S. D. Muller, A. Daoud-Bouattour, D. Belouahem-Abed, I. Ben Haj Jilani, S. Ben Saad-Limam, M. Benslama, H. Ferchichi-Ben Jamaa, L. Rhazi & Z. Ghrabi-Gammar

Peat mosses (*Sphagnum*) and related plant communities of North Africa. I. The Numidian-Kroumirian range (Algeria-Tunisia)

Abstract

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The southern limit of peat mosses (genus *Sphagnum*) in the western Mediterranean basin is located in North Africa, where they are rare and restricted to a few wet habitats. Based on herbarium specimens from 1861 to 1958, on recent collects and on floristic surveys, the present paper addresses the taxonomy, distribution, and ecological significance of peat mosses of the Numidian-Kroumirian range. Despite 17 different names are mentioned in the literature and on herbarium specimens, only two species (*Sphagnum auriculatum* and *S. subnitens*) are attested in Numidia and Kroumiria. However, *S. subnitens*, only known from collects in 1948 and 1951 in Kroumiria, is considered as regionally extinct. *S. auriculatum* still occurs in several sites on Jbel Bir and Jbel Sra in Kroumiria, and in El Tarf region in Numidia, but it seems to have disappeared from Senhadja and El Kala regions (Algeria), and from Sejenane region (Tunisia), at both extremities of its ancient distribution area. It develops mainly within shrubby communities, often comprising *Alnus glutinosa* and *Erica scoparia*, and belonging to the regressive hydroseral series of the *Alnion glutinosae*. It constitutes a characteristic species of the pioneer stage of the succession, corresponding to the association *Cariceto-Sphagnetum* (*plumulosi*) *auriculati*. The present-day decline, along with the rarity and vulnerability of *Sphagnum* and associated species in Numidia and Kroumiria should lead to the rapid protection of their habitats, which are threatened of complete disappearance on the short term.

Key words: Bryophytes, wetland, alder carr, phytosociology.

Introduction

Peat mosses (genus *Sphagnum*) are widely distributed from the northernmost territories of North America and Eurasia to the southernmost regions of South America, Africa and Oceania. However, they are more diversified and widespread from temperate regions to the Arctic and the sub-Antarctic than in inter-tropical zones (Daniels & Eddy

1985). Their southern limit in Europe is located around the Mediterranean basin, where their occurrence has been reported from Portugal, Spain, southern France, Corsica, Italy and the Balkans (Daniels & Eddy 1985; Perini & al. 2002; Sérgio & al. 2003; Guerra & al. 2004; Casas & al. 2006; Hill & al. 2006; Guerra & Cros 2007; Neto & al. 2009), as well as from North Africa (Nègre 1952; Dahlgren & Lassen 1972; Düll 1984). Peat mosses of these regions have been relatively ignored by botanists, and the taxonomy, ecological significance, origin and actual distribution of the southernmost populations are largely unknown (Guerra & al. 2004).

