Turkish Journal of Botany

Volume 34 | Number 2 Article 2

1-1-2010

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TÜBİTAK

Research Article

Turk J Bot
34 (2010) 73-82
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doi:10.3906/bot-0903-21

Using vegetation units as salinity predictors in the Lower Cheliff Algeria

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Received: 30.03.2009
Accepted: 05.02.2010

Abstract: The Lower Cheliff plain is among the largest salted soils in north-western Algeria. In order to establish the relationships between the main soil factors and plant species in this stressed ecosystem, 133 relevés related to soil and vegetation were realized. Soil variables measured included electrical conductivity and calcium carbonate. The 133 relevés were arranged in clusters using k-means classification. The similarity analysis used to examine the variation in vegetation assemblage structure showed significant differences in taxonomical composition among groups of relevés. The phi coefficient of fidelity used then to extract the different vegetation units and to measure species concentration in each vegetation unit enabled us to extract a synoptic table with 6 vegetation units, exclusively related to conductivity. The results of redundancy analysis were concordant with k-means clustering results and showed that conductivity is the main factor affecting the vegetation distribution in the Lower Cheliff plain whereas $CaCO_3$ plays a secondary role. The approach used in this study enabled us to extract 4 ranges of salinity in the Lower Cheliff according to the optimum of salinity tolerated by each vegetation unit.

Key words: Analysis of similarity, fidelity, vegetation unit, conductivity, Lower Cheliff, Algeria

Introduction

The vegetal association is "a plant community characterized by definite floristic and sociological features", which shows by the presence of diagnostic species "a certain independence" (Braun Blanquet, 1928) and grows in uniform habitat conditions (Flahault & Schroter, 1910). These plant communities are recognized using diagnostic species as defined by Westhoff and Van der Maarel (1978). In this context, the term diagnostic species is an important concept in vegetation classification. It is a plant of high fidelity to a particular community serving as a criterion of recognition of that community (Curtis, 1959); it includes species that preferably occur in a single vegetation unit (character species) or in a few vegetation units (differential species) (Chytrý et al., 2002), whose relative constancy or

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abundance distinguish one association from another (Whittaker, 1962). They are species with a distinct concentration of occurrence or abundance in a particular vegetation unit (Bruelheide, 2000; Chytrý & Tichý, 2003). Their presence, abundance, or vigor are considered to indicate certain site conditions. Patterns of diagnostic species are assessed using relevés that are a record of vegetation composition that includes a comprehensive list of plants in a relatively small environmentally uniform habitat (Mueller-Dombois & Ellenberg, 1974). The floristic composition of that habitat can be expressed in a number of ways: simple measurements, such as plant species richness (Tracy & Sanderson, 2000; Fulbright, 2004), percent cover of plant types (Desoyza et al., 2000; Fernandez-Gimenez & Allen-Diaz, 2001), and fidelity measures (Chytrý et al., 2002).

The absence and presence of plant species is controlled by environmental variables, such as soil, topography, and climate (Parker, 1991; McDonald et al., 1996; Abd El-Ghani & Amer, 2003). Thus, floristic units have been used frequently as indicators of ecosystem processes and are considered a useful component of ecosystem classifications (Mueller-Dombois & Ellenberg, 1974; Rowe, 1984). Among the different environmental factors, soil is the most important in plant growth (Hoveizeh, 1997), so the presence/absence of species can be used as a bioindicator of soil conditions (Turner & Kelly, 1981; Wang, 1995).

Materials and methods

Study area

The plain of the Lower Cheliff is one of the largest quaternary alluvial plains of the Algerian western sublittoral with an area of about 450 km^2 and an average elevation of 70 m. It is located between latitude 35°48′3″-36°5′35″N and longitude 0°29′11″-0°56′37″E, about 35 km from the Mediterranean Sea. It is a syncline framed in the North by Dahra's hills composed of marls and clayey silt and in the South by Benziane's hills composed of schist and salted marls, which account for the high salinity of the plain (Figure 1).

