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Acacia tortilis var. *raddiana* communities in the northwestern Algerian Sahara

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ABSTRACT

The aim of this work is the phytoecological study of the *Acacia tortilis* var. *raddiana* desert savanna in the northwestern Algerian Sahara. Sixty-seven relevés were collected for this habitat from an area extending from the northern boundary of Béchar to the southern part of Kerzaz, a latitudinal gradient of 250 km. A detrended correspondence analysis identified two communities represented by 35 and 32 relevés. Canonical correspondence analysis highlighted the topography and the nature of the substratum as the main environmental factors explaining the distribution of the two groups. The most frequent community corresponded to the *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association Quézel 1965. It is associated with large wadi-beds and alluvial plains. This association presents two facies: a saxicolous one characterized by *Farsetia occidentalis* and *Trichodesma calcaratum* and a sandy facies with *Kickxia aegyptiaca* and *Brocchia cinerea*. The second community corresponds to the *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association Quézel 1965, typical of narrow wadi-beds with rocky substrates. The floristic composition reveals fewer taxa of tropical origin and a reduced list of characteristic species is proposed. Details of the range of the two syntaxa identified are provided. They are compared with the other *Acacia tortilis* var. *raddiana* associations described for the Algerian central Sahara.

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Acacia tortilis var. *raddiana* communities; desert vegetation; multivariate analysis; phytosociological diagnosis; wadi geomorphology

Introduction

The vegetation of the Algerian Sahara has long been known for its distinctiveness and phytogeographical interest and complexity. Quézel (1978) indicates the existence of nine biogeographical domains for the Sahara out of 14 for North Africa. An even more detailed phytogeographical description provided by Le Houerou (1990, 1995) which, extended to the Sahelian territories, suggests the existence of 16 domains that cover the Sahara. The limits of these phytogeographical subdivisions (zones) are outlined in Figure 1. The vegetation description in the present paper falls into the northwestern Saharan domain of Quézel (1978), corresponding more or less to the same zone proposed by Le Houérou (1990, 1995).

The special character and landscape diversity of the northwestern Sahara has attracted many botanists over the last century (Tits 1925; Maire 1938; Guinet 1954, 1958; Guinet and Sauvage 1954). Tree species are rare in the Sahara and plant communities with *Acacia tortilis* var. *raddiana* as the dominant stratum are the most widespread vegetation units in the Saharo-Arabian belt (Ozenda 1958; Boulos 1995). *Acacia tortilis* var. *raddiana* is an African (Sahelo-Sudanian) element (Ross 1981). This species occurs abundantly in all northern and eastern African countries and extends eastward to the Arabian Peninsula (Brenan 1983; Kennenni 1991). In this paper, we used the flora of Ozenda (2004) for species identification. Nomenclature follows Dobignard and Chatelain (2010–2013) for all the species of the present study.

Early descriptions of *Acacia* communities were provided by Guinochet and Quézel (1954), Quézel and Simonneau (1963), Quézel (1965), Barkoudah and Van Der Sar (1982). In the northwestern Sahara, the "pseudo-steppe" of *Acacia tortilis* var. *raddiana* and *Panicum turgidum* is the main community that occupies non-saline wadi-beds (Guinet 1954; Quézel 1965). Recently, Bensaid, Aït-Mohand, and Echaïb (1996) studied the spatio-temporal dynamics of *Acacia tortilis* var. *raddiana* while Benhouhou (1991) and Benghanem (2009) studied the ecology and phytosociology of *Acacia tortilis* var. *raddiana* communities in the Ougarta mountains (Figure 2). To date, however, although

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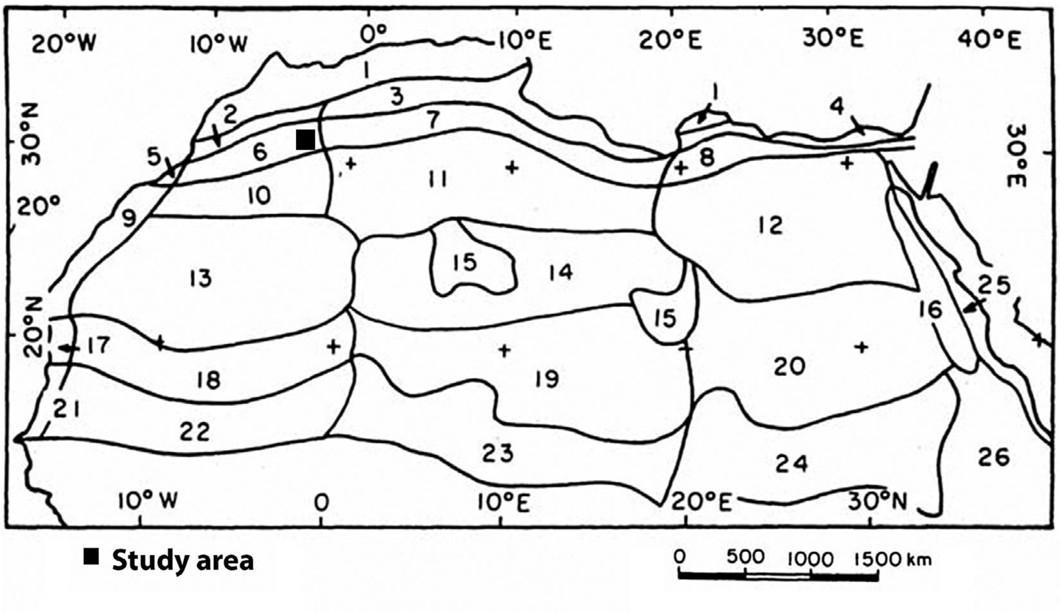

Figure 1. Sketches of the phytogeographical subdivisions of the Sahara and neighbouring territories by Le Houérou (1990, 1995). 1: Mediterranean region (semi-arid to hyper-humid zones); 2: Western arid steppe zone; 3: Central arid steppe zone; 4: Eastern arid steppic zone; 5: Oceanic northern Sahara zone; 6: Western Northern Sahara transition zone; 7: Central Northern Sahara transition zone; 8: Oriental Northern Sahara transition zone; 9: Oceanic central Sahara; 10: Northwestern central Sahara; 11: Northern central Sahara; 12: Northeastern central Sahara; 13: Western central Sahara; 14: Central central Sahara; 15: Central Sahara highlands; 16: Eastern Sahara highlands; 17: Oceanic southern Sahara; 18: Western southern Sahara; 19: Central southern Sahara; 20: Eastern southern Sahara; 21: Oceanic Sahel; 22: Western Sahel; 23: Central Sahel; 24: Eastern Sahel; 25: Eastern Sahara, fringes of the Red Sea; 26: Soudano-Angolan region, Eastern-African domain, mountain zone.

Acacia communities dominate almost all Saharan wadis, relatively few phytosociological and ecological studies of these communities have been carried out in Algeria (Barry, Celles, and Manière 1981; Benhouhou, Dargie, and Gilbert 2003; Gaci 2012; Boucheneb and Benhouhou 2012). This contrasts with some other studies performed in other parts of the Sahara (Danin 1983; Kenneni 1991; Abd El-Ghani and Amer 2003; Al-Atar, El-Sheikh, and Thomas 2012).

The aim of the present study focuses on the phytoecological and phytosociological analysis of the *Acacia tortilis* var. *raddiana* communities in the northwestern Sahara, in order to identify the main ecological gradients that structure these ecosystems and to propose a critical analysis of the phytosociological framework proposed by Quézel (1965). Furthermore, a comparison of the associations described with those found in the central Sahara domain in Algeria is made to strengthen the syntaxonomic system of *Acacia tortilis* var. *raddiana* communities.

Study area and methodology

The study area is bounded in the north by a line level with the city of Béchar, while the southern limit is represented by the oasis of Kerzaz; the oasis of Béni-Abbès represents an approximately central location. The latter is located 1200 km southwest of Algiers (Figure 2).

Climate

Descriptions of climate and bioclimate are based on rainfall and temperature data obtained from the nearest meteorological stations to the study area: Béchar and Béni-Abbès. Data were gathered from the National Meteorological Office (NMO) for a period of 40 years (1967 to 2007) and from Dubief (1959) for an earlier period spanning 24 years (1926 to 1950) (Table 1).

