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Relationship between lichen diversity and air quality in urban region in Bourdj Bou Arriridj, Algeria

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Abstract. *Fatima A, Messaoud R, Takia L. 2019. Relationship between lichen diversity and air quality in urban region in Bourdj Bou Arriridj, Algeria. Biodiversitas 20: 2329-2339.* The lichenic biodiversity can be an excellent instrument for measuring air quality biomonitoring in urban and industrial areas. Two bio-monitoring techniques were used to assess and map the levels of air quality in Bordj Bou Arreridj region (BBA), an urban area located in Eastern Algeria, and to identify species sensitive to air pollution. The first one was based on the diversity and abundance of epiphytic lichens, while the other technique was using two bio-indication indices. Epiphytic lichens were sampled from thirty-four stations chosen on the basis of the presence of suitable phorophytes on which it is possible to observe lichens. The assessment of lichen biodiversity was based on the calculation of lichenic abundance indices (LA) and the Shannon index (H'). For the determination of the different levels of air pollution, the indices of atmospheric purity (IAP) and lichen diversity (LDV) were used. There were 62 identified species belong to 19 families and 31 genera of lichens, among which crustacean and foliose thalli were the most common in the region. Lichen biodiversity decreased as the sampled location approaching industrial sources and road traffic. The IAP ranged from 16.19-79.82 and LDV values ranged from 12.50-52.16. The results showed a significant relationship between lichen diversity and air quality, and indicated low atmospheric pollution in the BBA region. This study allowed us to draw up a list of sensitive species and tolerant species to air pollution.

Keywords: Air quality, Algeria, lichen biodiversity, lichen sensitivity

INTRODUCTION

Over recent decades, air quality has become environmental problem worldwide due to industrial activities and road traffic. Atmospheric monitoring has been necessary to control air quality and reduce pollution sources (Stamenković et al. 2010; Attanayaka and Wijeyaratne 2013). The evolution of conventional measurement methods continues to advance the monitoring of air quality. A bio-monitoring using living organism offers an interesting complementary tool to estimate the impact of atmospheric pollution (Pinho et al. 2004).

Epiphytic lichens are defined as "permanent control systems" for estimating air pollution (Conti and Cecchetti 2001). They are extremely sensitive to environmental changes because of their physiologies (Loppi 2019). Lichens are the most used species in bio-indication to detect and monitor air quality. The sensitivity of lichens is related to their biological characteristics due to the lack of cuticle and stomata which allows pollutants to penetrate the whole surface of the organism (Krick and Loppi 2002; Nimis et al. 2002; Giordani 2007; Stamenković et al. 2010; Agnan et al. 2017).

Bio-indication techniques have been established based on the composition of the lichenic flora (Sett and Kundu 2016), mainly the Shannon diversity index (H') (Shannon and Weaver 1964), the lichen diversity value index (LDV) (Asta et al. 2002) and the atmospheric purity index (IAP) (LeBlanc and De Sloover 1970). These indices are used to estimate air pollution levels that affect lichen diversity (Van Haluwyn and Van Herk 2002; Krick and Loppi 2002; Svoboda 2007; Jayalal et al. 2015; Agnan et al. 2017), so that some environmental sources of pollution can be identified (Pinho et al. 2004; Das et al. 2013).

In this study, two quantitative bio-monitoring techniques were used, the first one is based on the diversity and abundance of epiphytic lichens and the second one is the use of two bio-indication indices. The purpose is to monitor and map the atmospheric pollution in Bordj Bou Arreridj region, and to establish a list of species sensitive to air pollution.

MATERIALS AND METHODS

Study area

Bordj Bou Arreridj (BBA) is an urban area located in northeast of Algeria with an area of 3920.42 Km^2. The region is characterized by a semi-arid continental climate with hot and dry summers, and harsh winters. Annual rainfall is irregular and varies between 300 and 700 mm/year. Epiphytic lichens from BBA province were sampled from 34 locations (municipalities) (Figure 1). The geographical coordinates of the sampled locations were recorded using GPS (Table 1).