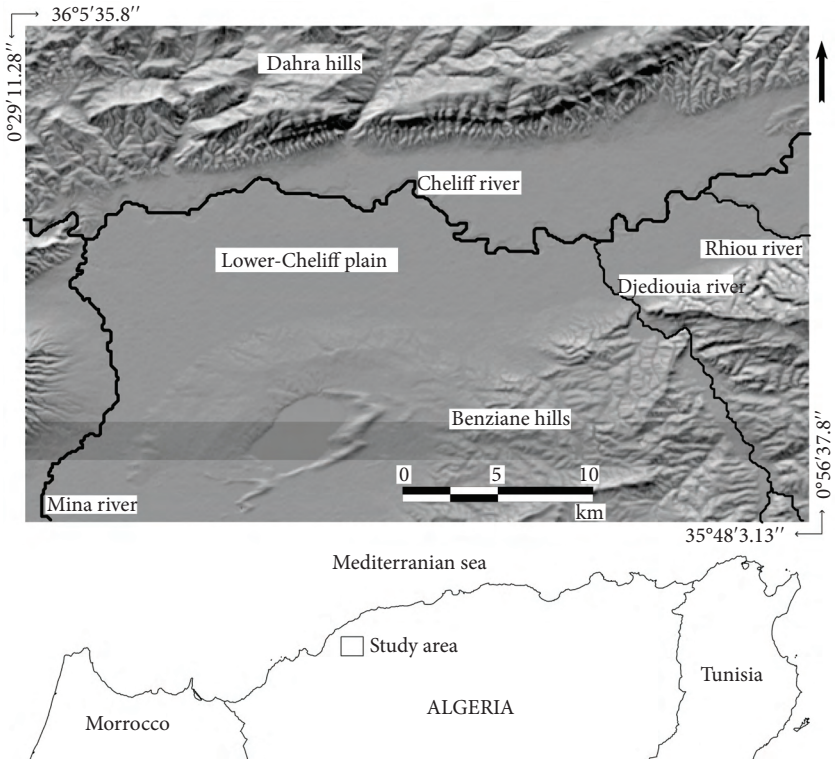

Figure 1. Location of the study area, showing the Lower Cheliff plain and the surrounding hills of Dahra in the north and Benziane in the south of north-western Algeria.

The study area lies within the semi-arid regions characterized by the minimal precipitation of 200 to 300 mm/yr, frequent droughts with a dry period of 7 months (Figure 2), and an annual average temperature around 20 °C, which increases the level of salinity.

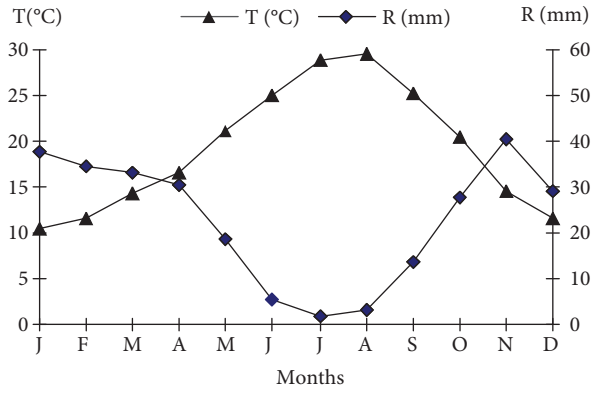

Figure 2. Climate diagram of the Lower Cheliff.

Soil and vegetation sampling

Vegetation relevés (sites) were recorded using the Braun-Blanquet seven-degree scale of abundance and dominance (Westhoff & Van der Maarel, 1978) and then transformed to 0-9 van der Maarel scale. All relevés were recorded at the territory of the Plain of the Lower Cheliff. A total of 133 relevés were recorded with 40 species counted; among them, 11 rare species were excluded from the analysis.

A total of 133 soil samples were collected at a depth between 0–30 cm. Measured soil factors were restricted to electrical conductivity (ECe) and calcium carbonate ($CaCO_3$), which represents the main problem affecting the soil and vegetation (distribution and presence/absence) in the region.

Data analysis

To cluster relevés into similar groups and identify the characteristic vegetation unit of each group, a k-means (MacQueen, 1967; Spath, 1980; Legendre & Legendre, 1998) cluster was applied, followed by phi coefficient of association (Sokal & Rohlf, 1995; Chytrý et al., 2002) to identify species discriminating between k-means groups. This method identifies indicator species that best characterize groups of relevés, and each species is associated with a Phi coefficient and a P-value obtained by the Fisher's test. The phi coefficient of association is a statistical measure of association, which can be used as a measure of fidelity.

To calculate the phi coefficient values, the same notation as that used by Bruelheide (2000) and Chytrý et al. (2002) was used in this study.

N = number of relevés in the data set; N_p = number of relevés in the particular vegetation unit; n = number of occurrences of the species in the data set; n_p = number of occurrences of the species in the particular vegetation unit.

$$\Phi = \frac{N.n_p - n.N_p}{\sqrt{n.N_p.(N-n).(N-N_p)}}$$

Calculations of the phi coefficient were done using the JUICE 6.5 program (Tichý, 2002).

Traditionally, the phi coefficient considers only the presence/absence of vegetation, so that fidelity values calculated using this coefficient are not influenced by species cover or abundance. The main advantage of phi coefficient is its independence of dataset size. The phi coefficient values range from –1 to 1. The highest phi value of 1 is achieved if the species occurs in all relevés of the vegetation unit and is absent elsewhere. A positive value lower than 1 mean that the species is absent from some relevés of the vegetation unit or is present in some relevés outside the vegetation unit. A value of 0 is obtained when the relative frequency of the species in the vegetation unit equals the relative frequency in the rest of the dataset, thus indicating no relation between the target species and the target vegetation unit.

The phi coefficient is affected by the relative size of vegetation units; removal of the dependence of the fidelity measures on the vegetation unit size needs standardization of the target vegetation unit.

After the standardization, the fidelity measure depends only on the relative frequencies within each relevés group. The phi values, after such standardization, are entirely independent of the size of the vegetation units and can be directly compared across different vegetation units (Tichý & Chytrý, 2006).