A study of Table 1 shows a decrease in rainfall between the two periods for both Béchar (79.9 mm to 69.5 mm) and Béni-Abbès (32.1 mm to 29.9 mm). Similarly, a slight increase in average temperature is observed. Climatic synthesis shows that Q_2 values are substantially the same for Béni-Abbès (2.70 and 2.75) for the two periods, with a slight decrease for Béchar (7.13 and 6.45).

The study area is located in the Saharan bioclimate with cold to mild winters for the first period (1926 to 1950) and milder winter for the second period (1967 to 2007).

Geology and geomorphology

The study area is located at the junction of three geomorphological units: the Great Western Erg, the Guir Hamada and the Ougarta mountains. The Great Western Erg occupies the eastern part of the study area and consists of extensive sand dunes of Quaternary origin (Nedjari 1995).

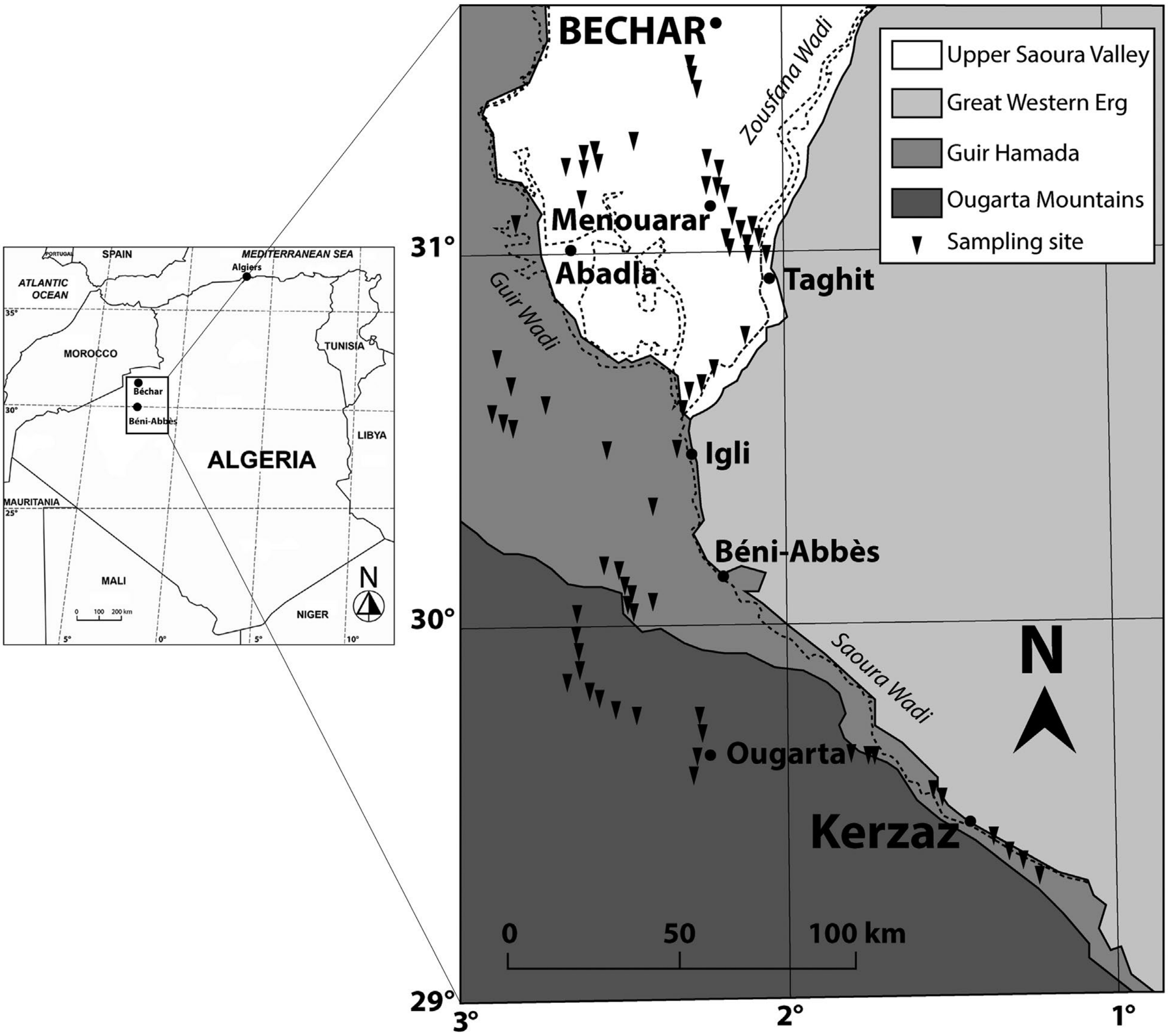

Figure 2. Geographical localization of the study area.

Table 1. Climatic data for the study area.

	Period							
	1926–1950 (Dubief, 1959)				1967–2007 (National Meterological Office)			
Stations	P (mm)	T (°C)	Q_2	Bioclimate	P (mm)	T (°C)	Q_2	Bioclimate
Béchar (791 m)	79.9	20.7	7.13	Saharan with cool winter	69.5	21.3	6.45	Saharan with temperate winter
Béni-Abbès (498 m)	32.1	22.8	2.75	Saharan with temperate winter	29.9	23.5	2.70	Saharan with temperate winter

The Guir Hamada, located in the northwestern part of the study area, is a vast rocky platform of about 10-m thick sandstone of Plio-Quaternary origin (Conrad and Roche 1965). The Ougarta mountains are located in the southwestern part of the study area, covering an area of about 6000 km^2 of Precambrian sandstones (Aït-Ouali and Nedjari 2006).

Water resources in the study area are represented by unconfined aquifers in the Quaternary terrain of the Guir Hamada and a few aquifer units in the Ougarta mountains (Roche 1973). Occasionally, irregular flooding of wadis in the Ougarta area results in a significant additional water source for the vegetation. Soils of the study area are raw mineral soils – the dominant substrate encountered in Saharan non-saline wadis (Dutil 1971). It is in these mountains that the best developed examples of the *Acacia* savanna community are encountered.

Sampling and data analyses

Sampling of the vegetation was carried out in March 2007 and 2008 over an area of about 50,000 km^2, stretching over 250 km. During this period, 67 floristic relevés were recorded. These were obtained from various different geomorphological wadi units (topography) as well as valleys and alluvial plains. The distribution of relevés is presented in Figure 2.

The quadrat area for the study was 100 m^2, which is the standard size for most comparable work in arid zones (Kassas 1953; Quézel 1965; Abd El-Ghani 1998; Benhouhou, Dargie, and Gilbert 2003).

The geomorphological wadi unit is the key factor in the description of these communities (Fossati, Pautou, and Peltier 1998; Benhouhou, Dargie, and Gilbert 2001; Al-Atar, El-Sheikh, and Thomas 2012). The geomorphological units identified and used for this study are: the primary and secondary wadi beds, different terrace levels, valleys and alluvial plains. The aim is to dissect out the relationship between the floristic variability and the various geomorphological facies of the wadi.

The floristic and ecological data collected were submitted to two kinds of multivariate analysis: detrended correspondence analysis (Hill and Gauch 1980) and canonical correspondence analysis (Ter Braak 1987). The software used was PC-ORD (McCune and Mefford 1999). These analyses helped to distinguish the plant communities observed in the study area and also to extract the dominant ecological gradients. Associations described are related to syntaxonomical units proposed by Quézel (1965) according to the phytosociological method of Braun-Blanquet (1952). Finally, a bibliographical review enabled the authors to compare the associations described in this study with all of the *Acacia tortilis* var. *raddiana* communities documented to date in the Algerian central Sahara.

Results

Ecological gradient analyses

The relevés performed in this study and distributed along the first two axes resulted into two main groups, A with 35 relevés and B with 32 relevés. Eigenvalues were 0.346 for the first axis and 0.259 for the second axis, suggesting that there are at least two gradients at work. Within group A, two sub-groups were distinguished: a1 (with six relevés) and a2 (with six relevés) (Figure 3).

