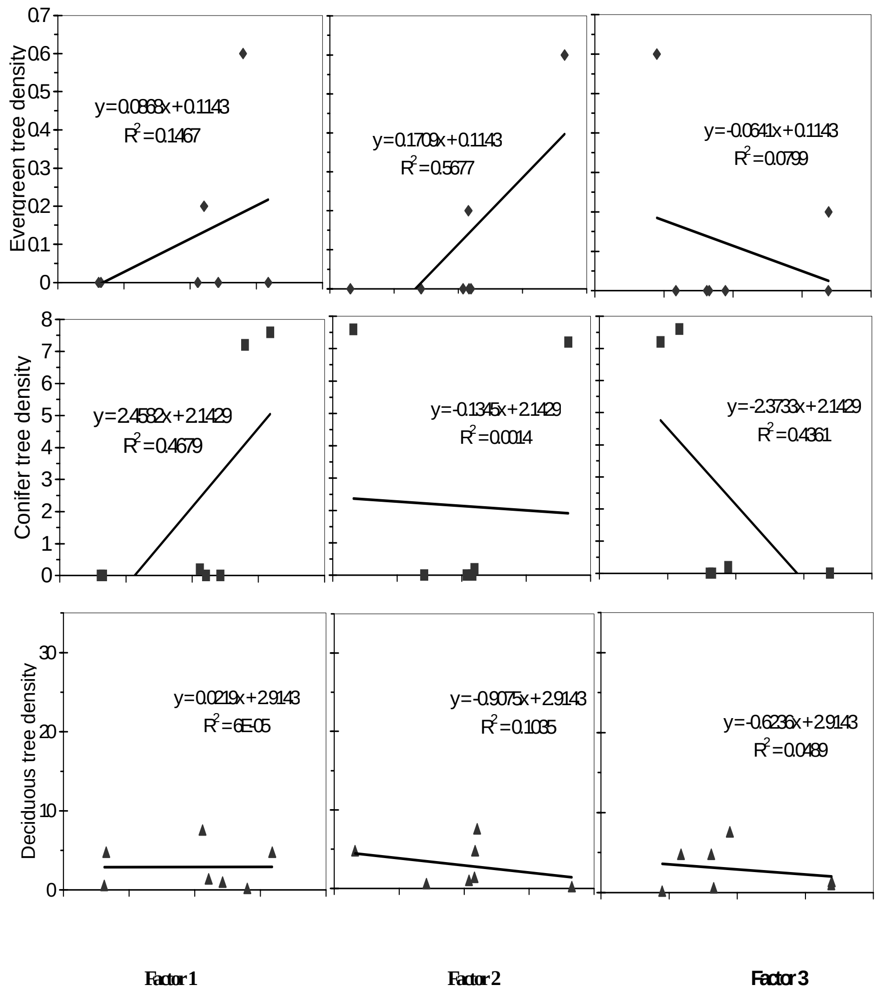


Figure 4. Evergreen, conifer and deciduous tree density (average number per 200 m^2) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively. The X axis values range from -2 to 2 with the tick mark placed after one unit.

TABLE 6

Average Number of Plants *per* 200 m^2 at Each Study Site in Lebanon

Species	Locations						
	Beshwat	Ehden	Batloun	Nahr Damour	Kfarnabrakh	Ayn w Zayn	Mazra’at Kfarzebian
A.syr	0.00	0.00	0.00	10.80	0.00	0.00	0.00
C.sil	0.00	0.20	11.80	1.00	2.33	0.00	0.00
J.exc	5.80	0.00	0.00	0.00	0.00	0.00	0.00
M.tril	0.00	1.20	0.00	0.00	0.00	0.00	0.00
O.carp	0.00	4.00	0.00	0.00	0.00	0.00	0.00
Q.cer	0.00	0.00	0.00	0.00	0.00	0.00	15.40
Q.coc	0.20	3.60	5.60	29.20	1.67	1.60	0.20
S.tor	0.00	0.20	0.00	0.00	0.00	0.00	0.00
S.off	0.00	0.60	0.20	0.60	0.00	0.00	0.00
OC (S)	0.00	14.20	3.60	0.40	0.00	1.20	1.60
OC (T)	0.00	7.60	0.00	7.20	0.00	0.20	0.00
OD (S)	9.00	22.00	31.80	16.00	56.33	24.40	25.20
OD (T)	0.60	4.80	1.40	0.20	1.00	7.60	4.80
OD (SS)	0.00	0.20	0.00	1.00	5.00	0.00	0.00
OE (S)	0.00	0.20	32.40	17.40	18.33	36.00	58.80
OE (T)	0.00	0.00	0.20	0.60	0.00	0.00	0.00
OE (SS)	20.20	0.00	45.80	11.60	25.00	161.40	0.00