Almost all clustering algorithms require that the final number of clusters depends on the user. If that number is not apparent from prior knowledge, it should be chosen in some way. Thus we stopped clustering when most species reached their maximum phi value.

To examine the variation in vegetation assemblage structure among relevés, we performed an ANOSIM (analysis of similarity) (Clarke, 1993; Clarke & Warwick, 1994; Clarke & Gorley, 2001) using Bray-Curtis similarity. Each test in ANOSIM produces an R statistic comparing the differences among relevés within a group with the similarities among relevés between groups. R will assume values near 1 when similarities between relevés within groups are higher than those between relevés from different groups, and vice versa for values near -1. Values close to 0 are indicative of no differences among groups. ANOSIM calculations were performed using PAST program 1.9 (Hammer et al., 2001).

In order to establish the main links between environmental variables and vegetation assemblage patterns, a redundancy analysis (RDA) was performed. First, a detrended correspondence analysis (DCA) (Hill & Gauch, 1980) was conducted to test if a model with unimodal (CCA) or linear (RDA) response curve should be used in ordination analysis. Results of the DCA showed that gradient length was 3.95 for axis 1 to 2.53 for axis 4; thus, both RDA and CCA may give correct results (Jongman et al., 1996, Leps & Smilauer, 2003). As the percentage of total variance explained by RDA (34.2%) was higher than CCA (29.4%), we considered it more appropriate to perform an RDA.

Results and discussion

Relevés k-means clustering

As the final number of clusters in any clustering algorithm depends on the user, we consider it more appropriate to use the phi coefficient values. Indeed this coefficient evolves in a progressive way during subdivisions until it reaches a maximum value when all the similar stations are gathered in only one group, which represents the ideal conditions for each species. Thus for 10 subdivisions the maximum fidelity coefficient value is reached at the 6th subdivision for the majority of our species, which means that these species are well characterized ecologically at this level of the hierarchy. This justifies our choice of 6 groups of relevés summarized in synoptic Table 1. Each group is characterized by a characteristic vegetation unit and each vegetation unit is composed of diagnostics species with high fidelity according to phi coefficient and Fisher's test.

For the subdivisions' k-means (Figure 3), it is remarkable that conductivity is the principal environmental factor influencing the distribution of the vegetation whereas the percentage of $CaCO_3$ has a secondary influence. The main structure (k = 2) of the hierarchical dendrogram (Figure 3) contrasts stations with high salinity and stations with low salinity with all the Chenopodiaceae and Caryophyllaceae individuals in one group (stations with high salinity). The heterogeneity of the stations with high salinity is revealed by lower phi values of most species, which increase when the stations with high salinity are isolated during the k-means clustering process. With a phi value highly significant according to the Fisher's test at the 6th level of hierarchy, *Suaeda maritima, Torilis nodosa, Atriplex halimus,* and *Bellis perennis* are the best examples of a characteristic species. *Suaeda fruticosa* and *Spergularia marina* are the 2 differential species of the salty stations with a larger ecological amplitude revealed by a maximum phi value at the lower level of hierarchy (k = 2). For the stations with low salinity, the phi value of all characteristic species grows regularly as the relevés are subdivided and better characterized.

During the different levels of hierarchy of k-means clustering, it's remarkable that the major parameter controlling the distribution of vegetation is conductivity whereas the percentage of calcareous sediments ranked the second. Indeed these vegetation units are clearly distributed according to ECe and indicate by their presence or absence certain conductivity.

Therefore, distribution of the vegetation units according to salinity results in 4 levels of salinity as summarized in Table 2: the 1st level that's unsalty indicated by the presence of species of the vegetation units E and F (these 2 vegetation units are separated according to the percentage of calcareous as shown in Figure 3); the 2nd level that's averagely salty with a clear

Table 1. Synoptic table of 133 relevés of the Lower Cheliff salted soils, based on fidelity. Diagnostic species (values in bold) are those with significant φ value according to the Fisher's test (*** P < 0.001; ** P < 0.01; * P < 0.05) ranked by decreasing value of φ.