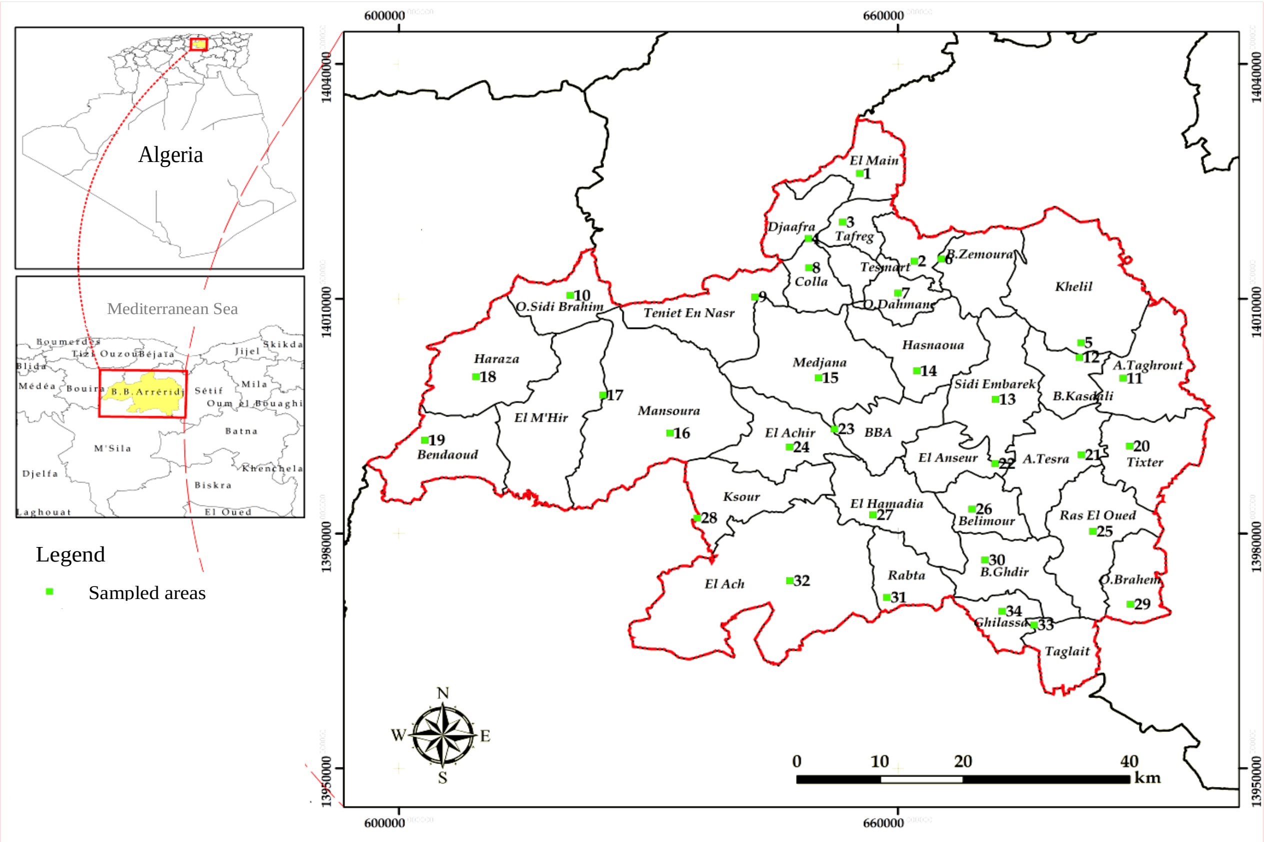

Figure 1. Sampled locations in Bourdj Bou Arreridj province, Algeria

Table 1. Geographic coordinates of the sampled locations

Locations	Latitude (N)	Longitude (E)	Altitude (m)
El Main	36°21'59.9"	4° 43'56.9"	983
Tassameurt	36°15'52.7"	4°48'11.3"	629
Tefreg	36°18'39.3"	4°42'30.2"	1131
Djaafra	36°17'33.6"	4°39'42.9"	1335
Khelil	36°10'1.6"	5°1'25.9"	964
Bordj Zemoura	36°15'59.7"	4°50'21.2"	913
Ouled Dahmane	36°13'41.2"	4°46'50.1"	1250
Colla	36°15'32.3"	4°39'43.3"	1250
Teniet En Nasr	36°13'34.8"	4°35'21.9"	1250
Ouled Sidi Brahim	36°13'52.1"	4°20'31.5"	580
Ain-Taghrout	36°7'31.2"	5°4'44.6"	907
Bir Kasdali	36°9'0.9"	5°1'16.7"	955
Sidi Embarek	36°6'13.6"	4°54'29.3"	1011
Hasnaoua	36°8'17.6"	4°48'13.6"	993
Medjana	36°7'55.6"	4°40'20.5"	1052
Mansoura	36°4'16.1"	4°28'21.6"	807
El M'hir	36°6'57.1"	4°23'2.7"	557
Haraza	36°8'20.1"	4°12'52.6"	1201
Ben Daoud	36°3'59.3"	4°8'42.7"	1050
Tixter	36°2'49.3"	5°5'8.6"	947
Aïn Tesra	36°2'17.3"	5°0'75.8"	1039
El Ansseur	36°1'47.5"	4°53'80.1"	980
Bordj Bou Arreridj	36°4'22.6"	4°41'31.5"	901
El Achir	36°3'10.8"	4°37'54.6"	967
Ras El Oued	35°56'58.9"	5°2'2.8"	1078
Belimour	35°58'40.8"	4°52'25.2"	937
El Hamadia	35°58'24.1"	4°44'29.4"	819
Ksour	35°58'22.8"	4°30'25.2"	1250
Ouled Brahem	35°51'53.7"	5°4' 55.5"	1259
Bordj Ghédir	35°55'8.5"	4°53'22.5"	1387
Rabta	35°52'40.8"	4°45'28.8"	834
El Ach	35°53'56.4"	4°37'44.4"	853
Taglait	35°50'35.4"	4°57'10.4"	1434
Ghilassa	35°51'35.1"	4°54'39.1"	1171

Sampling procedure

The sampled stations were chosen on the basis of the presence of suitable phorophytes on which it is possible to observe lichens. This work was carried out from May 2017 to July 2018. The quantification of the lichens was carried out by fixing a transparent grid (20 x 50 cm) consisting of 10 squares of 10 x 10 cm each on the most species-rich trunk faces, at a height of 100 to 150 cm above the ground to avoid any contamination by the soil (Kirschbaum and Wirth 1997; Asta et al. 2002; Bargagli and Nimis 2002; Conti 2008).

Lichens were identified in the field and unidentified samples were collected for identification in the laboratory. Determination guides and chemical reagents were used (Boistel 1986; Roux 1990; Jahns 1996; Van Haluwyn et al. 2013). A recovery coefficient was assigned to each species harvested.

Index calculations

The Shannon-Weaver diversity index (H') was calculated by using species abundances to measure the lichen biodiversity of each location (Shannon and Weaver 1964; Lepš and Hadincová 1992). This index is based on the following formula: $H' = -\sum_{i=1}^{i=n} (Pi * \ln Pi)$

Where: *H'*: Diversity; *i*: lichenic species; *Pi*: the proportional abundance of *i* species*; n:* total number of species observed.

Two bio-indication markers were calculated to evaluate the pollution in the BBA area:

The lichen diversity value (LDV)

LDV is defined as the average of the sum of frequencies of the species found in the sampled trees (Asta et al. 2002) and formulated as follow:

$$LDV = \sum_{i=1}^{i=n} fi / n$$

Where: *fi is* the sum of the frequencies of all the species found on a sampled tree

The index of atmospheric purity (IAP)

IAP is an index of air quality determined from the flora of epiphytic lichens (LeBlanc and De Sloover 1970; Krick and Loppi 2002) and formulated as follow:

$$IAP = \frac{1}{10} \sum_{i=1}^{i=n} (Qi * fi)$$

Where: *n*: number of lichen species found in a location; *Qi* is the ecological index of *i* species (the average number of species which coexist with each species); *fi* is the recovery coefficient of each species.