Analysis of the relevés and species distribution along the first axis revealed the appearance of two ecological gradients (Figure 4).

Axis 1 corresponds to a geomorphological gradient that opposes the relevés taken from large wadi beds, bordered by alluvial terraces and fans (negative side), to relevés from narrow rocky wadi beds (positive side) (Figure 3). Hence, the analysis helped to distinguish two major geomorphological units of the "wadi habitat": (i) a unit where the wadi shows both a minor (channel) and a major wadi bed (floodplain), which is characterized by species associated with gravelly sandy substrates such as *Panicum turgidum*, *Citrullus colocynthis* and *Acanthorrhinum ramosissimum*, and (ii) a rocky unit epitomized by woody chasmophils such as *Rhus tripartita*, *Maytenus senegalensis* and *Ceratolimon feei*.

For the second axis, a clear contrast appears between relevés on sandy substrates for the negative part of the axis which feature perennial psammophilous plants such as *Kickxia aegyptiaca* and therophytes such as *Brocchia cinerea*, *Neurada procumbens* and *Ifloga spicata*. On the positive side of this axis, are located the relevés taken from coarse to gravelly substrates, with high-frequency species here including *Trichodesma calcaratum*, *Farsetia occidentalis* and *Kebirita roudairei*. The distinction between relevés taken from sandy substrates and those from gravelly-coarse substratum highlights the soil texture as the main environmental gradient along the second axis. The projection of two gypsophilic species: *Caroxylon vermiculatum* and *Tetraena alba*, reflects minor local edaphic affinities which have limited importance in the structure of the studied communities. The analysis also reveals that the altitudinal variations observed were not discriminative.

A topographic sequence is presented in Figures 5a and 5b to illustrate the distribution of the floristic groups identified in relation to ecological gradients.

Syntaxonomic description

The phytosociological examination of the data has led to the assigning of the vegetation to two main plant communities: (i) the association with *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* Quézel 1965 (group A), and (ii) the association with *Acacia tortilis* var. *raddiana* and *Rhus tripartita* Quézel 1965 (group B) (Figure 3). Within the phytosociological framework established by Quézel (1965) for the north-western Sahara, these two associations are included into the *Antirrhineto-Zillion macropterae* alliance Quézel 1965, the *Pergularieto-Pulicaretalia* order Quézel 1965 and the *Pergularieto-Pulicarietea* class Quézel 1965.

The *Acacia tortilis* var. *raddiana, Panicum turgidum and Foleyola billotii* association Quézel *1965*

This association is characteristic of wadi beds, terraces and sediment fans on gravelly-sandy soils, mainly in the Ougarta mountains, at altitudes between 375 and 650 m (Figure 6).

Relevés of this association are grouped in Table 2 and are represented by:

The association (A), a chasmophil *facies* (a1) with *Farsetia occidentalis* and *Trichodesma calcaratum* and a psammophil *facies* (a2) with *Kickxia aegyptiaca* and *Brocchia cinerea*. Both of these *facies* were observed on wadi terraces.

For the relevés made in the same area, among the species proposed by Quézel (1965) as characteristics of the association, seven species of tropical origin were

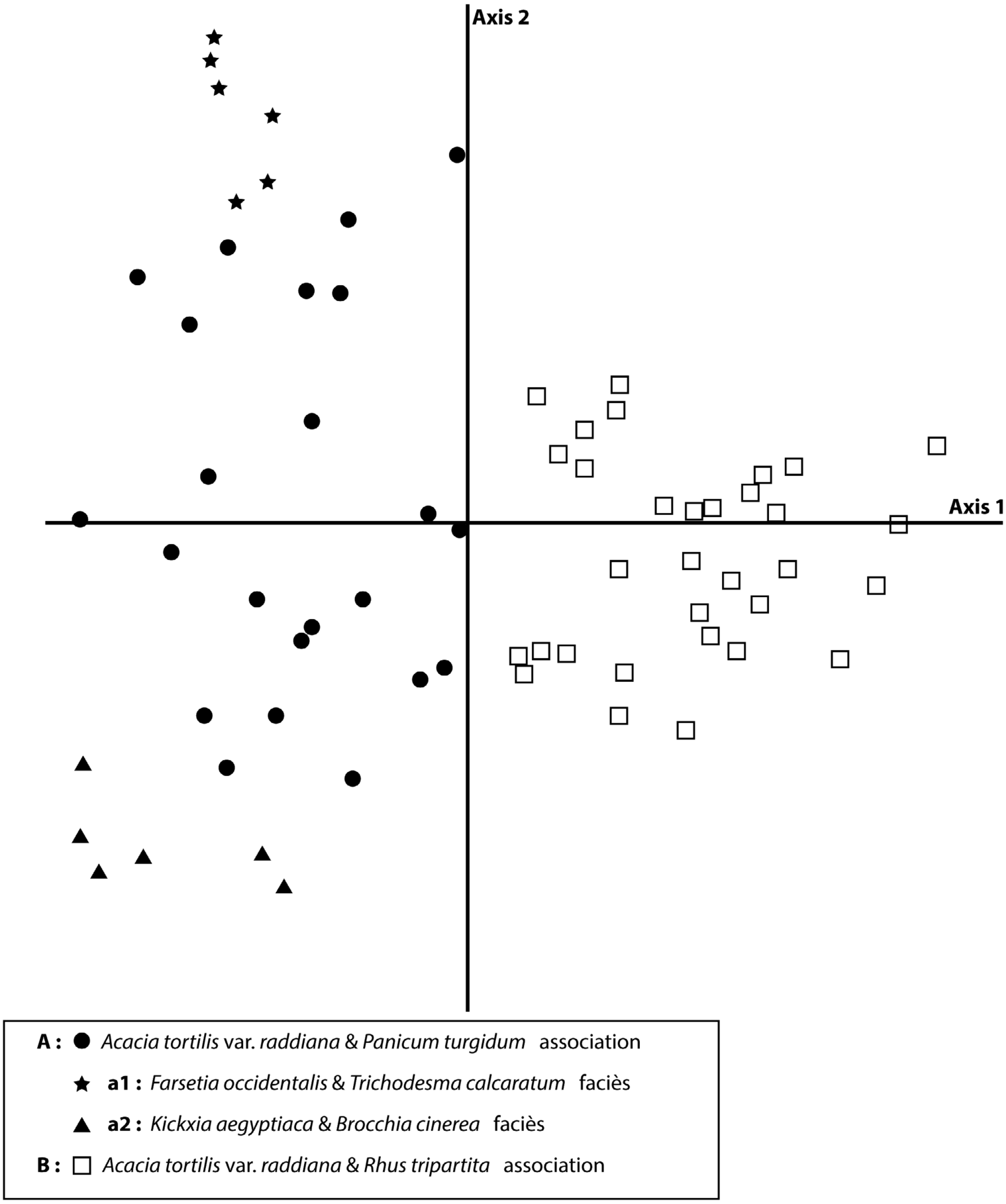

Figure 3. Ordination diagram of a detrended correspondence analysis of 67 relevés of the study area.

absent from those recorded during this study: *Caylusea hexagyna*, *Seetzenia lanata*, *Maerua crassifolia*, *Senna italica*, *Acacia ehrenbergiana*, *Astragalus akkensis* and *Lavandula coronopifolia*. An endemic species of the southeastern Moroccan desert and the Ougarta mountains, *Foleyola billotii*, was similarly not recorded.

The *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association Quézel 1965

This association is found on rocky terrain in narrow wadi beds and has been recorded from an altitudinal range between 500 and 690 m (Figure 7). It has been observed from both rocky wadis of the southern djebel slopes in the Béchar area as well as rocky wadis in the Igli and Taghit region.

With regard to the syntaxonomic level, the analysis of Table 3 shows that this association belongs to the same higher syntaxonomic units as the *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association. It is also distinguished by a large proportion of characteristic species, which are typical of the *Atractylion babelii* alliance Quézel 1965 and the *Gymnocarpeto-Atractyletalia* order Quézel 1965 of rocky terrain and hamada, with this cohort being typified by species such as: *Gymnocarpos decandrus*, *Perralderia coronopifolia*, *Deverra battandieri* and *Ceratolimon feei*.