Synoptic table	Code	Percentage synoptic table with fidelity Phi coefficient						Percentage frequency					
Group No.		A	B	C	D	E	F	A	B	C	D	E	F
No. of relevé		26	33	30	21	20	3	26	33	30	21	20	3
Number of diagnostic species		5	6	4	2	6	9	5	6	4	2	6	9
Diagnostic species of the vegetation unit A													
Suaeda maritima (L.) Dumort	*Su.m(Ch)*	**37,9*****	—-	—-	—-	—-	—-	**38**	9	7	10	5	.
Arthrocnemum macrostachyum Moric.	*Ar.m(Ch)*	**31,3****	—-	—-	—-	—-	—-	**12**	.	.	.	.	.
Agrostis vulgaris L.	*Ag.v(Po)*	**30,2****	18,8	21,3	2,6	—-	—-	**73**	61	63	43	.	.
Diagnostic species of the vegetation unit B													
Atriplex halimus L.	*At.h(Ch)*	—-	**29,7****	—-	0,6	—-	—-	4	**18**	.	5	.	.
Spergula sp. L.	*Sp.s(Ca)*	13,5	**24,8****	8,2	2,7	—-	—-	69	**82**	63	57	20	.
Salsola vermiculata L.	*Sa.v(Ch)*	16	**23,2***	9,7	4,7	—-	—-	50	**58**	43	38	10	.
Common diagnostic species of vegetation units A and B													
Suaeda fruticosa (L.) Forssk	*Su.f(Ch)*	**33,2*****	**24,7***	14,5	15,4	—-	—-	**100**	**91**	80	81	35	.
Spergularia marina (L.) Griseb.	*Sp.m(Ca)*	**27,5***	**25,9***	—-	—-	—-	—-	**35**	**33**	13	.	.	.
Diagnostic species of the vegetation unit C													
Bellis perennis L.	*Be.p(As)*	—-	0,7	**28****	5,7	—-	—-	12	15	**37**	19	5	.
Hypochaeris glabra L.	*Hy.g(As)*	—-	9,6	**25,5****	8,4	—-	—-	62	73	**90**	71	45	33
Plantago coronopus L.	*Pl.c(Pl)*	6,2	21,2	**24,3***	12,6	—-	—-	50	67	**70**	57	15	.
Diagnostic species of the vegetation unit D													
Phalaris arundinacea L.	*Ph.a(Po)*	—-	7,3	14	**23,5**	—-	—-	15	24	30	**38**	.	.
Plantago lanceolata L.	*Pl.l(Pl)*	—-	2,3	—-	**18,9**	12,1	—-	.	9	3	**19**	15	.
Diagnostic species of the vegetation unit E													
Torilis nodosa L.	*To.n(Ap)*	—-	—-	—-	—-	**43,4*****	—-	.	.	3	5	**30**	.
Scorpiurus muricatus L.	*Sc.m(Fa)*	—-	—-	—-	0,9	**23,3***	—-	.	3	3	5	**15**	.
Foeniculum vulgare L.	*Fo.v(Ap)*	—-	—-	—-	15,8	17	—-	.	.	.	10	**10**	.
Diagnostic species of the vegetation unit F													
Lolium multiflorum Lam.	*Lo.m(Po)*	—-	—-	—-	—-	8	**56,3***	.	9	3	5	25	**67**
Cirsium vulgare (Savi) Ten.	*Ci.v(As)*	—-	—-	—-	7,6	—-	**36,9***	.	.	3	14	5	**33**
Erodium cicutarium L.	*Er.c(Ge)*	—-	—-	—-	—-	6,6	**33,4***	.	3	7	5	15	**33**
Onopordum acanthium L.	*On.a(As)*	—-	—-	—-	—-	6	**32,4***	4	.	3	10	15	**33**
Calendula arvensis L.	*Ca.a(As)*	—-	—-	—-	—-	8,9	**26,5***	4	6	7	10	20	**33**
Sinapsis arvensis L.	*Si.a(Br)*	—-	—-	1	—-	5,1	**21,4***	8	3	17	14	20	**33**
Leucanthemum vulgare Lam.	*Le.v(As)*	—-	8,6	—-	6,6	—-	**19,5***	23	55	33	52	40	**67**
Medicago sativa L.	*Me.s(Fa)*	—-	1,7	3,1	—-	12	**18***	12	48	50	43	60	**67**
Common diagnostic species of vegetation units E and F													
Scolymus hispanicus L.	*Sc.h(As)*	—-	—-	—-	—-	**10,8***	**29***	.	.	10	10	20	33
Species with phi value < 16.7 and no significant fidelity to any vegetation unit according to the Fisher's test													
Hordeum murinum L.	*Ho.m(Po)*	0,9	11,2	—-	—-	—-	5,6	62	73	60	57	45	67
Beta vulgaris maritima L.	*Be.m(Ch)*	—-	5,2	9	—-	—-	—-	65	73	77	62	60	67
Anagallis arvensis L.	*An.a(Pr)*	—-	—-	1,3	—-	13,9	12,1	19	12	23	10	35	33
Melilotus officinalis (L.) Lam.	*Me.o(Fa)*	—-	—-	—-	—-	13,6	11,8	12	15	20	19	35	33

k = 2 Clusters

82 relevés
ECe = **14** mmhos $CaCO_3$ = **17.07**%
Su.f(Ch) (**42.1*****), *Ag.v(Po)* (**41.8*****), *Sp.m(Ca)* (**41.7*****), *Sp.s(Ca)* (**37.2*****), *Sa.v(Ch)* (**27.6****), *Pl.c(Pl)* (**24.5****), *Su.m(Ch)* (**19.5***), *At.h(Ch)* (15), *Ho.m(Po)* (15), *Be.p(As)* (14.3), *Ar.m(Ch)* (13.7), *Hy.g(As)* (13.4), *Be.m(Ch)* (5.3), *Ph.a(Po)* (1.3)