Peat mosses of North Africa are encountered in peat-forming wetlands, previously described as 'tourbières' (Nègre 1952) or 'poor fens' (Dahlgren & Lassen 1972) – and even as 'bogs' in southern Spain (Guerra & al. 2004) –, although they are strongly different from northern peatlands. Despite these wetlands count among the most endangered habitats of North Africa and the number of rare plant species they harbour, they have been poorly studied and very few are presently protected. They are however known for a long time, at least since the botanical investigations of Trabut in 1861, Cosson in 1883 and Gauthier-Lièvre in 1925 (Cosson 1885; Gauthier-Lièvre 1931), and some studies enhanced their major botanical and biogeographical interests (Pottier-Alapetite & Labbe 1951; Pottier-Alapetite 1952, 1954, 1958, 1959; Braun-Blanquet 1953). If only two botanical studies have focused on them in Kroumiria (Nègre 1952) and northern Morocco (Dahlgren & Lassen 1972), respectively, several studies have reported the observation of *Sphagnum* species, with a rather confused taxonomy. 17 different species names can indeed be found in the related literature and on herbarium specimen from North Africa: *S. acutifolium* Ehrh. ex Schrad., *S. amblyphyllum* (Russ.) Zickend., *S. auriculatum* Schimp., *S. crassicladum* Warnst., *S. cuspidatum* Hoffm., *S. cymbifolium* Hedw., *S. graveti* Russ., *S. gravetii* Russ., *S. laricinum* (Wils.) Spruce ex Ångstr., *S. obesum* (Wils.) Warnst., *S. plumulosum* Röll., *S. plumulosum* var. *pallens*, *S. rufescens* (Nees) Limpr., *S. rufescens* var. *turgidum*, *S. subsecundum* Nees, *S. subsecundum* var. *confortum* Besch., and *S. subsecundum* var. *turgidum* (Cosson 1885; Gauthier-Lièvre 1931; Pottier-Alapetite & Labbe 1951; Nègre 1952; Pottier-Alapetite 1952, 1954, 1958, 1959; Braun-Blanquet 1953; Stéfanesco 1966; Jelenc 1955, 1967; Dahlgren & Lassen 1972; Ben Tiba 1980; Düll 1984; Daniels & Eddy 1985).

Our recent botanical investigations (2006-2010), conducted in northwestern Tunisia, northeastern Algeria and northern Morocco, provide new insight for assessing the taxonomy and distribution of North African *Sphagnum* species. The present note presents the data collected from the Numidian-Kroumirian range, and discusses them in regard to literature and herbarium specimens. It focuses more particularly on the ecological and dynamical significance of North African *Sphagnum* populations. A second part (in preparation), presenting the data collected from northern Morocco, will discuss their historical and biogeographical significance.

Materials and methods

Systematic botanical investigations have been conducted for five years (2006-2010) in wetlands of the Numidian-Kroumirian range. This mountain area, centred on Aïn Draham, encompasses the northern Algerian-Tunisian boundary. It is limited on the north by the

Mediterranean Sea, on the south by the high Mejerda valley, on the west by the wetland complex of Annaba-El Kala and on the east by the artificial lake of Nefza, which separates Kroumiria from Mogods hills. Our investigations have been extended westwards to the coastal plains of Annaba-El Kala and Guerbès-Senhadja, and eastwards to the Mogods hills, but we failed to recover the *Sphagnum* populations noted there earlier.

Eight habitats were found to harbour *Sphagnum* (Fig. 1). Phytosociological relevés (according to Braun-Blanquet 1932) have been systematically realised, and specimens collected in each habitat for identification. Plant inventories and relevés previously performed in plant communities with *Sphagnum* (Gauthier-Lièvre 1931; Nègre 1952; Braun-Blanquet 1953) have been integrated in the study.

Ancient herbarium specimens of *Sphagnum* from Numidia and Kroumiria have been consulted and verified at the Herbarium of Université Montpellier-2 (MPU), at the Laboratoire des Plantes Médicinales of Institut National Agronomique de Tunisie, and at the Herbarium of Institut Scientifique de Rabat. Identifications of *Sphagnum* species are based on Crum (1984), Daniels & Eddy (1985) and Andrus (2007), those of vascular plants on floras of Algeria (Quézel & Santa 1962-1963), Tunisia (Cuénod 1954; Pottier-Alapetite 1979-1981) and North Africa (Maire 1952-1987). The nomenclature of vascular plants follows Le Floc'h & al. (2010). Duplicates of the collected specimens are deposited at the Herbarium Mediterraneum Panormitanum (PAL), at the Herbarium of Université Montpellier-2 (MPU), at the Institut des Sciences de l'Evolution of Université Montpellier-2, at the Herbarium of Faculté des Sciences of Université Tunis El Manar (TUN), at the Laboratoire des Plantes Médicinales of Institut National Agronomique de Tunisie, and at the Herbarium of Genes Bank of Tunisia.