Again, for the relevés realized in the same region, among the characteristic species proposed by Quézel (1965) for this association, two tropical species, with low frequency, were notably absent from our relevés: *Cenchrus ciliaris* and *Tricholaena teneriffae*.

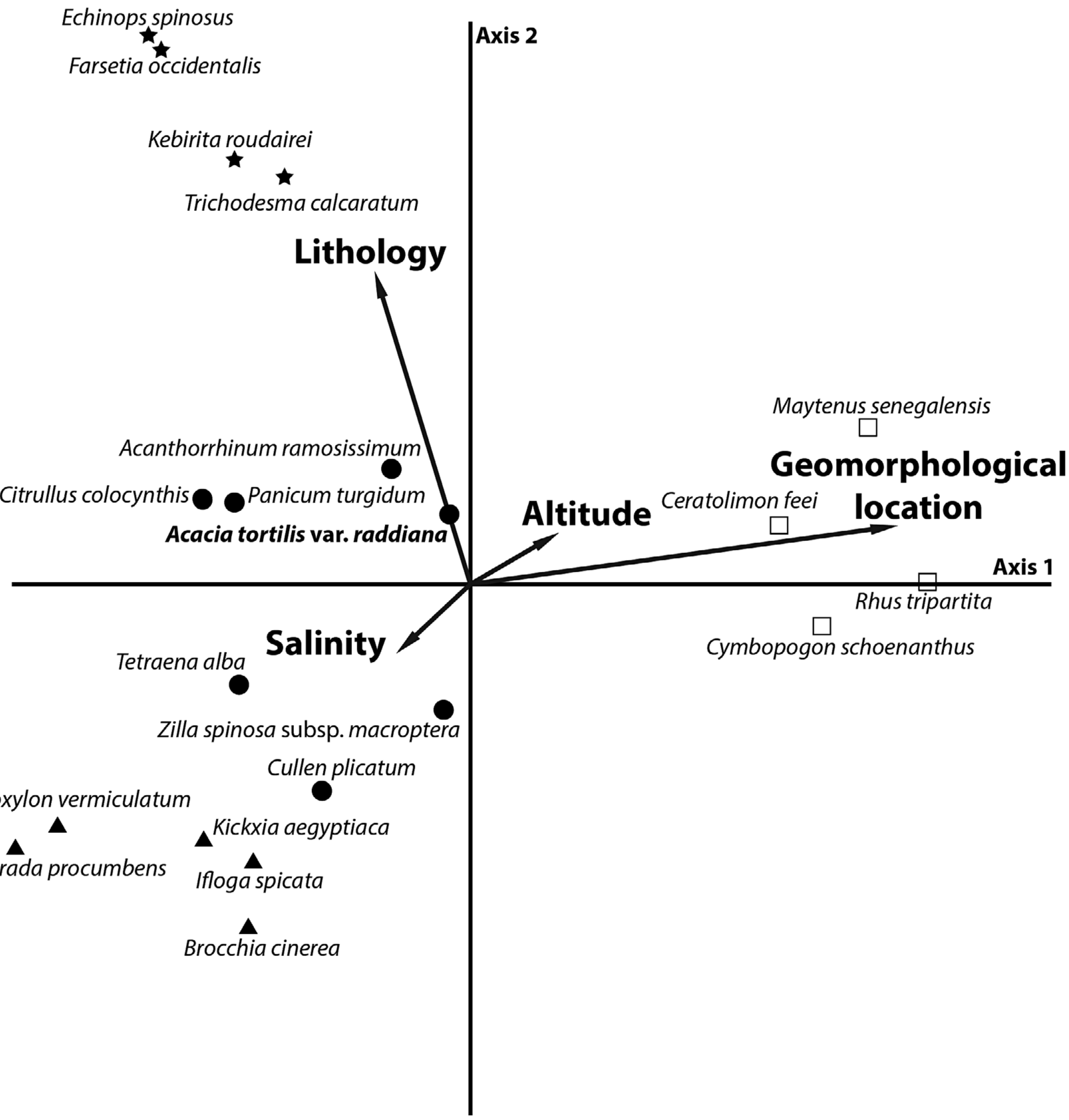

Figure 4. Species scatter and main ecological factors produced by canonical correspondence analysis of the 67 relevés.

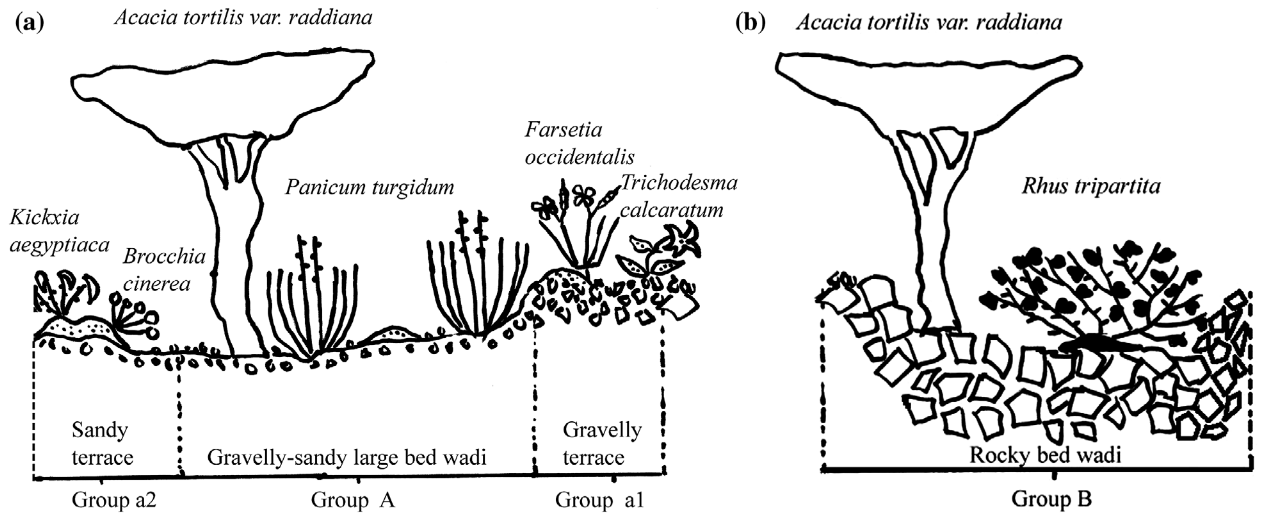

Figure 5. Topographic sequences of (A) the *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association and its two *facies*; and (B) the *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association.

Figure 6. The *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association Quézel 1965, Ougarta, A.N. Benghanem, 31 March 2014.

Discussion

Phytoecological characterization of plant communities with *Acacia tortilis* var. *raddiana*

The differences between the two associations with *Acacia tortilis* var. *raddiana* existing in the northwestern Algerian Sahara are related to the different geomorphological characteristics of the wadi and their substrates. These gradients are closely linked to water availability, a crucial limiting factor in arid environments (Abd El-Ghani 1998; Fossati, Pautou, and Peltier 1998; Kadmon and Danin 1999; Ali, Dickinson, and Murphy 2000; Abd El-Ghani and Amer 2003; Brinkmann et al. 2009).

For the northwestern Sahara, Quézel (1965) describes this savanna through three associations of which two have been identified and thoroughly described in this work.

The comparison of the floristic relevés of the *Acacia raddiana*, *Panicum turgidum* and *Foleyola billotii* association shows that eight characteristic species from the 12 proposed by Quézel (1965) were not reported during the present investigation. Not only were many characteristic species proposed by Quézel (1965), but these are all characterized by both relatively low frequencies (between 6% and 20%) and a wide geographical distribution of tropical Saharo-Arabian origin. In addition, *Lavandula coronopifolia* and *Trichodesma africanum* are typical species of rocky outcrops and therefore their identification by Quézel as characteristic species of the *Acacia* "pseudo-steppe" may have been mistaken, considering this ecological association.