51 relevés
ECe = **2.74** mmhos $CaCO_3$ = **18.12**%
Sc.h(As) (**27.7*******),** *To.n(Ap)* (**23.4****), *Ca.a(As)* (**22.2****), *Fo.v(Ap)* (**20***), *Ci.v(As)* (**18.5***), *On.a(As)* (**17.8***), *Si.a(Br)* (**17.4***), *Lo.m(Po)* (**17.3***), *Me.s(Fa)* (15), *Me.o(Fa)* (14.9), *Pl.l(Pl)* (14.7), *Sc.m(Fa)* (11.9), *Er.c(Ge)* (11.9), *Le.v(As)* (11.2), *An.a(Pr)* (11.1).

k = 3 Clusters

58 relevés
ECe = **16.8** mmhos $CaCO_3$ = **17.34**%
Sp.m(Ca) (**38.6*****), *Su.f(Ch)* (**35.5*****), *Sp.s(Ca)* (**28.4*****), *At.h(Ch)* (**23.4***), *Su.m(Ch)* (**22.9****), *Ag.v(Po)* (**22.7****), *Sa.v(Ch)* (**20.8***), *Ar.m(Ch)* (18.7), *Ho.m(Po)* (13.7).

38 relevés
ECe = **6.22** mmhos $CaCO_3$ = **17.21**%
Be.p(As) (**23.3***), *Hy.g(As)* (**19.1***), *Pl.c(Pl)* (**19.1***), *Ph.a(Po)* (7.4), *Be.m(Ch)* (4.7).

37 relevés
ECe = **2** mmhos $CaCO_3$ = **18**%
To.n(Ap) (**32.1*****), *On.a(As)* (**26.2****), *Lo.m(Po)* (**21.7***), *Sc.h(As)* (**19.2***), *Er.c(Ge)* (**18.7***), *Ci.v(As)* (18.6), *Sc.m(Fa)* (18.6), *Fo.v(Ap)* (17.2), *Me.s(Fa)* (13.7), *An.a(Pr)* (11.8), *Si.a(Br)* (11.7), *Pl.l(Pl)* (11.6), *Ca.a(As)* (9),*Me.o(Fa)* (7.1), *Le.v(As)* (2.7).

k = 4 Clusters

45 relevés
ECe = **18** mmhos $CaCO_3$= **16**%
Sp.m(Ca) (**35.1*****), *Su.f(Ch)* (**28.5*****), *Sp.s(Ca)* (**27.2*****), *Su.m(Ch)* (**22.7***), *Ar.m(Ch)* (**22.5***), *Ag.v(Po)* (**27.2****), *Sa.v(Ch)* (**20.5***), *At.h(Ch)* (15.7).

37 relevés
ECe = **8.5** mmhos
$CaCO_3$ = **17.11** %
Be.p(As) (**22.9****), *Ag.v(Po)* (**22.5***), *Su.f(Ch)* (**20.2***), *Hy.g(As)* (**19.3***), *Pl.c(Pl)* (16.5), *Ho.m(Po)* (9.9), *Be.m(Ch)* (6.3).

25 relevés
ECe = **3.7** mmhos
$CaCO_3$ = **18.3**%
Ph.a(Po) (**24.8***), *Le.v(As)* (15.3), *Pl.l(Pl)* (12.9),

26 relevés
ECe = **1.7** mmhos $CaCO_3$ = **18**%
To.n(Ap) (**43*****), *Lo.m(Po)* (**31.5****), *Er.c(Ge)* (**28.4****), *On.a(As)* (**27.5****), *Fo.v(Ap)* (**22.9***), *An.a(Pr)* (**20.2***), *Me.o(Fa)* (**20***), *Sc.h(As)* (**19.2***), *Me.s(Fa)* (**18.9***), *Ca.a(As)* (16.5), *Sc.m(Fa)* (16.3), *Si.a(Br)* (16), *Ci.v(As)* (15.1).

k = 5 Clusters

26 relevés
ECe = **22** mmhos
$CaCO_3$ = **16.3**%
Su.m(Ch) (**36.2*****), *Su.f(Ch)* (**27.4*****), *Ar.m(Ch)* (**30.7****), *Ag.v(Po)* (**23.7****), *Sp.m(Ca)* (**24.3***).

33 relevés
ECe = **12.4** mmhos
$CaCO_3$ = **18.11**%
At.h(Ch) (**28.7****), *Sp.s(Ca)* (**23****), *Sp.m(Ca)* (**22.6***). *Sa.v(Ch)* (**17.9***), *Ho.m(Po)* (13).

27 relevés
ECe = **6.8** mmhos
$CaCO_3$ = **16.66**%
Be.p(As) (**24.6****), *Hy.g(As)* (**21.6****), *Pl.c(Pl)* (**18.1***), *Be.m(Ch)* (10.6).

22 relevés
Mean ECe = **3.3** mmhos
Mean $CaCO_3$ = **18.5**%
Ph.a(Po) (**22.7***), *Le.v(As)* (18), *Pl.l(Pl)* (**17.1***), *Fo.v(Ap)* (15.6).