Statistical analysis

The data were first subjected to the Principal Components Analysis (PCA) to examine the relationship between the indicators used in this study and the identification of existing relationships between biodiversity and the stations. Cluster analysis using Unweighted Pair Group Method with Average (UPGMA) was carried out on the original variables and on the Manhattan distance matrix to look for hierarchical associations among the populations. The cluster analyses were carried out using STATISTICA 10 software.

RESULTS AND DISCUSSION

Lichen diversity

The sampling of epiphytic lichens from 34 stations in the BBA region allowed us to identify a total of 62 lichen species (Table 2). It was found that the identified species belong to 31 genera (Figure 2.A), grouped into 19 lichenic families (Figure 2.B). Ten lichenic families are represented by one species and the rest of the species are distributed among 9 families. The *Parmeliaceae* and *Lecanoraceae* families are rich, with 10 lichen species each, followed by *Physciaceae* (9 species) and *Teloschistaceae* (8 species). In the study area, the genera *Lecanora* and *Physcia* are the richest in species, while 22 genera are represented by a single species.

Biological richness and abundance showed a high heterogeneity among the stations studied. The lichen diversity values showed that *Xanthoria parietina* is the most common species found in the BBA region (Figure 3.A); it was present in all stations, with the exception of the Rabat and El-Ach stations. *Buellia griseovirens* and *Physcia tenella* were observed in 20 and 18 stations respectively, *Caloplaca ferruginea* and *Physcia aipolia* in 15 stations, *Physcia adscendens* in 13 stations, *Xanthoria polycarpa, Hypogymnia farinacea* and *Caloplaca flavorubescens* in 12 stations. The rest of the species were found in 2 through 11 stations. Overall, the lichen species were distributed into 37 crustose, 22 foliose, 1 fruticose, 1 squamulose, and 1 lepers morphologies (Figure 3.B).

Biodiversity index

The Shannon index (H') shows variability in the region with an average of 2.99 ± 1.11 and a relative standard deviation (RSD) of 37.12% (Table 3). The high values of the (H') index were recorded in the rural areas with the highest value (6.69) was recorded in the rural Teniet En-Nasr station. The low values of the (H') index were between 0.63 and 1.86, and were recorded in urban locations: El-M'hir, BBA, El Ansseur, Khelil, and El-Hamadia.

Air quality indices

The calculation of the index of atmospheric purity (IAP) and the index of lichen diversity (LDV) (Table 3) allowed us to estimate the air pollution in the BBA region.

LDV Index

We note that the LDV index shows a small variation in the region with an average of 30.04 ± 8.88 and a RSD of 29.56%. The results of the LDV index show that 79.41% of the sampled locations are characterized by a low diversity of lichens. The lowest values of the LDV were recorded at the El M'hir, El-Ach and BBA locations, indicating very low lichen diversity. On the other hand, the locations with higher values of the LDV were recorded in the rural locations of Ksour, Haraza and Teniet En-Nasr. These values indicate that these locations are characterized by moderate lichen diversity.

IAP Index

In the area studied, low variability of the IAP index was noted with a coefficient of variation of 29.09% and an average of 46.19 ± 13.44. The values of the IAP index reveal the presence of three pollution zones in the BBA region according to the five-areas of the LeBlanc and De Sloover scale (1970). The polluted locations were grouped in zone III while the majority of the locations belonging to zone IV were slightly polluted locations. The rural location of Teniet En-Nasr, in the southwest of the BBA area, was the least polluted location in the region with a high value of IAP (79.82).

Principal component statistical analysis (PCA)

In order to determine the different levels of air quality in the BBA region, and get the groups out of the homogeneous locations, a principal component statistical analysis (PCA) was carried out on the thirty-four locations based on the coupling of the bio-indication and biodiversity indices.

The indices calculated for the different sampled stations show a very important variability (Figure 4). The index of atmospheric purity (IAP) shows more variation within the locations, followed by the lichen diversity value index (LDV) and the specific diversity index (% SP). The other two indices, the lichen abundance index (LA) and the Shannon index (H') showed very little variability.

The results from the PCA did not allow a good characterization of our locations from the point of view of pollution as the separation of the locations is not clear (Figure 5). On the other hand, two sites stand out from the cloud formed by all the populations. The rural location of Teniet En-Nasr is characterized by high values of all the indices used, indicating that this location is free from pollution. The second location of El-Anseur is an urban location characterized by low values of the indices calculated.

The second statistical analysis, based on the Unweighted Pair Group Method with Average (UPGMA) and the city-block distance (Manhattan), was also carried out. This analysis confirms the results from the PCA and separates the thirty-four stations into two distinct clades (Figure 6).

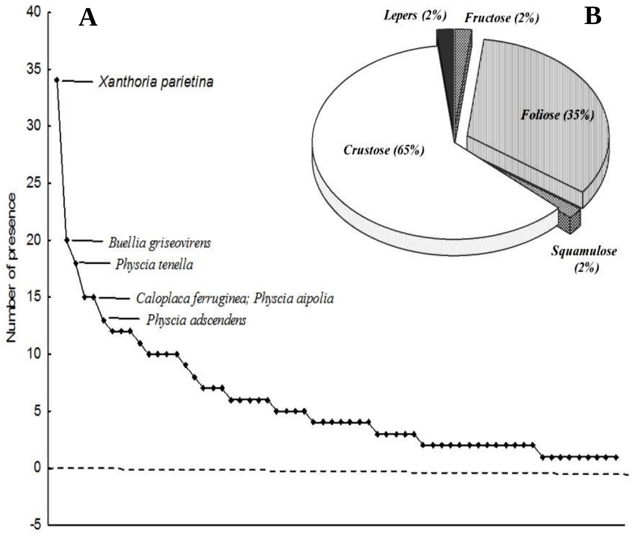

Figure 3. Lichen diversity based on: A. Species abundance, B. Proportion of morphologic types