Results

Ancient herbarium specimens and new collects

All observed specimens except three (Table 1) present relatively constant morphological and anatomical characters. Firstly, the subsecond branch leaves measuring 1.2 to 3.0 mm length, and the hyaline cells of branch leaves with numerous ringed pores in series along the commissures point to the section *Subsecunda*. Secondly, the stem cortex is always 1-layered; stem leaves, larger than 1.2 mm, are fibrillose at least in the upper third and often to below half-way, sometimes entirely; fibrillose hyaline cells of stem leaves have generally more commissural pores on the outer (abaxial) face than on the inner (adaxial) one. These features lead to attribute all these specimens to the morphologically and anatomically variable species *Sphagnum auriculatum* Schimp. (Fig. 2). A few individuals differ from adjacent ones by less fibrillose stem leaves, with a variable number of pores, sometimes almost lacking on both faces. Such variants however range within the variability of the species, as defined by Daniels & Eddy (1985). The specimens collected from Numidia and Kroumiria (Table 1) occur in two growth forms: some are rather erect, green to brownish, with branches of capitulum strongly curved, and others are prostrate, dark-greenish, with branches less curved. Both forms, presenting the diagnostic features of *S. auriculatum*, are thought to represent adaptations to the environment, and more especially to local hydrological conditions (Guerra & al. 2004): indeed, the plants are erect and denser in dryer conditions, and organised in loose

Fig. 1. Investigated wetlands with Sphagnum auriculatum in the Numidian-Kroumirian range: (a) Dar Fatma, (b) Aïn Zouama, (c) Sources du 18e haut, (d) Camps du 18 e, (e) Le Merij, (f) Le Mouajene, (g) Piste de Lebga, (h) Aïn Bergougaïa (photos S.D. Muller: a-d, May 2009; e-h, April 2010).

carpets in wetter habitats. No sporophytic capsule has been observed, neither on living individuals in the field nor on herbarium specimens.

Although our identifications agree with Crum (1984), Daniels & Eddy (1985) and Dahlgren & Lassen (1972), who only mention *S. auriculatum* or its synonym *S. subsecundum* var. *rufescens* (Nees & Hornsch.) Hüben. in North Africa, it should be noted that the subdivision of the section *Subsecunda* is not well achieved (Shaw & al. 2008; R. Gauthier pers. comm.) and the synonymies found in literature are rather confused. Crum (1984) considers only one species (*S. subsecundum* Nees) subdivided in 5 subspecies, which are elevated to the rank of species within a *S. subsecundum* complex by other authors (e.g., Daniels & Eddy 1985; Andrus 2007). According to Shaw & al. (2008), this complex would comprise three gametophytically haploid species (*S. subsecundum* Nees, *S. contortum* Schultz, and *S. platyphyllum* (Lindb.) Warnst.), and four gametophytically diploid species (*S. auriculatum* Schimp. in Europe, *S. lescurii* Sull. in North America, *S. carolinianum* Andrus in North America, and *S. inundatum* Russ. in North America and Europe).

The three different specimens, conserved at the Institut National d'Agronomie de Tunis (Tunisia) and at the Institut Scientifique de Rabat (Morocco), have been respectively collected in Kroumiria by Lebly in 1948 and by G. Malençon in 1951 (Table 1). They are morphologically and anatomically identical. Branch leaves are characterised by hyaline cells with large pores not crowded in commissural rows, and by triangular-trapezoidal green cells exposed on the inner (adaxial) face. Such features point to the section *Acutifolia*. Fascicles contain 2 spreading branches and 2 pendent ones, and the dry plants are markedly irridiscent. The stem cortex is 4-layered and without pores; stem leaves are triangular with marked apices and hyaline cells not fibrillose; branch leaves are conspicuously not 5-ranked, with a few large pores mainly located at the inner surface of hyaline cells. These features allow attributing the concerned specimen to *Sphagnum subnitens* Russ. & Warnst. (Fig. 2).