25 relevés
ECe = **1.7** mmhos $CaCO_3$ = **17.89**%
To.n(Ap) (**44.4*****), *Lo.m(Po)* (**33****), *Sc.h(As)* (**21.5***), *Er.c(Ge)* (**20.3***), *Me.o(Fa)* (**20.2***), *An.a(Pr)* (**20.2***), *On.a(As)* (**19.2***), *Ca.a(As)* (**18***), *Me.s(Fa)* (**17.5***) *Sc.m(Fa)* (17.4), *Ci.v(As)* (16.2), *Si.a(Br)* (10.9).

k = 6 Clusters

A: 26 relevés
ECe = **22** mmhos
$CaCO_3$ = **16.3**%
Su.m(Ch)(**37.9*****), *Su.f(Ch)*(**33.2*****), *Ar.m(Ch)*(**31.3****), *Ag.v(Po)*(**30.2****), *Sp.m(Ca)*(**27.5***).

B : 33 relevés
ECe = **12.4** mmhos
$CaCO_3$ = **18.11**%
At.h(Ch) (**29.7****), *Sp.m(Ca)*(**25.9***), *Sp.s(Ca)* (**24.8****), *Su.f(Ch)*(**24.7***), *Sa.v(Ch)* (**23.2***), *Ho.m(Po)* (11.2).

C: 30 relevés
ECe = **6.5** mmhos
$CaCO_3$ = **16.8**%
Be.p(As)(**28****), *Hy.g(As)*(**25.5****), *Pl.c(Pl)*(**24.3***), *Be.m(Ch)*(9).

D : 21 relevés
ECe = **3** mmhos
$CaCO_3$ = **18.3**%
Ph.a(Po)(23.5), *Pl.l(Pl)* (18.9).

E: 20 relevés
ECe = **1.7** mmhos
$CaCO_3$ = **19.3**%
To.n(Ap) (**43.4*****), *Sc.m(Fa)* (**23.3***), *Fo.v(Ap)* (**17***), *An.a(Pr)* (13.9), *Me.o(Fa)* (13.6).

F: 3 relevés
ECe = **1.2** mmhos
$CaCO_3$ = **9** %
Lo.m(Po) (**56.3***), *Ci.v(As)* (**36.9***), *Er.c(Ge)* (**33.4***), *On.a(As)* (**32.4***), *Sc.h(As)* (**29***), *Ca.a(As)* (**26.5***), *Si.a(Br)* (**21.4***), *Le.v(As)* (**19.5***), *Me.s(Fa)* (**18***).

Figure 3. Site clusters obtained by k-means method, with the associated indicator species. The phi values are indicated in brackets along with P-value significance according to the Fisher's test (*** P < 0.001; ** P < 0.01;* P < 0.05). Significant phi values are indicated in bold characters. For species abbreviations, see Table 1.

Table 2. Conductivity levels versus vegetation distribution in salted soils of the Lower Chelif.

Range	Designation	Vegetation unit
1st level	Unsalty	E and F
2nd level	Averagely salty	C
3rd level	Salty	B
4th level	Highly salty	A

predominance of the vegetation unit C; the 3rd level that's salty indicated by the vegetation unit B; and the vegetation unit A indicates the 4th level that's highly salty. As the species of the vegetation unit D are not significant according to the Fisher's test, the conductivity level of this vegetation unit is not mentioned.

Evolution of the phi coefficient

Many species are typical of lower hierarchy levels, whereas others typify higher hierarchy levels. The evolution of the phi coefficient for 10 subdivisions (Figure 4a, b, and c) as the groups are subdivided often show strong differences among species. First, there are at first the species that are present almost everywhere and have a maximum phi coefficient when all the salty stations are gathered in only 1 group (Figure 4a), such as *Suaeda fruticosa*, *Agrostis vulgaris*, *Spergularia marina,* and *Spergula* sp; as soon as these relevés are subdivided (abscissa of the histogram) the phi coefficient begins decreasing, which means that these 4 species are generalist species typical of salty stations. The typical species of the intermediate levels (Figure 4b) show an increasing phi coefficient followed by a decreasing values, such as *Suaeda maritima, Atriplex halimus, Torilis nodosa, Lolium multiflorum, Bellis perennis,* and *Phalaris arundinacea*. Finally, more specialized species (Figure 4c), such as *Arthrocnemum macrostachyum,* are common to stations with high salinity that was revealed by a maximum phi value at level 10. The strongest phi coefficient values are observed for the high levels, when the groups are very well characterized ecologically.