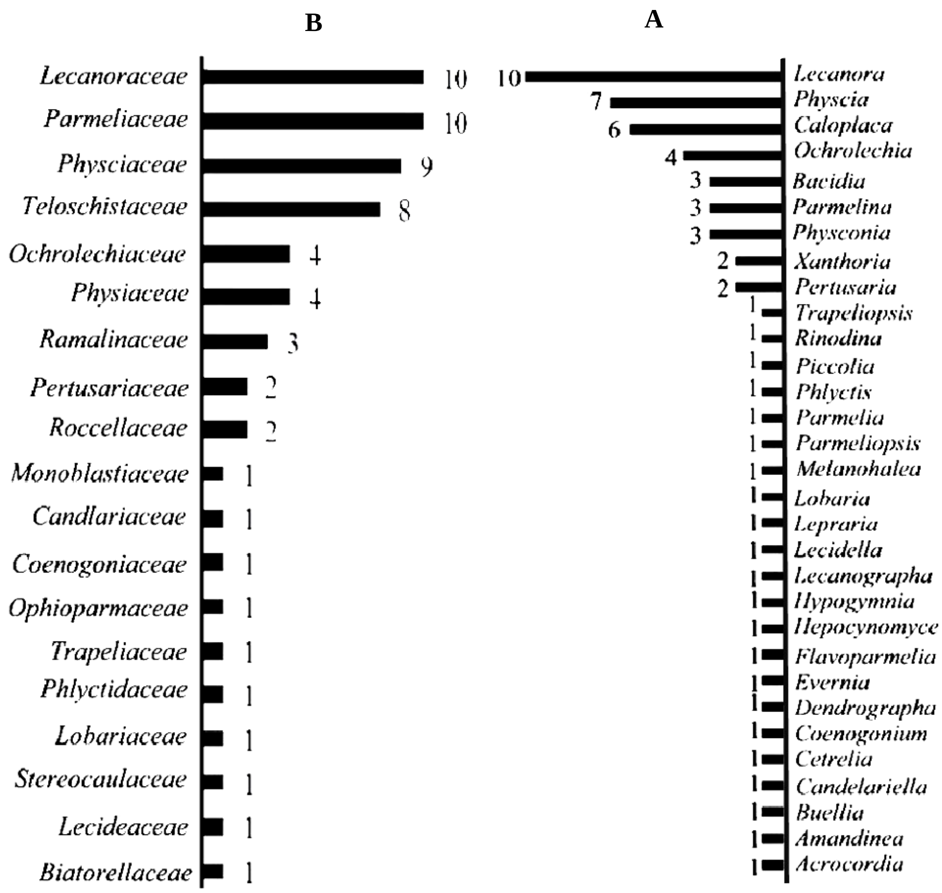

Figure 2. Lichen diversity of Bordj Bou Arreridj area, Algeria based on: A. Genera, B. Families

Table 2. Frequency of lichens in Bordj Bou Arreridj area, Algeria

Species	El Main	Tassameurt	Tefreg	Djaafra	Khelil	Bordj Zemoura	Ouled Dahmane	Colla	Thenit En Nasr	Ouled sidi Brahim	Ain Taghrout	Bir Kasdali	Sidi Embarek	Hasnaoua	Medjana	Mansoura	El M'hir	Haraza	Ben Daoud	Tixter	Ain Tesra	El Ansseur	B.B.Arreridj	El Achir	Ras El Oued	Belimour	El Hamadia	Ksour	Ouled Brahem	Bordj Ghédir	Rabta	El Ach	Taglait	Ghilassa	F.M
Acrocordia gemmata								0.20	0.05																										0.01
Amandinea punctata									0.08									0.25													0.07				0.01
Bacidia arceutina									0.22			0.18									0.25										0.15	0.03			0.02
Bacidia friesiana																		0.20			0.13														0.01
Bacidia rubella							0.13														0.22									0.15					0.01
Buellia griseovirens		0.48		0.28	0.43	0.22			0.15			0.27	0.60	0.30	0.25		0.07			0.35			0.17	0.33	0.48	0.17	0.33		0.17			0.08	0.25	0.33	0.17
Caloplaca cerina				0.25															0.13		0.17				0.25	0.13									0.03
Caloplaca cerinella											0.18	0.07				0.05				0.05									0.32	0.12	0.43				0.04
Caloplaca ferruginea				0.70	0.48	0.15					0.15	0.18	0.05	0.45				0.38		0.32	0.07				0.23	0.37				0.62	0.60	0.40			0.15
Caloplaca flavorubescens						0.50					0.18	0.12	0.30							0.12					0.43	0.13			1.00	0.47	0.05		0.42	0.60	0.13
Caloplaca hungarica					0.13											0.23															0.07				0.01
Caloplaca pyracea						0.17			0.08		0.12	0.05									0.22			0.07						0.08					0.02
Candelariella xanthostigma							0.30																					0.17	0.15		0.28				0.03
Cetrelia olivetorum																													0.13					0.37	0.01
Coenogonium pineti				0.17					0.15	0.08								0.12			0.08								0.22						0.02
Dendrographa decolorans					0.28					0.25	0.17		0.32					0.08					0.50		0.17					0.43	0.33	0.27			0.08
Evernia prunastri								0.08	0.08																										0.005
Flavoparmelia caperata																			0.17																0.005
Hypocenomyce scalaris				0.27		0.23				0.30		0.20			0.15				0.27		0.30			0.17									0.20	0.12	0.06
Hypogymnia farinacea		0.50	0.08				0.47				0.05	0.12			0.30	0.05				0.18	0.10				0.07								0.35	0.25	0.07
Lecanographa amylacea																																0.23			0.01
Lecanora allophana									0.23																										0.01
Lecanora argentata			0.22					0.30	0.20			0.03			0.08			0.45						0.40											0.05
Lecanora carpinea																															0.20	0.10			0.01
Lecanora chlarotera			0.15				0.15		0.15		0.15													0.05											0.02
Lecanora compallens										0.22													0.15												0.01
Lecanora conizaeoides									0.17						0.15							0.67					0.32								0.04
Lecanora meridionalis								0.15	0.10			0.03						0.18																	0.01
Lecanora praesistens																															0.22	0.03			0.01
Lecanora rugosella																												0.32							0.01
Lecanora strobilina													0.17	0.25		0.23								0.17				0.17							0.03
Lecidella elaeochroma									0.08																										0.00
Lepraria incana	0.10						0.25	0.13						0.13		0.28								0.33				0.32	0.17	0.50				0.33	0.07