Previous identifications from literature and ancient herbarium specimens

Despite all the specimens identified in the present work are attributed to only two species, some other names are found in literature and on ancient herbarium specimens, unfortunately without details about diagnostic features. We now discuss the reliability of these previous identifications, and assess the actual taxonomy of the Numidian-Kroumirian *Sphagnum* populations in the light of modern systematic (Shaw & al. 2008).

Sphagnum auriculatum has been previously mentioned in Kroumiria, without specification of localities, by Pottier-Alapetite (1954, 1959). Most of the names found in literature and on herbarium specimens are synonyms of this species: it has been noted in Kroumiria under the names *S. subsecundum* (Cosson 1885; Braun-Blanquet 1953; Table 1), *S. obesum* and *S. crassicladum* (Pottier-Alapetite & Labbe 1951; Pottier-Alapetite 1952, 1954, 1959), and has been reported from an alder carr 24 km from El Kala, under the name *S. graveti*, and from Marais de Bou Merchen between Lac Melah and El Kala, under the name *S. subsecundum* var. *confortum* (Gauthier-Lièvre 1931). The name *S. laricinum* (Jelenc 1967), while corresponding to *S. contortum* Schultz., also certainly refers to *S. auriculatum*. The herbarium specimens from northeastern Algeria, respectively noted as *S. cymbifolium*, *S. rufescens* and *S. subsecundum*, have been verified and reassigned by us to *S. auriculatum* (Table 1). Although *S. rufescens* and *S. subsecundum* can be considered as synonyms of *S. auriculatum*, *S. cymbifolium* (= *S. palustre*) definitely cor-

responds to an erroneous identification, and the section *Sphagnum* (= *Palustria*, *Cymbifolia*) should be considered as absent from North Africa. All these data agree with our field observations, which only concern *Sphagnum auriculatum*.

The case of *Sphagnum subnitens* is more complex. Its past occurrence is attested in Kroumiria by three herbarium specimens, all originating from the vallon du Merij, on the southern flank of Jbel Bir (Fig. 2; Table 1). Because there is no herbarium specimen of *S. capillifolium* (only mentioned as *S. acutifolium* by Pottier-Alapetite 1954, 1959), we guess that this species was noted by confusion with *S. subnitens*. Both species are indeed very similar: the main differences are the pronounced irridescence of *S. subnitens*, and the presence of fibrils on hyaline cells of stem leaves only in *S. capillifolium*. *S. subnitens* has been noted (as *S. plumulosum*; Pottier-Alapetite & Labbe 1951; Nègre 1952; Pottier-Alapetite 1954, 1959; Ben Tiba 1980) at Sources du 18^{e}, Dar Fatma, and Vallon du Merij. Nègre (1952), in particular, gives a detailed description of *Sphagnum* stands at Sources du 18^{e}, where he defines the association *Cariceto-Sphagnetum plumulosi* Labbe & Nègre 1952:

« L'association, localisée dans les tourbières, se présente comme tous les groupements à Sphaignes de l'Europe moyenne sous forme d'un tapis continu de Bryophytes. Elle occupe rarement de grandes surfaces et ne se rencontre que sur de petits replats. Les eaux ferrugineuses très acides (pH 4,5 à 6) y coulent faiblement ou même stagnent longtemps. Le tapis de Sphaignes se développe en général sur 30 cm d'épaisseur.