With regard to *Foleyola billotii*, an endemic chamephyte of the Ougarta mountains and of southeastern Morocco, present in 35% of the relevés published by Quézel (1965), was also absent from the relevés performed for the present study. The same species was also absent from the floristic lists of Quézel and Simonneau (1963), Barkoudah and Van Der Sar (1982), and Benhouhou, Dargie, and Gilbert (2003) for this association. However, it is important to note that field investigations conducted by Benghanem and Benhouhou (personal observation, 30 March 2014) have confirmed its presence – albeit at very low frequency – in our study area. This recent observation confirms the eastern boundary of its distribution in the Ougarta mountains (Quézel 1964, 1978).

The absence of these taxa, or failure to detect them, as seems to have been the case for *Foleyola billotii*, could be related to the increase in the intensity of certain anthropogenic activities (grazing and wood cutting). Hence, we would hypothesize that the vegetation ascribed in

Table 2. The *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association (Quézel 1965).

Quadrat number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
Area (m^2) × 10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
Altitude (m)	420	530	518	529	552	547	528	520	542	505	524	505	429	404	407	405	424	437	438	557	600	407	611	590	577	653	574	578	580	416	405	400	381	422	375	
Total cover (%)	10	15	15	15	15	10	15	5	10	20	5	15	10	10	10	10	20	5	5	10	10	5	10	10	20	10	20	10	15	5	5	15	15	15	10	
Number of taxa	11	13	15	14	18	16	21	7	15	22	13	23	11	12	17	7	16	7	8	13	12	14	18	19	14	13	11	13	17	11	15	11	13	15	19	
																																				C
Characteristics of the association																																				
Acacia tortilis var. *raddiana*	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	4	3	3	3	3	3	3	3	4	3	4	3	3	3	3	3	3	3	3	V
Panicum turgidum	2	2	.	2	2	2	2	.	.	2	2	2	2	2	.	.	2	.	.	.	.	.	.	2	.	2	.	2	.	2	1	1	.	.	1	III
Cullen plicatum	.	.	.	2	.	1	.	2	1	1	1	2	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	II
Trichodesma africanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	I
Kickxia aegyptiaca & Brocchia cinerea **Faciès**																																				
Kickxia aegyptiaca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	2	1	+	2	+	1	.	.	.	.	.	.	II
Brocchia cinerea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	1	1	+	.	.	.	.	.	.	II
Caroxylon vermiculatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	.	1	1	1	.	.	.	.	.	.	I
Euphorbia calyptrata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	1	1	.	.	.	.	.	.	I
Ifloga spicata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	+	1	.	.	.	.	.	.	I
Farsetia occidentalis & Trichodesma calcaratum **Faciès**																																				
Farsetia occidentalis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	2	2	2	1	+	II
Trichodesma calcaratum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	+	1	1	+	II
Kebirita roudairei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	1	+	I
Echinops spinosus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	+	.	+	I
Characteristics of the *Antirrhineto-Zillion macropterae* Quézel 1965																																				
Acanthorrhinum ramossisimum	2	1	2	.	1	.	2	2	2	2	1	2	1	2	2	.	2	2	1	2	.	2	.	.	.	.	.	.	.	.	2	.	.	1	2	IV
Zilla spinosa subsp. *macroptera*	.	2	2	2	2	1	2	.	1	1	.	2	.	.	.	2	1	1	.	2	.	.	.	.	2	1	1	2	2	.	.	.	.	.	.	III
Launaea arborescens	.	1	2	2	2	1	2	2	2	.	1	.	1	.	1	1	2	1	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	1	III
Anvillea gracinii	1	+	.	1	1	.	2	.	.	.	1	.	.	.	1	.	.	.	1	.	2	.	.	.	.	.	.	.	.	+	+	.	.	+	.	II
Pituranthos chloranthus	.	1	2	1	.	1	1	.	.	2	.	2	.	.	.	.	.	.	.	2	1	.	2	.	.	.	.	.	.	.	.	.	.	.	.	II
Rhanterium adpressum	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	I
Salvia pseudo jaminiana	.	.	.	2	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Characteristics of the *Pergulario-Pulicarietalia & Pergulario-Pulicarietea* Quézel 1965																																				
Pergularia tomentosa	.	.	.	1	.	.	2	1	1	.	.	2	.	1	.	1	1	1	2	1	3	2	.	.	.	.	.	.	.	2	2	.	2	2	2	III

Pennisetum divisum	.	.	2	.	1	.	.	.	1	2	.	.	2	2	2	2	2	.	1	.	.	.	2	.	2	.	.	.	.	.	.	1	2	2	1	III
Heliotropium bacciferum	.	.	.	.	.	.	.	.	1	+	.	1	.	.	.	.	1	.	1	.	2	.	1	1	.	.	.	.	+	1	1	.	1	2	1	III
Citrullus colocynthis	.	.	1	1	.	.	2	.	2	1	.	.	.	.	.	.	1	.	.	.	.	.	2	.	.	.	1	1	.	.	1	1	1	.	1	II
Ruta tuberculata	.	1	.	1	.	.	1	.	.	1	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	I
Centaurea pungens	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I
Bassia muricata	.	.	.	.	.	.	.	.	.	1	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	I
Marrubium deserti	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	2	.	.	.	.	I
Pulicaria crispa	.	1	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	I
Launaea residifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	I
Morettia canescens	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	I
Psammophils																																				
Stipagrostis plumosa	.	.	.	.	+	1	.	.	.	.	+	+	.	.	.	.	.	.	1	.	1	1	1	1	.	.	.	.	.	1	.	.	1	1	1	II
Fagonia glutinosa	+	.	.	.	+	1	+	.	.	.	.	+	.	+	+	.	.	.	.	.	.	+	.	+	.	+	.	.	.	.	.	.	.	.	.	II
Asphodelus viscidulus	.	.	.	.	+	1	1	.	.	.	.	+	.	.	.	.	.	.	.	1	.	.	+	+	.	.	.	.	1	.	.	.	.	.	.	II
Asphodelus tenuifolius	.	1	.	.	.	1	1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	1	1	.	.	.	.	.	.	II
Cleome africana	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	2	.	2	.	.	2	1	.	.	.	.	.	.	I
Matricaria pubescens	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	I
Crotalaria saharae	.	.	1	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	I
Catananche arenaria	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	I
Euphorbia guyoniana	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	I
Eremobium aegyptiacum	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	I
Astragalus gyzensis	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	I
Retama retam	.	.	2	.	2	2	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Silene villosa	.	.	.	.	+	.	.	.	.	+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	I
Tourneuxia variifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	I
Plantago psyllium	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	I
Lifago dielsii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	1	.	.	.	.	.	.	.	.	.	I
Noelettia chrysocomoides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	I
Launaea nudicaulis	.	1	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	I
Spitzelia coronopifolia	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I
Astragalus maeroticus	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I

(*Continued*)

Table 2. (*Continued*)

Quadrat number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
Asthenatherum forskahleii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	I
Ziziphus lotus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	I
Schismus barbatus	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Rhetinolepis lonadioides	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Hippocrepis multisliquosa	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Picridium orientale	.	.	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Chasmophils																																				
Asterisucus graveolens	.	.	.	+	1	1	.	.	1	+	.	.	+	+	1	.	+	.	+	1	.	.	+	2	1	1	+	.	.	1	.	+	1	+	+	IV
Gymnocarpos decandrus	2	.	1	1	1	1	1	1	1	1	.	.	2	1	1	.	.	.	.	1	.	1	2	.	.	.	.	.	.	.	+	.	.	1	.	III
Perralderia coronopifolia	.	1	.	+	.	.	1	.	1	.	1	1	1	.	1	.	+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	1	.	II
Convolvulus supinus	.	.	1	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	1	+	+	II
Helianthemum lippii	.	.	.	.	.	+	1	.	+	.	.	.	.	.	.	.	+	.	.	1	.	1	.	.	.	.	.	.	.	.	+	.	.	.	.	II
Deverra battandieri	.	1	.	.	.	.	.	.	.	.	1	.	1	2	2	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	I
Farsetia aegyptiaca	2	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	1	1	I
Diplotaxis pitardiana	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	I
Erodium glaucophyllum	.	.	.	.	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Eremophyton chevallieri	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Ceratolimon feei	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Cymbopogon schoenanthus	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Atractylis serratuloides	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Halo-gypsophils																																				
Traganum nudatum	2	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	1	.	.	.	.	1	2	.	.	.	.	.	.	.	.	2	.	.	.	II
Salsola baryosma	1	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	2	.	+	.	.	.	.	.	.	.	.	.	.	I
Anabasis articulata	1	.	.	.	.	.	.	.	.	.	.	.	2	.	2	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Tetraena album	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
Randonia africana	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	I
Suaeda mollis	.	.	.	.	.	.	.	.	.	.	.	.	1	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Salsola tetragona	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Atriplex halimus	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I