Lobaria amplissima			0.30																								0.13								0.01
Melanohalea elegantula											0.17								0.57																0.02
Ochrolechia alboflavescens																												0.50							0.01
Ochrolechia androgyna			0.07													0.28																			0.01
Ochrolechia pallescens			0.08									0.03						0.22			0.17														0.01
Ochrolechia subviridis	0.13						0.32							0.13															0.17						0.02
Parmeliopsis ambigua		0.22		0.28		0.25			0.12			0.10	0.08								0.12				0.05			0.22							0.04
Parmelia sulcata				0.07										0.25		0.07									0.22										0.02
Parmelina carporrhizans									0.08																										0.00
Parmelina pastillifera									0.10																										0.00
Parmelina tiliacea	0.12								0.15		0.28		0.07		0.10	0.10									0.27				0.20				0.62	0.08	0.06
Pertusaria coccodes																				0.50	0.33	0.33				0.33	0.33							0.17	0.06
Pertusaria flavida																										0.22			0.33						0.02
Phlyctis argena																							0.13							0.13					0.01
Physcia adscendens	0.28	0.15	0.18			0.23		0.13			0.22			0.10				0.15								0.27		0.15		0.03			0.17	0.28	0.07
Physcia aipolia	0.38		0.17	0.35		0.23		0.58	0.73	0.28					0.23		0.20	0.27						0.28				0.27	0.13		0.02	0.10			0.12
Physcia biziana		0.15							0.15						0.05																				0.01
Physcia leptalea									0.30																										0.01
physcia stellaris	0.22		0.12	0.33		0.18		0.12	0.18				0.43		0.05		0.18		0.32					0.12											0.07
Physcia tenella	0.25	0.57					0.50	0.72	0.17	0.15			0.17	0.25					0.15	0.10	0.35		0.25			0.30		0.47	0.43	0.20			0.32	0.40	0.17
Physcia tribacioides		0.08	0.17							0.13								0.13																	0.02
Physconia distorta	0.13		0.17				0.33	0.08	0.12																			0.42					0.17	0.10	0.04
Physconia grisea			0.28			0.27				0.28	0.05					0.12												0.45							0.04
Physconia perisidiosa																					0.12								0.13						0.01
Piccolia ochrophora																		0.15													0.05	0.03			0.01
Rinodina roboris									0.07	0.25						0.17		0.07						0.25											0.02
Trapeliopsis flexuosa						0.32															0.33					0.30		0.17				0.33	0.17		0.05
Xanthoria parietina	0.90	0.95	0.97	0.95	0.88	0.90	0.95	0.93	0.90	0.95	0.77	0.83	0.77	0.83	0.75	0.62	0.80	0.98	0.83	0.78	0.83	1.00	0.55	0.65	0.57	0.83	0.92	0.68	1.00	0.42	0.03	0.18	0.96	0.77	0.78
Xanthoria polycarpa			0.63			0.17	0.13	0.33	0.40	0.28				0.10	0.38			0.78		0.05				0.13									0.33		0.11
LA	2.52	3.10	3.58	3.65	2.22	3.81	3.53	3.76	5.21	3.18	2.48	2.21	2.95	2.80	2.50	2.20	1.25	4.41	2.43	2.45	3.78	2.00	1.75	2.95	2.73	3.05	2.03	4.28	4.55	3.15	2.47	1.61	3.94	3.80	

Note: F.M: Average frequency of species; LA: Lichen abundance. (Lichen Abundance: Sum of the average frequencies of the species identified in the sampled stations)

Table 3. Indices of biodiversity and bio-indication

Studied stations	Biodiversity index			Bio-indication index		
	Percentage of specific diversity	Lichen abundance (LA)	Shannon index (H')	LDV	IAP	IAP areas*
El M'hir	6.45	1.25	0.99	12.50	16.19	Polluted (area III)
El Main	14.52	2.52	2.51	25.17	24.95	
Ain Taghrout	19.35	2.48	3.05	24.83	28.37	
Bordj Bou Arreridj	9.68	1.75	1.86	17.50	29.92	
Ben Daoud	11.29	2.43	2.05	25.50	30.45	
Hasnaoua	16.13	2.80	2.91	28.00	33.39	
Rabta	19.35	2.47	3.08	24.67	33.65	
Bir Kasdali	20.97	2.21	2.84	22.16	34.18	
Khelil	8.06	2.22	1.45	22.16	36.62	Slightly polluted (area IV)
El Ach	16.13	1.61	2.41	16.17	35.58	
Djaafra	17.74	3.65	2.93	38.16	39.83	
Tassameurt	12.9	3.1	2.16	34.33	42.75	
Mansoura	17.74	2.2	2.96	22	43.16	
Belimour	16.13	3.05	3.13	30.5	43.9	
Ras El Oued	16.13	2.73	3.04	27.33	45.00	
Colla	19.35	3.76	3.14	37.66	45.53	
Tixter	14.52	2.45	2.36	24.5	47.01	
Aïn Tesra	25.81	3.78	4.62	37.83	47.27	
Medjana	17.74	2.5	2.93	25	47.35	
Tefreg	22.58	3.58	3.71	35.83	47.59	
Sidi Embarek	16.13	2.95	2.73	29.5	48.05	
Ouled Sidi Brahim	17.74	3.18	3.25	31.83	49.31	
Ouled Dahmane	17.74	3.53	3.01	36.5	51.23	
El Hamadia	8.06	2.03	1.44	20.33	54.22	
Haraza	24.19	4.41	4.08	44.16	54.35	
El Ansseur	4.84	2	0.63	20	54.76	
Taglait	17.74	3.94	3.37	37.66	54.76	
Ghilassa	19.35	3.8	3.66	38	57.51	
Ouled Brahem	22.58	4.55	3.73	36.5	57.65	
El Achir	19.35	2.95	3.54	29.5	60.00	
Bordj Zemoura	20.97	3.18	4.05	38.33	61.39	
Bordj Ghédir	17.74	3.15	3.16	31.5	65.07	
Ksour	22.58	4.28	4.29	43.66	69.64	
Teniet En Nasr	41.94	5.21	6.69	52.16	79.82	Unpolluted (area V)
Average	17.46	2.99	2.99	30.04	46.19	
SD	6.60	0.90	1.11	8.88	13.44	
RSD	37.80	30.10	37.12	29.56	29.09	