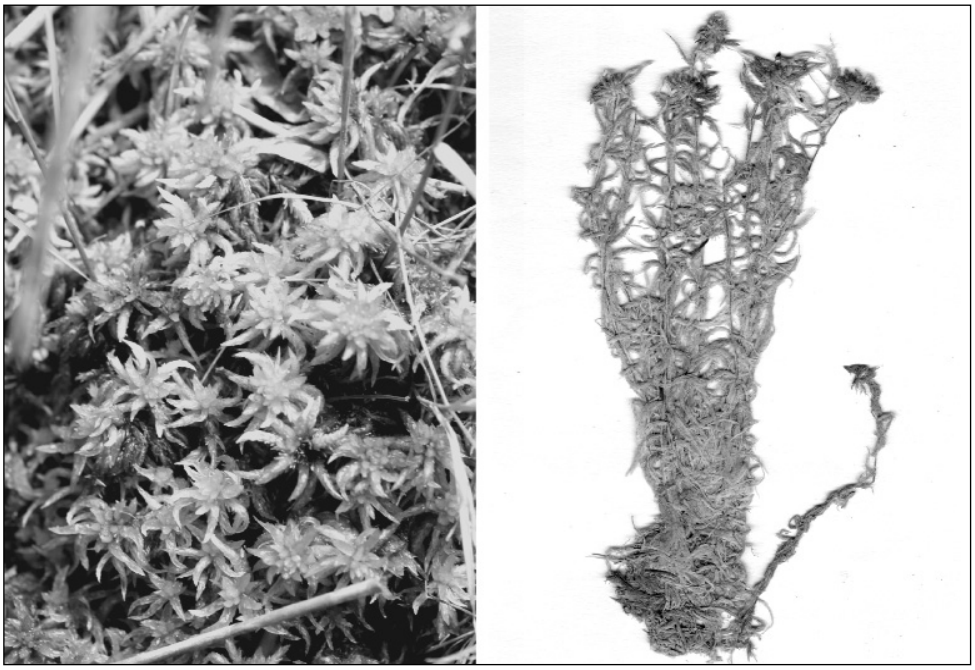

Fig. 2. Peat mosses of Kroumiria and Numidia. Left: *Sphagnum auriculatum*, Sources du 18^{e} haut (photo: S.D. Muller, May 2009). Right: Herbarium specimen of *Sphagnum subnitens*, collected by Lebly in 1948 at Le Merij (Institut National Agronomique de Tunisie).

On peut distinguer trois étapes dans la vie de l'association. A la phase initiale, où le sol est encore entièrement immergé, l'association paraît caractérisée essentiellement par Sphagnum plumulosum*,* Eleocharis multicaulis*,* Anagallis crassifolia *et peut-être* Danthonia forskalii*. Au fur et à mesure que se consolide le substrat, s'installent des espèces qui, tout en ne se développant que sur sol solide, supportent d'avoir les pieds dans l'eau : c'est le cas d'*Hypericum afrum*,* Carex punctata *qui caractérisent la phase optimale. Sur les feuilles de* Quercus faginea *en décomposition et légèrement immergées, croît abondamment* Mitrula paludosa*. Puis, avec l'exhaussement continu du substrat, surviennent les plantules des espèces de la lande ou des suintements sur sols fixés :* Erica arborea*,* E. scoparia*,* Hedera helix*,* Alnus glutinosa *et* Bellis radicans*.*

Les trois relevés suivants, pris dans les environs des sources du Dix-huitième, donnent un aperçu de ces trois phases. »

We visited, in 2008 and 2009, the three concerned zones (Sources du 18^{e}, Dar Fatma, and Vallon du Merij), and only found there *S. auriculatum*, associated with almost all the species mentioned by Nègre (Table 2). This suggests that the mentions of *S. plumulosum* were erroneous, like the one of *Danthonia forskalii* (= *Centropodia forsskaolii* (Vahl) Cope), a Saharan species confused by Nègre (1952) with *Danthonia decumbens*. Our identifications of *S. auriculatum* agree with the first identification as *S. subsecundum* by M. Bescherelle (cited in Cosson 1885), secondly erroneously reassigned to *S. plumulosum* by Pottier-Alapetite & Labbe (1951). This suggests that, despite *S. subnitens* was effectively present in Kroumiria, most of its mentions in literature should be considered to refer to *S. auriculatum*.