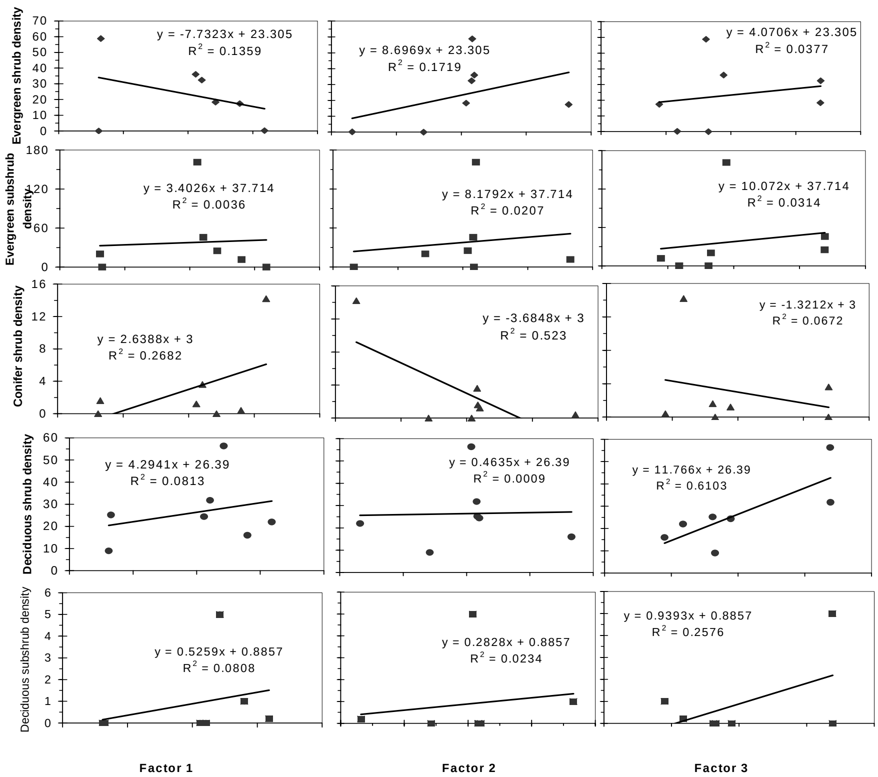


Figure 5. Evergreen, conifer and deciduous shrub and sub shrub density (average number per 200 m^2) plotted against Factor 1, Factor 2 and Factor 3 from the left to the right respectively. The X axis values range from -2 to 2 with the tick mark placed after one unit.

DISCUSSION

Site effects

The vegetation characteristics of the nine dominant tree ecosystems in Lebanon (*Acer syriacum*, *Cercis siliquastrum*, *Malus trilobata*, *Sorbus torminalis, Ostrya carpinifolia*, *Styrax officinalis*, *Quercus coccifera*, *Quercus cerris, Juniperus excelsa*) were different (Table 6). The hypothesis that each ecosystem has a unique environment (climate and soil) that allows certain woody plant species to grow was supported by the data in the study. However, this was not true for the sites Ayn w Zayn and Batloun as discussed later in the text.

The Beshwat ecosystem had low annual rainfall, dry summers, an average annual temperature of 12°C and a clayey soil texture. However the soil nutrients of K, Ca, Mg, P, Fe, Na and Mn, occurred at medium to very high concentrations (Table 2) with the exception of Cu (data not shown). The site was less subject to human influence due to its unfavorable conditions for crop production, but was susceptible to soil erosion which allows xerophytes species such as *Astragalus species* to exist. Overgrazing and soil erosion at this site, kept the trees and shrubs small and less than 1 m tall. With the exception of *J. excelsa* which showed a basal area ranging from 175 up to 11500 cm^2 in 1000 m^2, most other identified shrubs and trees were much smaller in size and may have been overestimated because actual stem caliber was less than that assigned (DBH= 2.5 cm, see materials and methods).

Ayn w Zayn and Kfarnabrakh sites had similar floristic diversity (Tables 1 and 4). The locations had similar altitude, climate, soil texture and soil chemical characteristics, with the exception of soil P (very high in Kfarnabrakh, 61.5 ppm, and very low in Ayn w Zayn, 2.1 ppm), soil organic matter content (6.6 vs 3.1 %) and soil calcium carbonate (69.6 vs 28.2 %, Table 2). Based on the Simpson index, the two sites had a similar distribution (with respect to the basal area) of species present.