Note: * Pollution zones based on the IAP scale according to Le Blanc and De Sloover (1970): 1-5.5 (extremely polluted zone); 5.6-15.5 (heavily polluted area); 15.6-35.5 (polluted area); 35.6-75.5 (weakly polluted zone); > 75.6 (non-polluted area)

The first clade is represented by the Teniet En-Nasr location, as the unpolluted location, with a significant abundance of lichens (5.21%) forming nine families. It represents the greatest lichen diversity of the region studied. The second clade is divided into two branches. The first branch is represented by the El-M'hir location which showed very low lichen abundance (1.25%) and a very low percentage of specific diversity (6.45%). On the other hand, the second branch which is in turn subdivided into two sub-branches includes the rest of the stations with low lichen abundance values, with the exception of Bordj Bou Arreridj, Hamadia, El-Ansseur, Mansoura, El-Ach, Khelil and Bir Kasdali stations.

Coupling the bio indication and biodiversity indices

In order to determine the different levels of air quality in the BBA region, a distribution of the locations was carried out based on the coupling of the bio indication and biodiversity indices (Figure 7).

The highest values of the IAP (79.82%) and the LDV (52.16%) were recorded at Teniet En-Nasr in which 26 species were found. This rural mountain location is separated from the rest of the studied locations with a rich epiphyte diversity and clean air quality. Followed by the locations of Haraza, Ksour, Ain Tesra and Ouled Brahem, these locations are characterized by a fairly pure air quality. All locations have a moderate air quality; i.e. moderately polluted, with a variety of medium epiphytic lichens and the majority of these locations are far from industrial sources.

On the other hand, several stations namely: El-Ansseur, Bordj Bou Arreridj, Ben Daoud, El-Hamadia, El-Main and Tixter have a slightly polluted air. These stations are located near roads, factories and quarries, and generally this type of pollution causes poor lichen diversity. We note in particular that the El-M'hir station recorded the lowest values of the IAP and LDV indices with 16.19% and 2.50% respectively.

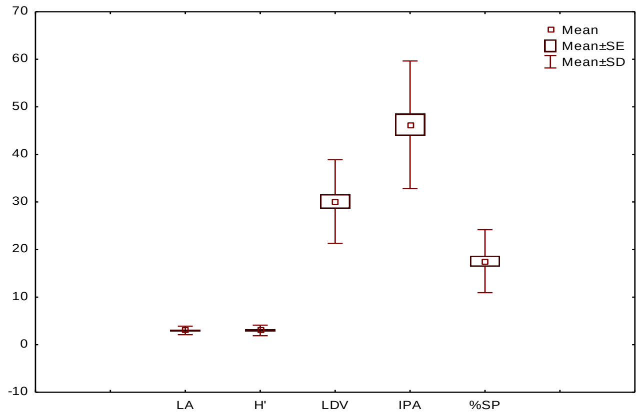

Figure 4. Variability of biodiversity and bio-indication indices

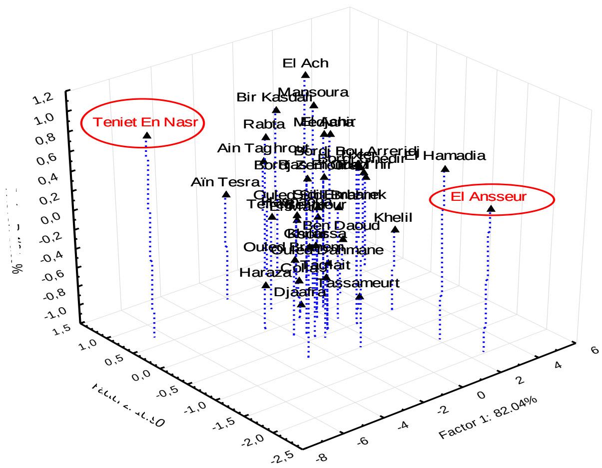

Figure 5. Spatial projection of locations based on the first three axes from the PCA