Discussion

The investigated wetlands with Sphagnum auriculatum in the Numidian-Kroumirian range

Nine habitats harbouring *Sphagnum auriculatum* populations have been found in Numidia and Kroumiria (Fig. 1). Three of them have been previously investigated for botany and/or palaeoecology: Dar Fatma, Sources du 18^{e} haut, and Ain Bergougaia. The *Sphagnum* populations are generally very small and composed of sparse patches more or less prostrated on the organic substrate, or developed as small carpets at the foot of *Erica scoparia* and *Juncus conglomeratus*.

Dar Fatma (36°49'06"N; 08°46'29"E; 781 m a.s.l., Tunisia, Fig. 1a). The site of Dar Fatma is a very original wetland (with a statut of Reserve since 1993), constituted of several raised circular mounds of waterlogged peat, measuring about 6-10 m in diameter and 1 m high, separated by wet lawns and surrounded by dryer scrublands of *Erica scoparia* and *Pteridium aquilinum*. The wet peat mounds are covered by dense herbaceous meadows harbouring a number of rare plants comprising the North African endemics *Bellis prostrata* and *Solenopsis bicolor*. The *Sphagnum* population has been found in the marginal shrubby belt, under an *Erica scoparia* scrub. It constitutes small loose carpets mixed with *Aulacomnium palustre*, and covered by *Anagallis crassifolia*, *A. tenella*, *Bellis prostrata*, *Carex punctata*, *Danthonia decumbens*, *Dorycnium rectum*, *Eleocharis uniglumis*, *Galium palustre* subsp. *elongatum*, *Holcus lanatus*, *Hypericum afrum*, and *Potamogeton*

polygonifolius (Table 2). The presence of *Aulacomnium palustre* in this site has previously been noted by De Sloover (1965). The accumulated peat has been studied first by Ben Tiba & Reille (1982), and more recently by Stambouli-Essassi (2002) and Stambouli-Essassi & al. (2007). These studies reveal sedimentary records longer than 40,000 years, which despite the low chronological control and hiatuses of sedimentation constitutes the longest palaeoecological sequences in North Africa.

Aïn Zouama (36°46'29"N; 08°47'30"E; 510 m a.s.l., Tunisia, Fig. 1b). The site of Aïn Zouama is a peaty forest hollow, surrounded by dense treed formation of *Quercus canariensis* bordered by *Myrtus communis*, *Rubus ulmifolius*, *Salix pedicellata*, and *Hypericum afrum*. In addition, the site presents *Baldellia ranunculoides* subsp. *repens*, *Callitriche stagnalis*, *Galium palustre* subsp. *elongatum*, *Helosciadium crassipes*, *Isoetes velata*, *Lotus hispidus*, *Mentha pulegium*, and *Silene laeta*. The *Sphagnum* population occupies a surface of a few square meters, as a loose carpet on a marginal flat waterlogged peat surface, among wood fragments and associated with *Bellis prostrata*, *Illecebrum verticillatum*, *Isolepis cernua*, *Juncus bufonius*, *J. heterophyllus*, *Lythrum portula*, and *Panicum repens* (Table 2).