Additional species: *Albuca amaena* + (11), *Moricandia arvensis* + (12), *Forskahlea tenacissima* + (7),*Jaubertia reboudiana* + (3),*Fagonia longispina* +(21), *Astragalus gombo* subsp. *gombiformis* + (26), *Diplotaxis harra* + (10), *Fredolia aretioides* + (29)

Figure 7. The *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association Quézel 1965,Taghit, A.N. Benghanem, 27 March 2014.

this study to this association is a floristically impoverished ecological state, for which we propose to retain the following characteristic species: *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Cullen plicatum.* Despite the floristic discrepancies between relevés published by Quézel (1965) and those from the present study, a detrended correspondence analysis confirmed that they correspond to the same association. Furthermore, the ecological variability of this association is again clearly illustrated along the first axis of Ffigure 8 where the rocky facies is at one end and the sandy facies at the other end of the axis 1 (Figure 8).

The *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association was confirmed by this study in the north-western Algerian Sahara, as being confined to rocky wadis and was less widely distributed than the previous one. Comparison between floristic lists published by Quézel and Simonneau (1963) and Quézel (1965) and those from the present study clearly indicates a lower frequency of two characteristic taxa for the latter: *Rhus tripartita* and *Maytenus senegalensis.* Considering the absence of two other characteristic taxa, *Cenchrus ciliaris* and *Tricholaena teneriffae*, from our relevés, their low frequency in the original association and their multiregional biogeographical distribution (Barry and Celles 1972–1973), their labelling as characteristic species seems no longer to be justified. Again, this is an impoverished version of the association where two species are absent and two others have low frequency, *Maytenus senegalensis* (I) and *Rhus tripartita* (II) (Table 3). The detrended correspondence analysis of the relevés published by Quézel (1965) and the current study confirm that we are dealing with the same association. The distribution of the relevés within the scattergram, where relevés made by Quézel (1965) are plotted at the positive end of the first axis, is due to the absence of *Cenchrus ciliaris* and *Tricholaena teneriffae* (Figure 9).

Phytogeography of plant communities with *Acacia tortilis* var. *raddiana*

These present results enable us to precisely describe the geographical limits of the *Acacia raddiana*, *Panicum turgidum* and *Foleyola billotii* association. Its eastern boundaries correspond to the eastern fringes of the Ougarta mountains because further east, in the northern Sahara subdivision, *Foleyola billotii* is absent (Quézel 1978). Its western boundaries correspond to the eastern limits of the *Acacia raddiana* and *Foleyola billotii* association described by Quézel et al. (1995) from the middle valley of the Draa in Morocco. The southern limits of the association correspond to the Kerzaz region, 100 km south of Béni-Abbès. Further south, both climatic and edaphic conditions prevent the development of

Table 3. The *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association Quézel 1965.

Quadrat number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Area (m^2)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Altitude (m)	657	654	536	654	640	648	633	605	535	522	572	538	520	516	638	675	688	662	691	670	653	645	653	658	665	653	675	538	596	660	655	684	
Total cover (%)	20	20	20	12	10	20	20	15	20	15	15	15	10	10	17	20	12	20	10	20	10	15	15	10	10	20	10	10	17	20	10	15	
Number of taxa	17	16	19	19	13	16	11	17	16	14	15	19	12	15	12	11	18	11	14	19	9	13	13	12	13	19	11	10	18	15	20	15	
																																	C
Characteristics of the association																																	
Acacia tortilis var. *raddiana*	4	4	4	3	3	4	4	3	4	3	3	3	3	3	3	4	3	4	3	4	3	3	3	3	3	4	3	3	3	4	3	3	V
Cymbopogon schoenanthus	1	1	1	1	.	1	.	.	1	.	1	1	1	.	.	2	2	1	1	2	.	.	2	2	1	2	2	1	2	1	2	1	IV
Rhus tripartita	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	2	.	.	2	.	.	.	.	.	.	2	.	.	.	.	.	2	II
Maytenus senegalensis	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Characteristics of the *Antirrhineto-Zillion macropterae* Quézel 1965																																	
Anvillea gracinii	1	2	1	1	2	1	2	1	1	1	1	1	+	1	1	1	1	1	1	.	1	1	1	1	.	1	.	1	+	1	1	2	V
Zilla spinosa subsp. *macroptera*	2	2	1	2	1	1	2	1	1	1	1	1	2	1	1	1	2	2	1	1	.	.	1	.	1	1	.	.	2	2	2	.	V
Acanthorrhinum ramossisimum	.	1	1	2	1	2	2	1	2	.	.	1	.	1	.	.	.	.	.	.	2	2	2	2	.	1	1	.	1	.	.	2	IV
Launaea arborescens	2	2	1	2	.	2	2	1	.	.	.	1	2	.	1	.	.	2	.	.	+	2	2	2	.	.	.	.	2	2	.	.	IV
Pituranthos chloranthus	.	.	.	2	2	.	1	1	.	.	.	1	1	.	.	.	2	1	.	.	.	1	.	.	.	.	.	.	.	.	+	.	II
Rhanterium adpressum	.	1	.	1	.	.	.	.	.	.	.	.	1	1	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	1	.	II
Carthamus duvauxii	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	1	I
Salvia pseudo jaminiana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Characteristics of the *Pergulario-Pulcarietalia* & *Pergulario-Pulicarietea* Quézel 1965																																	
Morettia canesens	1	1	+	1	1	1	1	1	.	1	1	.	.	.	1	1	1	.	1	1	.	.	+	1	1	1	.	.	1	.	1	1	IV
Pergularia tomentosa	.	.	1	+	+	1	.	1	1	1	.	1	1	1	.	.	.	1	.	1	1	2	.	.	.	.	.	.	.	.	.	.	III
Pennisetum divisum	.	.	+	.	.	1	.	2	1	2	2	.	.	2	.	.	.	.	.	1	.	.	.	.	.	2	.	.	1	2	2	.	II
Launaea residifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	+	1	.	1	.	1	.	.	II
Pulicaria crispa	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.	.	.	.	.	2	.	.	.	.	.	.	I
Heliotropium bacciferum	.	.	.	.	.	.	.	1	.	.	.	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	I