Surprisingly, sites such as Ayn w Zayn, and Batloun, although they shared similar climatic, soil physical and chemical characteristics, differed in the number and type of species present (Tables 1, 4 and 6). Ayn w Zayn was the least diverse site in terms of number of species and species evenness based on Shannon and Simpson indices. Ayn w Zayn is an open site where *Quercus* species dominated. The site was subject to grazing and anthropological disturbance from cutting trees, cultivation and building houses. Shrubs such as *Spartium junceum*, *Calycotome villosa*, *Cistus reticus*, and *Salvia fruticosa,* species generally associated with degraded sites, grow with *Q. coccifera*. Other tree species include *Pinus pinea*, *Pinus brutia*, *Acer syriacum*, *Ceratonia siliqua*, *Pistacia lentiscus*, *Arbutus andrachne*, and *Phyllirea media*.

The Nahr Damour site was the most diverse in species number based on Simpson and Shannon's indices. The site had a closed canopy of *Acer*, *Cercis, Laurus*, *Quercus*, *Pistachia,* and *Nerium*, in near equal abundance. Climatic variables were critical in determining species richness patterns and were the strongest predictors of species diversity (Chiarucci *et al.,* 2001, Richerson & Lum, 1980). It might be that climatic conditions in this site resulted in a higher species richness than in other studied sites (Table 6). Nahr Damour, relative to the other sites, had the mildest climate, lowest elevation, frost free winters and hot dry summers that last 6 months, and received an annual rainfall of 600 mm per year with an average annual temperature of 20°C. The clayey loam soil in Nahr Damour was nutrient rich with high to very high concentrations of K, Ca, Mg, and Cu; medium concentrations of Fe, Zn, Mn, but a very low P concentration.

The Mazra'at Kfarzebian site, according to the Shannon's index, calculated from the basal area, was the most diverse. The site has its own uniqueness with respect to the vegetation type. The soil was loamy sand with a pH of 6.4, lower than the pH of other sites and is characterized by very low concentrations of K, Ca, Mg, and P, medium concentrations of Cu and Zn while Fe and Mn concentrations were high. This site was mainly dominated by mature stands of *Q. cerris* with a basal area ranging from 495 to 181180 cm^2, other species such as *Coronilla emeroides*, *Fumana thymifolia* and *Rhododendron ponticum* var *brachycharpum* fill the gap between the tree stands.

Species richness

Average total number of species per 200 m^2 varied among sites and was lowest in Beshwat and highest in Ayn w Zayn. Other studies have shown that species richness can vary among sites along an altitudinal gradient (Hegazy *et al*., 1998), however in this study; the difference in Shannon's and Simpson's diversity indices was small among sites from different altitudes. Simpson and Shannon's diversity indices are among the most widely accepted diversity indices (Poole, 1974). While the Simpson index expresses the relative evenness of the abundances of all the species or the degree of dominance of the predominant species, the Shannon index uses site diversity as indicated by the number of species to measure diversity. The diversity indices when calculated based on the number of species gave different results with regard to the least and most diverse sites from when they were calculated based on the basal area. Ayn w Zayn was identified as the least diverse site in terms of number of species and species evenness based on Shannon and Simpson but the richest in species number, and Nahr Damour as the most diverse site in terms of species number.

Shannon and Simpson's diversity indices both identified Beshwat as the least diverse site when they were calculated from species basal area. This might be due to the predominant presence of smaller size plants than *J. excelsa* which were assigned a DBH of 2.5 cm. However, results varied with respect to the most diverse sites which were Kfarnabrakh or Ayn w Zayn and Mazra'at Kfarzebian (according to Simpson and Shannon indices, respectively). A previous study showed that variation and opposing tends in response of the two indices can be expected (Nagendra, 2002).

Both diversity indices showed that woody species diversity decreases with increasing altitude (Fig. 1). Evergreen tree density compared to deciduous and conifer tree densities, was the only one influenced by altitude (it decreased with increasing altitude). On the other hand, conifer tree density was best correlated with soil physical and chemical properties (pH, $CaCO_3$, Fe, and OM). The three factors from this study failed to explain the density of evergreen shrubs and sub-shrubs species as well as deciduous tree density. Only soil OM content was related to deciduous shrub and sub-shrub species density.