Sources du 18^{e} haut (36°45'36"N; 08°41'28"E; 745 m a.s.l., Tunisia, Fig. 1c). The site of Sources du 18^{e} haut is an extended peat-forming wetland partly covered by *Alnus glutinosa*, *Cytisus villosus*, *Erica scoparia*, *Juncus conglomeratus*, *J. effusus*, *Myrtus communis* and *Salix atrocinerea*, and developed along a weak slope just below a permanent spring. This site harbours a great variety of habitats, from alder carrs and heath scrubs to open herbaceous lawns installed within inundated clearings. The wetland harbours *Anagallis crassifolia*, *A. tenella*, *Athyrium filix-femina*, *Bellis prostrata*, *Carex depressa*, *C. punctata*, *C. remota*, *Dactylorhiza munbyana*, *Danthonia decumbens*, *Eleocharis multicaulis*, *Hypericum afrum*, *Isolepis cernua*, *Juncus conglomeratus*, *J. effusus*, *J. tenageia*, *Lythrum junceum*, *L. portula*, *Mentha pulegium*, *Osmunda regalis*, *Phragmites australis*, *Potamogeton polygonifolius*, *Potentilla reptans*, *Pteridium aquilinum*, and *Solenopsis bicolor* (Table 2). *Sphagnum* is abundant on the site, but always as scattered small populations installed under *Juncus* tussocks or at the foot of *Erica* shrubs. While still impressive, this site strongly suffered from the construction of the water catchment supplying the close town of Aïn Draham, which resulted in the degradation of the site in the first half of the 20th century (Pottier-Alapetite & Labbe 1951; Pottier-Alapetite 1959).

Sources du 18^{e} bas (36°45'31"N; 08°41'28"E; 729 m a.s.l., Tunisia). The site of Sources du 18^{e} bas is a peaty carr developed in the bottom of a small valley originating from the previous site. The dense shrubby and arboreal plant cover occupies a large peat mound installed on a steep slope within the oak forest. The carr, dominated by *Alnus glutinosa*, *Erica scoparia*, *Hypericum afrum*, *Rubus ulmifolius* and *Salix atrocinerea*, presents a rich Pteridophytic understorey composed of *Athyrium filix-femina*, *Blechnum spicant*, *Osmunda regalis* and *Pteridium aquilinum*. *Sphagnum* is restricted to a small surface close to a brooklet at the wetland edge, where it is mixed with *Anagallis crassifolia*, *A. tenella*, *Bellis prostrata*, *Carex punctata*, *C. remota*, *Juncus effusus*, *Lythrum junceum*, and *Potamogeton polygonifolius* (Table 2).

Table 2. Plant species associated with *Sphagnum auriculatum* in Numidian-Kroumirian poor fens and carrs. The studied localities are: Bou Merchen (BM, Gauthier-Lièvre 1931), an unnamed alder carr 24 km from El Kala (K24, Gauthier-Lièvre 1931) and Aïn Bergougaïa (AB, this study). Kroumirian localities are: Col de Vincendon (CV, Braun-Blanquet, 1953), Dar Fatma (DF, this study), Aïn Zouama (AZ, this study), Sources du 18^e haut (S18, Nègre 1952; S18H, this study), Sources du 18^e bas (S18B, this study), Camps du 18^e (C18, this study), le Merij (ME, this study), le Mouajene (MO, this study), and Piste de Lebga (PL, this study). The AB relevé corresponds to the average of four relevés (Belouahem & al. 2010), the S18 relevé to the average of three relevés (Nègre, 1952), and the S18H relevé to the average of seven relevés (this study). Indices of abundance follow the Braun-Blanquet's (1932) scale: +, a few individuals; 1, 1-5 %; 2, 5-25 %; 3, 25-50 %; 4, 50-75 %; 5, 75-100 %. When indices are not available, only the presence (x) is noted. Bold characters identify the species characteristic of plant communities with *Sphagnum*.