Trichodesma africanum	.	.	2	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	I
Citrullus colocynthis	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	I
Ruta tuberculata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I
Transgressivs chasmophils (Characteristics of the *Atractylion babelii* & *GymnocarpetoAtractyletalia* Quézel 1965)																																	
Gymnocarpos decandrus	2	1	2	2	1	1	2	2	2	2	1	2	1	.	1	2	2	1	2	2	2	2	2	2	2	1	2	1	2	1	1	1	V
Deverra battandieri	1	1	.	2	.	2	1	1	.	2	2	.	.	2	.	.	1	.	1	1	.	2	.	1	1	2	2	2	2	+	1	.	IV
Perralderia coronopifolia	1	1	1	1	2	1	1	1	1	.	.	.	1	1	2	1	.	+	1	1	.	.	1	.	.	2	2	1	.	.	2	.	IV
Ceratolimon feei	1	.	.	+	.	.	.	1	2	1	1	.	.	.	.	.	2	.	.	2	.	.	1	.	1	.	1	+	.	.	1	.	III
Convolvulus supinus	+	1	.	+	.	+	.	.	1	.	.	1	.	+	.	.	+	.	.	.	.	.	+	.	.	1	.	.	.	1	+	1	II
Jaubertia reboudiana	.	.	2	.	.	.	.	.	2	2	+	.	.	.	.	.	2	.	2	2	.	.	.	.	.	.	.	.	+	.	1	+	II
Trichodesma calcaratum	1	.	.	.	.	.	.	.	+	.	1	.	.	.	.	.	2	.	.	2	.	.	.	.	1	.	.	.	.	.	.	.	II
Linaria sagittata	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	+	.	.	.	I
Chasmophils																																	
Asteriscus graveolens	.	2	1	1	2	1	1	1	1	.	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	.	+	1	2	V
Helianthemum lippii	+	1	.	1	+	.	.	.	.	+	+	+	.	1	1	.	1	.	.	1	.	1	.	1	1	1	.	.	+	+	+	1	III
Farsetia aegyptiaca	+	+	.	.	1	2	.	.	.	1	.	1	.	.	.	.	1	.	.	1	.	1	.	.	.	1	1	1	1	1	.	.	III
Eremophyton chevallieri	.	.	1	.	+	.	.	.	.	+	.	+	.	.	.	.	+	.	1	1	.	+	1	.	1	.	.	.	1	.	+	.	II
Salvia aegyptiaca	1	.	+	.	.	1	.	.	1	.	.	1	.	.	.	.	.	.	+	.	.	.	.	2	.	1	.	.	2	.	.	+	II
Diplotaxis pitardiana	.	.	1	.	.	.	.	.	.	+	.	.	.	+	1	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	1	+	II
Erodium glaucophyllum	+	.	+	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I

Additional species :*Matthiola longipetala* + (1), *Eryngium ilicifolium* + (3), *Hippocrepis multisiliquosa* + (4), *Crotalaria saharae* + (8), *Echium humile* subsp. *pycnanthum* + (12), *Rhetinolepis lonadioides* + (22), *Euphorbia calyptrata* + (27), *Diplotaxis harra* + (29), *Euphorbia guyoniana* + (15), *Tourneuxia variifolia* + (21), *Forskahlea tenacissima* + (30).

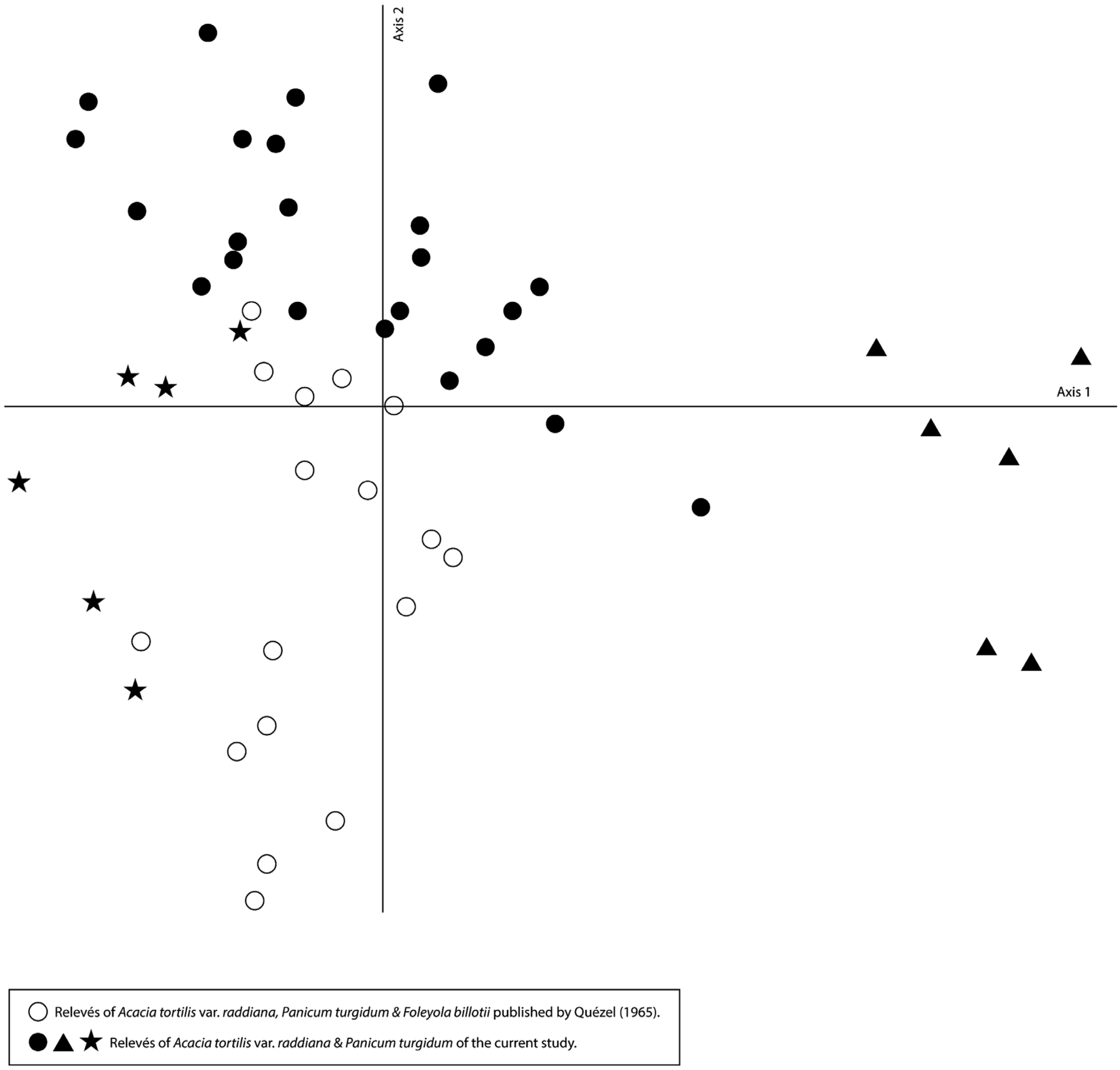

Figure 8. A comparative DCA of the *Acacia tortilis* var. *raddiana*, *Panicum turgidum* and *Foleyola billotii* association relevés (Current study vs. Quézel 1965).

well-established *Acacia* savanna. As for its northern limit at the northeastern area of its distribution, it is located in the Béchar region, 150 km north of Béni-Abbès. The geographical distribution of the *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association is relatively limited in area and corresponds to zones characterized by the rocky slopes of the djebels between Béchar in the north and Kerzaz in the south.

Further south, in the central Sahara, the desertic *Acacia* savanna corresponds to a different type – related to the *Acacio-Panicion* alliance Quézel 1965. Above the alliance level, this unit belongs to the same higher phytosociological units as the two associations described in this study. In this alliance, six *Acacia* associations are described, with the most common and widespread being the *Senna italica* and *Panicum turgidum* association Quézel 1965 that grows on gravelly-sandy substrates. The four other associations described by Quézel (1965) have smaller geographical distributions and are found on gravelly to sandy wadi beds. The sixth *Acacia* association, the *Acacia tortilis* var. *raddiana* and *Salvadora persica* Boucheneb and Benhouhou 2012, is closely associated with large wadi beds south of Tamanrasset and only develops where there are deep sandy compact soils (Table 4).

All of these associations, dominated by *Acacia tortilis* var. *raddiana* and *Panicum turgidum*, in the Algerian Sahara, share a common background flora with species such as: *Heliotropium bacciferum*, *Asteriscus graveolens*, *Cymbopogon schoenanthus*, *Morettia canescens*, *Pergularia tomentosa*, *Farsetia aegyptiaca* and *Kickxia aegyptiaca* (Maire 1940; Leredde 1957;Guinet 1958; Quézel 1964, 1965; Barry and Celles 1972–73; Barkoudah and Van Der Sar 1982; Ozenda 2004; Boucheneb and Benhouhou 2012).