Tree species occurrence

This model that included six variables was suitable for explaining the density of all eight species. Targeted species were not found in every studied site. *Cercis siliquastrum* was found in Nahr Damour, Batloun and Ehden sites. It was positively correlated with Mg (R^2= 0.21) and with soil OM (R^2= 0.51) which explains its strong correlation with Factor 3 (Fig. 3). The data confirmed previous reports (Anon, 1999) that the species is widely distributed in the Thermomediterranean zone in Lebanon (0-500 m altitude) and can be found up to 800 m altitude where it is associated with pine and oak forests. This species is indifferent to soil types (Anon, 1999). The regeneration potential of *C. siliquastrum,* expressed as the ratio of saplings to tree, in all three sites, averaged 0.55 per 200 m^2. It was observed that *C. siliquastrum* seed pods become infested with insects during their development in August through October, which destroys the seeds inside the pods. Therefore, chances for natural regeneration of the species were very low unless seeds were released from the pod before insect attacks. Recommendations are to identify the insect and prevent the seed loss in an effort to conserve the species at other sites throughout Lebanon.

Juniperus excelsa was present only in Beshwat and its density was negatively affected by rainfall (R^2= 0.57) but positively influenced by soil K content (R^2= 0.79), Ca content (R^2= 0.36), Fe content (R^2= 0.89), and by altitude (R^2= 0.25) (data not shown). In fact, the species was most influenced by Factor 1 (R^2 = 0.37), which was mainly weighted by soil physical and chemical properties. *Juniperus excelsa* grows only in the Oromediterranean zone in Lebanon (Abi Saleh and Safi 1988). It was observed that the species tends to be the only tree species in this zone with *Rhamnus libanotica* and shrub species such as *Berberis libanotica*, *Prunus prostrata*, *Cotoneaster nummularia* and *Pyrus syriaca*. In the site, *J. excelsa* had a ratio of saplings to trees of 1.1 per 200 m^2. The high K content in the soil (720 ppm) maybe related to the K function as an osmoticum and for stomatal control, increasing drought resistance in some species (Tisdale *et al*., 1993).

Acer syriacum was only found in Nahr Damour. It was observed that *A. syriacum* produces a good seed set every other year. The ratio of saplings to trees was 5 per 200 m^2 in this site, the highest of all targeted species.

Quercus coccifera density was mainly influenced by climatic variables such as mean annual temperature and altitude (R^2 = 0.61). The species was present in Nahr Damour, Ehden, Batloun, Kfarnabrakh, and Ayn w Zayn. The species density was negatively correlated with altitude (R^2= 0.78), and positively correlated with average annual temperature (R^2= 0.27) (data not shown). The species grows on the coast up to 1500 m altitude (United Nations Environment Program, 1996). The ratio of saplings to trees, averaged 1.0 per 200m^2 .The forests, where *Q. coccifera* is found, are degraded due to its continuous cutting for timber, fuel, agricultural tools; and land cultivation. Overgrazing and wood harvesting keep trees below 4-5 m in height. The species' area of coverage varies between 5 and 40 % with the high proportion in areas most difficult to access (United Nations Environment Program, 1996).

Malus trilobata, O. carpinifolia and S. torminalis densities are best explained by climatic variables. In fact, the three species are reported to grow in the same vegetation zone, the Supramediterranean zone, at altitudes between 1000-1500 m in Lebanon (Abi Saleh and Safi 1988). They were all found in the Ehden site which was characterized by a sandy loam soil and a pH of 7.8. The soil analysis revealed a high Ca (2277 ppm) and $CaCO_3$ content resulting in a positive correlation between *Malus trilobata, O. carpinifolia and S. torminalis* densities with $CaCO_3$ (R^2= 0.51). *Sorbus torminalis* was reported to occur most frequently on silt soils but can be found on calcareous, well drained and / or organic soils (Anon, 1999), however in the study, there was a low correlation of *S. torminalis* density with soil OM (R^2= 0.14). Isolated individuals of *O. carpinifolia and S. torminalis* were seen during field visits. Later visits confirmed poor quality seed set from these trees in seed testing studies. The poor quality seed set was mainly due to the lack of pollinators and out-crossing. *Malus trilobata* is reported to be rare (Mouterde, 1966; Hillier & Sons, 1973) and it is endemic to Lebanon (Mouterde, 1966). The respective ratios of saplings to trees were 0.2, 0.1 and 0.0 for *M. trilobata, O. carpinifolia and S. torminalis* per 200 m^2 in Ehden location. Although the site was a protected area and not subject to human interference, this data shows the need for reintroduction projects of the three species for better pollination and therefore conservation purposes.