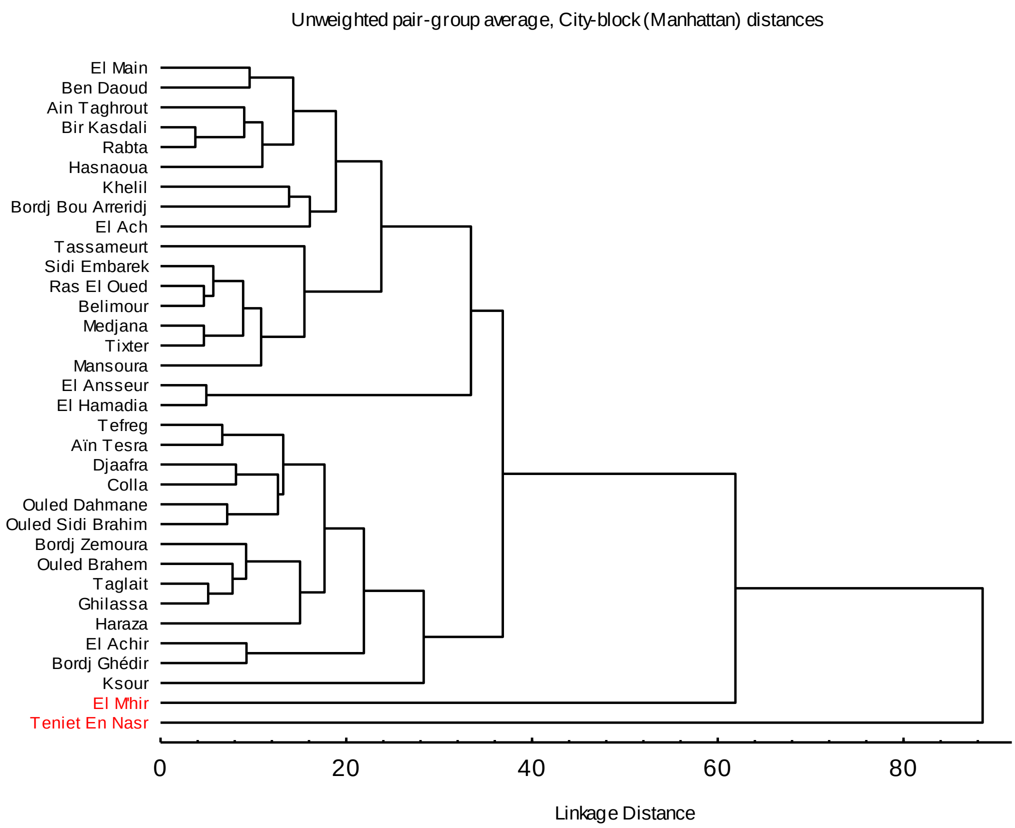

Figure 6. The result of clustering analysis using UPGMA based on the abundance of lichens

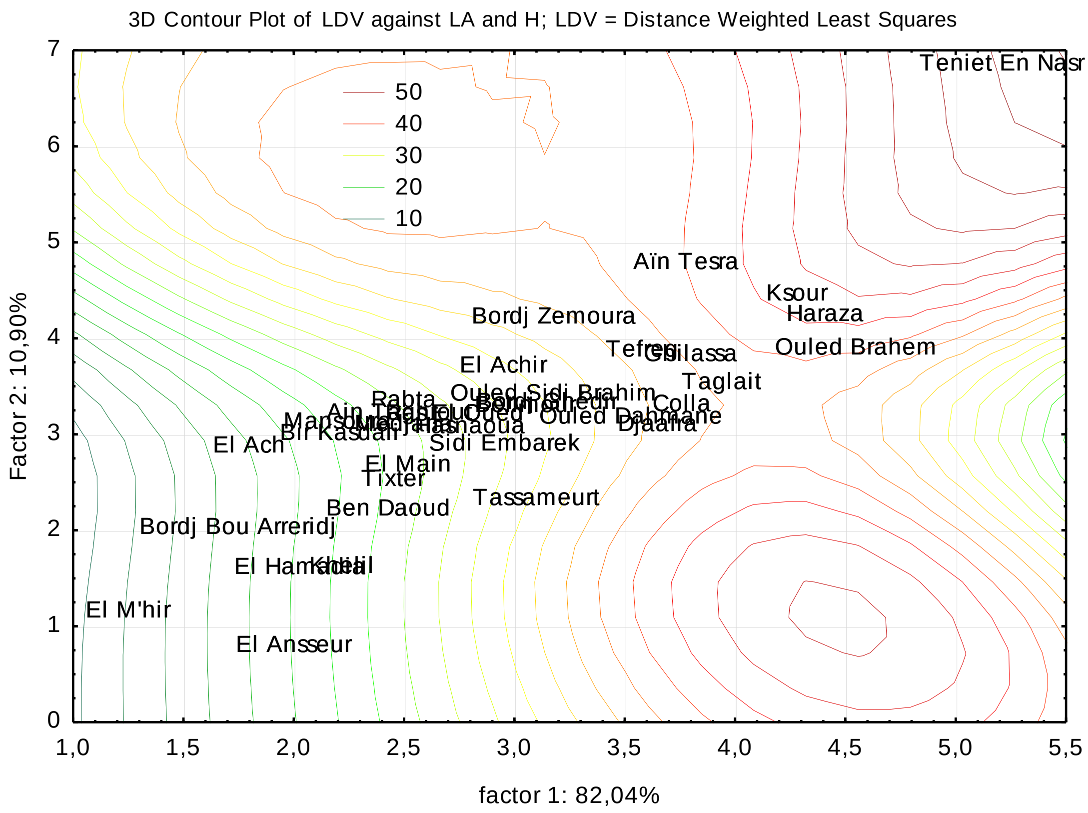

Figure 7. The map of air pollution in Bordj Bou Arreridj area, Algeria

Discussion

The results of the diversity of lichens in this study are similar to those found in urban areas in Algeria (Rebbas et al. 2011; Douibi et al. 2015; Lograda et al. 2015), in Italy (Giordani 2007) and in India (Das et al. 2013). In contrast, in southwest Portugal in the city of Sines, Llop et al. (2012) found different results.

Rich epiphyte vegetation with high species diversity was observed in rural stations, far from sources of pollution. The same observations have been reported by several authors (Batic and Mayrhofer 1996; Cazaux and Saint-Cricq 2010; Das et al. 2013; Agnan et al. 2017; Khastini et al. 2019). This diversity is influenced by important air humidity (Jayalal et al. 2015). The rural locations of El Ach, Ksour, El Main, Tassameurt and Taglait have a low specific diversity, which is probably due to the presence of a significant amount of the resin on the trunks of phorophytes which poisons lichens (Agnés and Galinou 1993; Kirschbaum and Wirth 1997).