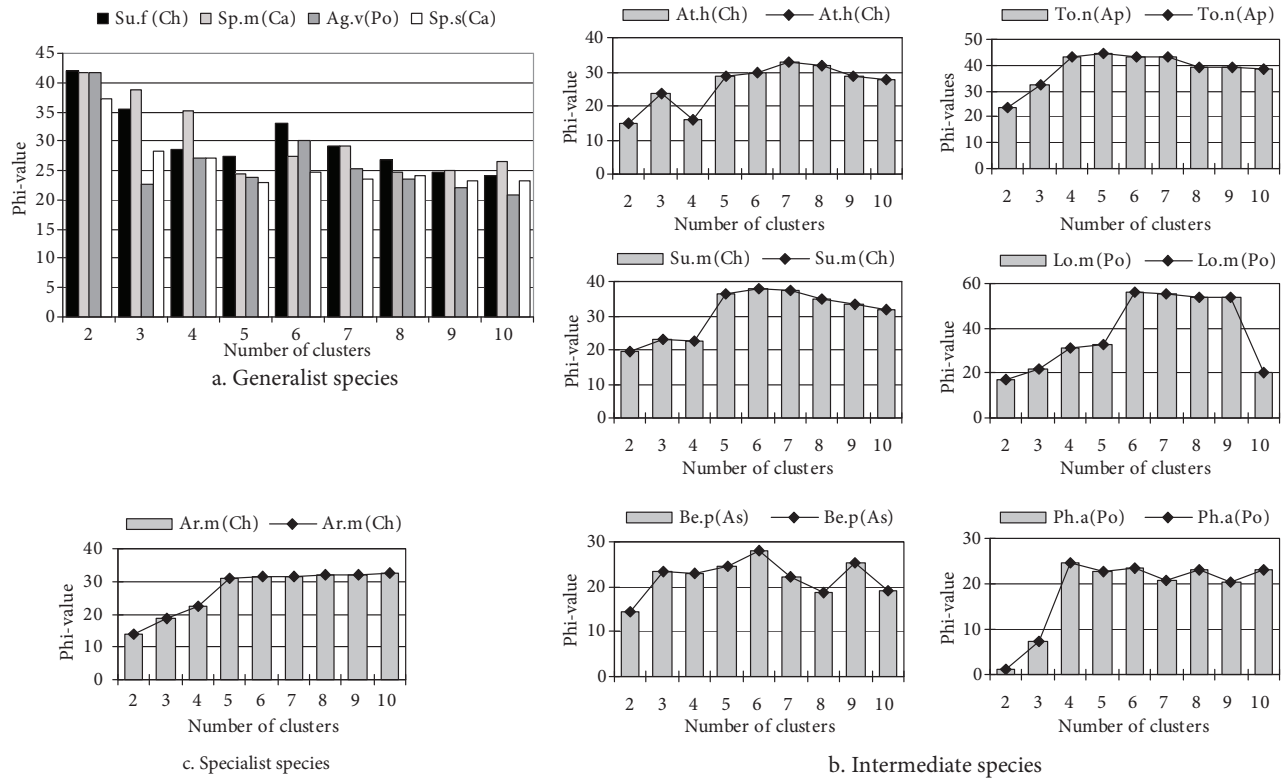

Figure 4. Evolution of the phi coefficient for 10 subdivisions. For species abbreviations, see Table 1.

Similarity analysis (ANOSIM)

Similarity analysis (ANOSIM) (Table 3) showed significant differences in taxonomical composition among groups. However, these differences are small between some groups (B, C and B, D), with non-significant P-values indicating an important overlap between vegetation assemblages. The most significant differences considering ANOSIM comparisons were found between salty groups (A, B, C) and unsalty groups (E and F), with highly significant P-values ($P < 0.001$). In the case of groups E and F, the negative value of R indicate that similarity between relevés within groups is lower than that between relevés of the 2 groups, which means that these 2 groups share many species and no differences were detected between them. Thus the result of similarity analysis (ANOSIM) showed clear differences of taxonomical composition at conductivity scale.

Redundancy analysis

Although a low percentage of species variability was explained by the first 2 axes of the RDA (8.9% of the total variation of the 29 species recorded in the 133 relevés), the variability explained by all canonical axes were significant ($F = 6.35$, $P < 0.01$) (Table 4) as indicated by Monte Carlo permutation tests (999 permutations). The first canonical axis is highly significant according to Monte Carlo permutation tests as it explains 8% of the total variability in the species data and 90.1% of variance in species-environment relation. This axis is highly negatively correlated with ECe (- 0.98) and differentiates between relevés according to their conductivity. The second axis negatively related to $CaCO_3$ explains only 0.9% of the variance in species data and 9.9% of variance in species-environment relation. As indicated by their perpendicular direction (Figure 5) no interaction was found between ECe and $CaCO_3$.

Table 3. Results of similarity analysis (ANOSIM) with a P-value (higher matrix) and an R-value (lower matrix).

Bray-Curtis similarity	P values (*** P < 0.001; ** P < 0.01; * P < 0.05)					
	A: (26 relevés)	B: (33 relevés)	C: (30 relevés)	D: (21 relevés)	E: (20 relevés)	F: (3 relevés)
R values	A: (26 relevés)	**0.0021** **	**0.0139** *	**0.0005** ***	**0** ***	**0.0004** ***
	B: (33 relevés)	0.08873	0.0783	0.1236	**0** ***	**0.0019** **
	C: (30 relevés)	0.0784	0.03166	**0.017** *	**0** ***	**0.0002** ***
	D: (21 relevés)	0.1452	0.04083	0.1126	**0.0012** **	**0.0311** *
	E: (20 relevés)	0.4735	0.371	0.4883	0.159	0.8546
	F: (3 relevés)	0.84	0.6541	0.7652	0.4146	-0.1363

Table 4. Summary statistics of RDA using forward selection of variables. Pearson correlations between significant environmental variables and the canonical axes are also shown.