Styrax officinalis was found at three sites (Ehden, Qammouaa, and Naes), however the latter two were not included in this study. These sites share different altitude, rainfall and mean annual temperature (personal observation). This confirms these results that its density was best explained by soil physical and chemical characteristics. The ratio of saplings to trees averaged 2.1 per 200 m^2 in Ehden, a medium average compared to the other species.

Quercus cerris was found in Mazra'at Kfarzebian that has the lowest soil pH of all sites. In Italy, this species is reported to grow in slightly acidic soils (Chiarucci *et al.,* 2001), which could explain why the density of *Q. cerris* was better correlated with Factor 1 (R^2=0.35). *Quercus cerris* was found in isolated stands and is a threatened species in Lebanon because of grazing, pruning branches all year long to provide it as fodder for livestock and from habitat loss for construction purposes. Its wood was prized for house construction until the later 20^{th} century, until the more widespread use of concrete. Most forests where this species grows were replaced by intensive cultivation of apple trees (Abi Saleh & Safi, 1988). Natural regeneration was very low; in fact the ratio of saplings to trees calculated was equal to 0.43 per 200 m^2. The acorns are damaged by an unidentified insect, in addition there are galls formed on the branches. Not only this is decreasing the species regeneration potential, but also during the field visits, it was noticed that Mazra'at Kfarzebian site, is becoming a sand excavation site and some trees were already destroyed.

Other factors affecting vegetation

This study shows that there are other non measured factors that can affect species diversity such as site history, slope, drought index, wind speed, and site aspect that influence solar radiation and evapotranspiration, and total nitrogen. The latter factors proved to be among the main factors influencing plant richness and characteristics (Fu *et al*., 2004, Richerson & Lum, 1980). Unlike other studies, there was no recognizable pattern between soil fertility and species richness, and between the sites with the highest available P and K contents and species diversity (Fu *et al.*, 2004). Nahr Damour, which was shown to be the most diverse site in terms of species number, had the lowest soil organic matter content and a very low P content. On the other hand, Beshwat, was the least diverse site, had the highest K concentration and a high P concentration. Available phosphorus in most sites was low (< 2.1 ppm) mainly caused by high soil pH levels. In basic soils, it is reported that the availability of soluble phosphates is reduced because phosphorus can complex with Ca to form insoluble calcium phosphates (Tisdale *et al*., 1993).

Ecosystem preservation and species conservation

The results from this study constitute the baseline for further studies and decision-making regarding the conservation of some species and their ecosystems. Some of the studied ecosystems had their unique set of climatic and soil characteristics, which determined the type of vegetation that grows in them. The species of interest are endangered and one way to conserve them is by encouraging their *ex-situ* and *in-situ* conservations. It is recommend *ex-situ* conservation for all the studied tree species. This can be achieved through the establishment of *ex-situ* facilities such as botanic gardens and seed banks. An alternative and a quicker option will be to encourage the cultivation of these species. Cultivation practices will satisfy both commercial and conservation purposes. The way to promote cultivation is to start campaigns that increase people's awareness about the ornamental characteristics of the tree species and introduce these species to the Lebanese nursery industry. Lebanese nurserymen can therefore propagate the species and sell the seedlings to local municipalities for street plantings and to customers who wish to plant those trees in their home gardens. Making these trees available in the market will ensure the return of these endangered species to their native habitats through reforestation projects and future reintroduction activities.

In-situ conservation is another form of conservation especially when the key is to conserve an entire ecosystem. It is recommend based on this study that an inventory be carried out on the sites of Nahr Damour and Mazra'at Kfarzebian due to the diverse number of woody species they harbor. In this case, the first step will be to provide a detailed inventory of the plant species within those ecosystems. Economic feasibility studies and socio-cultural dynamics need to be assessed in order to determine the possibility of turning these sites into 'protected areas' and maintaining the vegetation communities.

CONCLUSION

Each ecosystem of the eight species of interest provided a unique environment (climate and soil) that allowed a different type of vegetation than other ecosystems to exist. Nahr Damour was identified as the most diverse site in terms of species number whereas Ayn w Zayn was the least diverse. The least diverse site based on species basal area was Beshwat and the most diverse sites were Ayn w Zayn and Mazra'at Kfarzebian. Woody species diversity decreased with increasing altitude. Species of interest were not present at every studied site and for some; their density was better related to climatic conditions while others densities were better related to soil conditions. Recommendations are to promote the domestication of these species which will help preserve them and their ecosystems through reforestation and reintroduction activities.

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