A decrease of the specific diversity (< 20%) was found at the urban locations of Ras El-Oued, El-Ansseur, El-M'hir, El-Hamadia, Khelil, Tixter and Bordj Bou Arreridj. These locations are characterized by industrial activities (small industries and quarries) as well as the density of road traffic which cause the epiphytic vegetation to regress (Agnés and Galinou 1993; Gombert et al. 2004; Seaward 2008; Llop et al. 2012; Das et al. 2013; Sett and Kundu 2016; Khastini et al. 2019), Attanayaka and Wijeyaratne 2013; Kar et al. 2014). Elsewhere, pollution carried by wind may be another source that could affect stations in the south of the region, limiting the extent of epiphyte species by diminishing their abundance and diversity values (Käffer et al. 2011).

This heterogeneous distribution of epiphytic vegetation in the area studied is likely the result of alterations in atmospheric pollution and the ecological factors that play important role in the specific diversity of lichens (Jovan 2008; Das et al. 2013; Jayalal et al. 2015; Dron et al. 2016; Khastini et al. 2019). The overall average of the LDV index in the study area was low. This low rate of lichen diversity, especially in urban stations, could be due to road traffic and mining activities (quarries) (Svoboda 2007; Llop et al. 2012).

A great diversity of lichens was observed in the mountainous part of the region. These rural stations showed average LDV values. The results of the LDV values from our study are similar to those found in the Czech Republic and in the Bohemian Karst south-west of Prague (Svoboda 2007). The interpolations of the LDV values allowed us to identify the most disturbed locations which are assembled in zone IV (slightly polluted).

The results of IAP from our analysis are similar to those described in the literature; namely in Serbia (Stamenković et al. 2010), Sri Lanka (Attanayaka and Wijeyaratne 2013), India (Das et al. 2013), Korea (Jayalal et al. 2015) and France (Dron et al. 2016). On the other hand, in forest regions in France far from industrial sources, Agnan et al.

(2017) found higher values of IAP compared to those found in our study area.

Statistical tests indicated a significant correlation between the values of the LDV indices and those of the IAP; they increase with increasing species diversity and abundance of lichens. This strong correlation could be due to the unique use of frequencies in the LDV calculation method and the ecological index of each species (Q) included in the IAP formula (Loppi et al. 2004; Agnan et al. 2017).

Stations that have high IAP values with low species diversity were El-Ansseur, El-Hamadia and Khelil; while El Ach, Rabta, Bir Kasdali, and Ain Taghrout locations present an opposite trend. This difference is explained by the reaction of lichens to environmental alterations and by the recoveries of each species in these locations (Belnap et al. 2006; Das et al. 2013; Agnan et al. 2017).

Stations with the lowest averages of IAP and LDV, El-M'hir, BBA and Hasnaoua, show an alteration of air quality (Asta et al. 2002), which could be attributed to urbanization, industrial activities in particular (cement plants, quarries and paper mills) and the density of road traffic. Thus, the topography of the land and the wind of the most disturbed regions are significant natural sources affecting epiphytic lichens (Pinho et al. 2004; Stamenković et al. 2010; Das et al. 2013). Rural locations with little disturbance showed higher IAP values and moderate LDV values which indicate better air quality (Asta et al. 2002; Attanayaka and Wijeyaratne 2013; Jayalal et al. 2015).

Epiphytic lichens can be used as long-range indicators to monitor air quality (Das et al. 2013; Jayalal et al. 2015; Varela et al. 2018; Loppi 2019). Owing to the zoning of the indices of biodiversity and bio-indications, a deduction of the sensitivity of lichens to air pollution has been established in the BBA region.

The lichen species that are very sensitive to pollution are: *Evernia prunastri, Physcia tribacioides, P. leptalea, Parmelina pastillifera, P. carporrhizans, Lecidella elaeochroma* and *Lecanora allophana.*

The species which are sensitive to pollution are: *Parmelina tiliacea, Physcia biziana, P. tenella, Ochrolechia androgyna, O. alboflavescens, Coenogonium pineti, Trapeliopsis flexuosa, Bacidia rubella, B. friesiana, Acrocordia gemmata, Rinodina roboris, Pertusaria coccodes, P. flavida, Physconia perisidiosa, Lecanora rugosella, L. conizaeoides, Lobaria amplissima, Cetrelia olivetorum, Lecanographa amylacea* and *Xanthoria polycarpa.*

Lichen species which are tolerant to pollution are: *Amandinea punctata, Bacidia arceutina, Buellia griseovirens, Caloplaca cerina, C. cerinella, C. ferruginea, C. flavorubescens, C. hungarica, C. pyracea, Candelariella xanthostigma, Dendrographa decolorans, Flavoparmelia caperata, Hypocenomyce scalaris, Hypogymnia farinacea, Lecanora argentata, L. carpinea, L. chlarotera, L. compallens, L. meridionalis, L. praesistens, L. strobilina, Lepraria incana, Melanohalea elegantula, Ochrolechia pallescens, O. subviridis, Parmeliopsis ambigua, Parmelia sulcata, Phlyctis argeña, Physcia adscendens, P. aipolia, P. stellaris, Physconia distorta, P. grisea, Piccolia ochrophora* and *Xanthoria parietina*.

In conclusion, the present study allowed us to identify 62 epiphytic lichen species, 60% of which are crustose; tolerant to atmospheric pollution and more resistant to industrial and urban environment. In urban locations, the pollution is probably due to industrial activities; namely quarry activities and vehicle emissions, without neglecting the natural sources that influence the biodiversity of epiphytic lichens and their distribution in the Bordj Bou Arriridj region. The presence of epiphytic lichens plays an important role in determining the different areas of air pollution. By the presence of these lichens, we have shown that the air is slightly polluted in the BBA region. In addition, it was found that the most common species are tolerant species such as *Xanthoria parietina*, *Buellia griseovirens* and *Physcia aipolia*.

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