This common background flora is also found elsewhere in the Saharo-Arabian region (Bornkamm and Kehl 1990; Quézel et al. 1995; Léonard 2001;

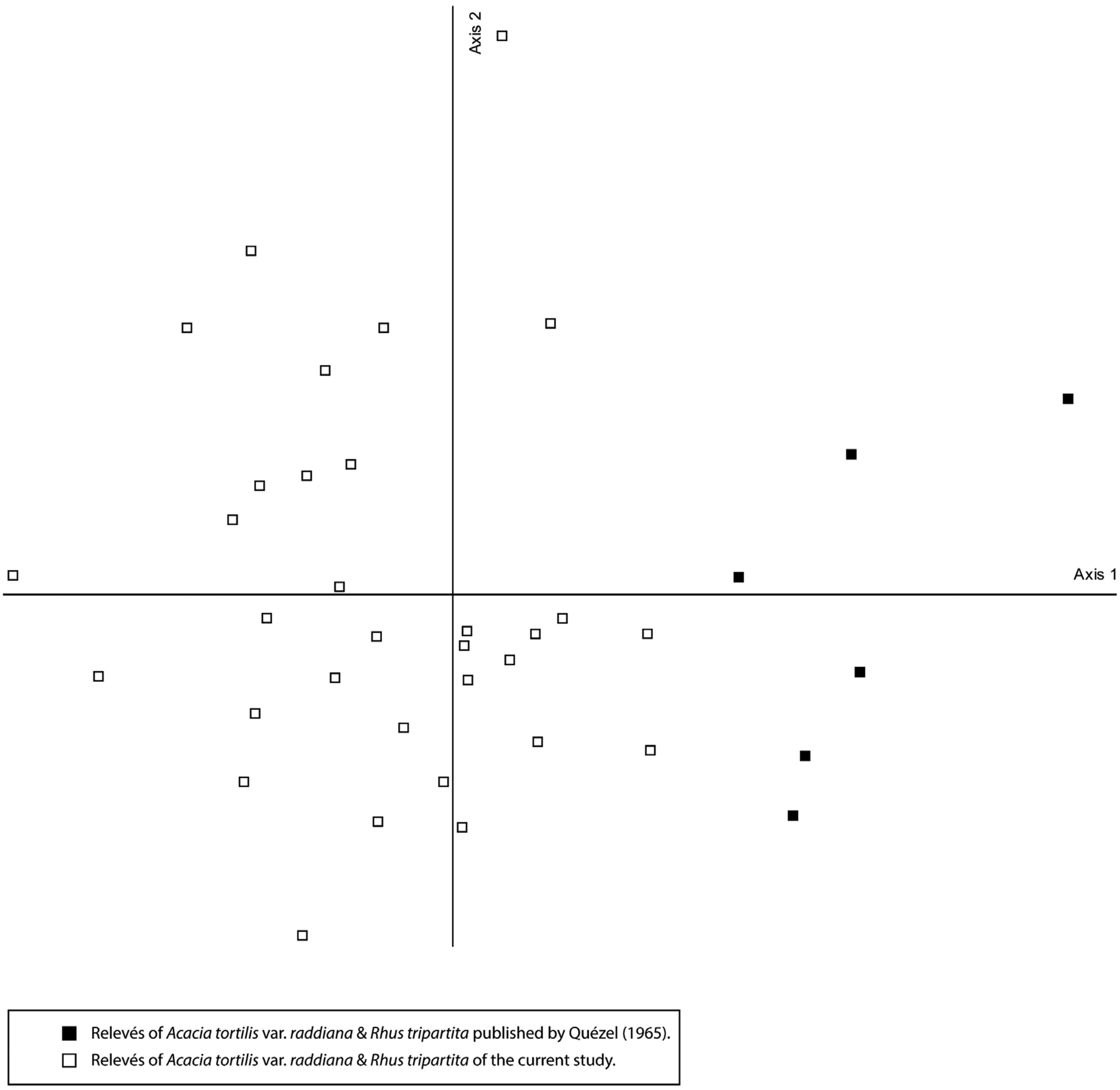

Figure 9. A comparative DCA of the *Acacia tortilis* var. *raddiana* and *Rhus tripartita* association relevés (Current study vs. Quézel 1965).

Munzbergova and Ward 2002; Grouzis and Le Floc'h 2003; Brinkmann et al. 2009). These *Acacia* communities described by the different authors differ principally in the proportion of taxa assigned to the main biogeographical groups: Saharo-Mediterranean and Mediterranean in the west and north of the Sahara, Soudano-Deccanian in the south, Irano-Turanian in the east and Saharan endemics depending on the geographical zone considered (Zohary 1973; Danin 1983; Batanouny 1987; El Demerdash, Hegazy, and Zilay 1995; Abd El-Ghani 1996; Abd El-Ghani and Amer 2003; Anthelme, Waziri Mato, and Maley 2008; Al-Atar, El-Sheïkh, and Thomas 2012).

General conclusion

Acacia tortilis var. *raddiana* and *Panicum turgidum* constitute probably the keystone species of the *Acacia* savanna in the northwestern and central Sahara. Each of the main geographical subdivisions of the Sahara is distinguished by subtle ecological variations highlighted by floristic differences. From this basis, and as also suggested by recent syntaxonomical studies (Boucheneb and Benhouhou 2012; Abdelkrim, Zeraia, and Bensettiti 2014), the current phytosociological framework needed to be re-examined in order to propose a clearer syntaxonomic hierarchy of the *Acacia tortilis* var. *raddiana* communities in the Algerian Sahara, and the whole Sahara desert. For instance, as far as the third association (*Acacia tortilis* var. *raddiana* and *Ziziphus lotus* Quézel 1965) related the *Antirrhineto-Zillion* that Quézel (1965) found in the northwestern Sahara, relevés from the present study did not confirm its existence. Results suggest merging this third association with the *Acacia raddiana*, *Panicum turgidum* and *Foleyola billotii* association. In other words, it may be better to rationalize the *Acacia tortilis* var. *raddiana* savanna of the northwestern Sahara into two associations within which several

Table 4. *Acacia tortilis* var. *raddiana* associations in the Algerian Sahara.

Class	Order	Alliance	*Acacia tortilis* var. *raddiana* associations	Ecology	Localisation	Author(s)
Pergulario-Pulicarietea Quézel 1965	*Pergulario-Pulicarietalia* Quézel 1965	*Antirrhineto-Zillion macropterae* Quézel 1965	*Acacia tortilis* var. *raddiana, Panicum turgidum* and *Foleyola billotii*	Gravelly-sandy wadis	Northwestern Algerian Sahara	Quézel (1965)
			Saxicolous facies *: Farsetia occidentalis and Trichodesma calcaratum*			
			Psammophilous facies*: Kickxia aegyptiaca* and *Brocchia cinerea*			
			Acacia tortilis var. *raddiana* and *Rhus tripartita*	Rocky wadis		
		Acacio-Panicion Quézel 1965	*Senna italica* and *Panicum turgidum*	Gravelly-sandy wadis	Algerian central Sahara	
			Senna alexandrina and *Tephrosia purpurea* subsp. *leptostachya*	Gravelly wadis		
			Solenostemma arghel and *Acacia ehrenbergiana*	Rocky cliffs		
			Leptadenia pyrotechnica and *Chrozophora brocchiana*	Shallow compact sand wadis		
			Cullen plicatum and *Hyoscyamus muticus*	Gravelly to gravelly-sandy wadis		
			Acacia tortilis var. *raddiana* and *Salvadora persica*	Deep sandy compact wadis		Boucheneb and Benhouhou (2012)

facies could be identified (according to local topographical and edaphic parameters). Also, is it necessary to define two different alliances, *Antirrhineto-Zillion* for the northwestern Sahara and *Acacio-Panicion* for the central Sahara, when they are so floristically similar to each other? Results of our study support this approach – but need to be confirmed by further field investigations.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Brendan O'Hanrahan is a freelance ecologist who graduated from Aberdeen University (UK). *Contribution:* participated at the beginning of field data sampling, helped in the general discussion, particularly the ecological approach and his perfect mastery of the English language has facilitated the writing of this article and meeting the level of quality required by the Botany Letters.

Frédéric Médail is a professor at the Mediterranean Institute of marine and terrestrial Biodiversity and Ecology (France). *Contribution:* his experience in the Saharan domain helped greatly to improve the present paper with an in-depth reflection on data interpretation and the general discussion.

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