	Axis 1	Axis 2
Eigenvalues:	0.08	0.009
Species-environment correlations:	0.664	0.374
Cumulative percentage variance of species data:	8	8.9
Cumulative percentage variance of species-environment relation:	90.1	100
Correlations with the first 2 axes		
ECe (conductivity)	- 0.98**	- 0.21
$CaCO_3$	0.29	- 0.96**
Monte Carlo test (999 permutations)	F	P-value
significance of the first canonical axis:	11.34	0.0020
significance of all canonical axes:	6.35	0.0020

** P < 0.01

The results of RDA are highly concordant with k-means clustering results and shows that conductivity is the main factor affecting the vegetation distribution in the Lower Cheliff plain whereas $CaCO_3$ plays a secondary role. Figure 5 shows that all the Chenopodiaceae and Caryophyllaceae as well as some Poaceae and Asteraceae are positively correlated with conductivity. This less diverse group according to Shannon Weiner diversity index (1.35) and Simpson diversity index (0.6) is an indicator of salty soils while the second, more diverse group (Shannon Weiner diversity index (1.41), Simpson diversity index (0.64)), which is negatively correlated with conductivity, is an indicator of healthy soils.

Conclusion

Salinity classification has been traditionally based on abiotic classification. However, salinity is subject to temporal variations due to the fluctuations in precipitation and periodic drought. The challenge is how to obtain a realistic view of the salinity dynamics in Lower Cheliff on the basis of abiotic measurements. If not measured continuously, abiotic factors are unlikely to reflect the dynamics of salinity but continuous measurements are time-consuming. In contrast, the knowledge of the flora is an easy and fast way for evaluating the ecological conditions as shown by the redundancy analysis species distribution in Lower Cheliff exclusively related to salinity. Thus the composition of the vegetation community could be an alternative to reliably assess the salinity fluctuations. The concept of vegetation units presented here offers an alternative to overcome the drawbacks of single abiotic approaches. Using salinity tolerances and preferences of vegetation units, this approach enables the evaluation of salinity at given sampling relevés. Our results show that some vegetation units are typical to salty soils, such as vegetation unit A indicating highly salty soils and vegetation unit C indicating salty soils, on the other hand, vegetation units E and F indicate healthy soils. The evolution of the phi coefficient as the groups are subdivided differentiates between generalist, intermediate, and specialist species. *Suaeda fruticosa*, *Agrostis vulgaris*, *Spergularia marina,* and *Spergula* sp were among the most abundant species in our survey and are generalist species; *Arthrocnemum macrostachyum* is typical of stations with high salinity;

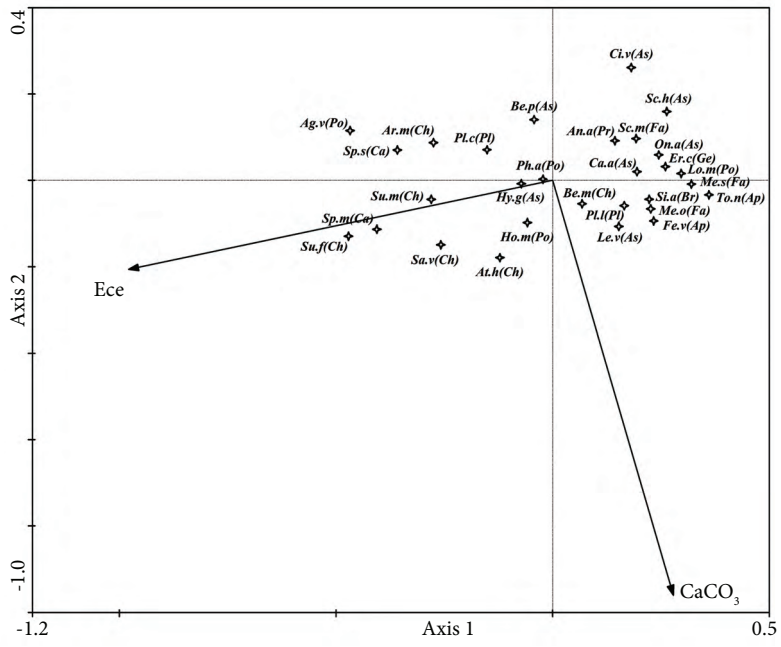

Figure 5. Redundancy analysis of 29 species and 2 explanatory variables at 133 relevés in the plain of Lower Cheliff. Both axes of the ordination plot explain 8.9% of the species variance and 100% of the species-environment relation.

whereas the remaining species are intermediate species differentiating various levels of salinity.

The Lower Cheliff was chosen for demonstrating an application of this study. The composition of the flora might be different in other regions. However, as long as the salinity tolerances and preferences of the flora are known, the level of salinity can be easily estimated at any given site.

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