	Numidia			Kroumiria									
	BM	K24	AB	CV	DF	AZ	S18	S18H	S18B	C18	ME	MO	PL
Aulacomnium palustre (Hedw.) Schwägr.			+		1								
Campylopus pilifer Brid.										+			
***Sphagnum auriculatum* Schimp.** (= *Sphagnum obesum*)	**x**	**x**	**3**	**x**	**2**	**2**	**3-4**	**2-3**	**2-3**	**3**	**5**	**2**	**3**
Aira cupaniana Guss.					+				1	1-2			
Alisma plantago-aquatica L.			1-2										
Allium triquetrum L.								+					
***Alnus glutinosa* (L.) Gaertn.**	**x**	**x**	**2-3**				**+**	**2-3**	**3**		**1**		
***Anagallis crassifolia* Thore**	**x**	**x**	**+**	**x**	**3**		**+**	**1-2**	**+**	**1-2**			
***Anagallis tenella* (L.) L.**	**x**	**x**	**1**		**1**			**1**	**1.2**		**3**		**1**
Aphanes floribunda (Murb.) Roth.												+	
Asplenium adiantum-nigrum L.			+										
Athyrium filix-femina (L.) Roth.			1-2				+	1	2-3		1-2		3
Baldellia ranunculoides subsp. *repens* A.Löve & D.Löve	x			x		3							
Bellis annua L.						1				+			
***Bellis prostrata* Pomel** (= *B. radicans*)	**x**		**1-2**		**1**	**4**	**1**	**2**	**2**		**2**	**2**	**2-3**
Blechnum spicant (L.) Roth.									2				
Brachypodium sylvaticum (Huds.) P.Beauv.								+					
Briza maxima L.								+					
Briza minor L.								1	+	+			
Bromus hordeaceus L. subsp. *hordeaceus*										+			
Callitriche stagnalis Scop.			1-2			3-4							
Calicotome villosa (Poir.) Link			1-2										
Calystegia sepium (L.) R.Br.		x	1-2										
Campanula alata Desf.	x	x											
Carex depressa Link							+						
Carex distans L.	x												
Carex divulsa Stokes										1			
Carex hispida Willd.	x	x											
Carex pendula Huds.			+										

Table 2. continued.

	Numidia			Kroumiria									
	BM	K24	AB	CV	DF	AZ	S18	S18H	S18B	C18	ME	MO	PL
***Carex punctata* Gaudin**			+		**2-3**		+	**1**	**1**	**1**	**2**		**2**
Carex remota L.			1-2				+	1	2				2-3
Carex sylvatica Huds.													1
Cerastium atlanticum D.R.				x									
Cynosurus polybracteatus Poir.					+			+					
Cytisus villosus Pourr. (= *C. triflorus*)			1-2					+					+
Dactylorhiza elata (Poir.) Soó subsp. *elata*								+					
***Danthonia decumbens* (L.) DC.** (= *Sieglinglia decumbens*)					**2**		**1**	**1**					
Dittrichia viscosa (L.) Greuter (= *Inula viscosa*)											1		
Dorycnium rectum (L.) Ser. (= *Bonjeania recta*)	x		1		+				2				
***Eleocharis multicaulis* (Sm.) Desv.**	**x**	**x**					**2**	**2-3**		**2**			**2-3**
Eleocharis palustris (L.) Roem. & Schult.	x	x											
Eleocharis uniglumis (Link) Schult.	x				1								
Erica arborea L.	x		2-3				+	+	1-2		2	2	1
***Erica scoparia* L.**	**x**	**x**	**2**		**2-3**		**+**	**2-3**	**2-3**	**3**	**1**	**1**	
Frangula alnus Mill. (= *F. dodonaei*, *Rhamnus frangula*)	x	x	+										
Fuirena pubescens (Poir.) Kunth			**1**										
***Galium palustre* subsp. *elongatum* (C. Presl) Lange**	**x**		+	**x**	**1**	**2**							
Galium parisiense L. subsp. *parisiense*								+					
Galium scabrum L.								+	1			+	+
Hedera helix L.			2				+	1	1		+		+
Helosciadium crassipes W.D.J. Koch ex Rchb. (= *Apium crassipes*)						5							
Holcus lanatus L.					1-2								
***Hypericum afrum* Lam.**	**x**	**x**	**2**		**2**		**1**	**2**	**3**	**1**	**2**		**1-2**
Illecebrum verticillatum L.	x					3							
Isoetes duriei Bory												1.2	
Isoetes velata A.Braun						2							
***Isolepis cernua* (Vahl) Roem. & Schult.** (= *Scirpus savii*)	**x**		**1**		+	**3**		**1**	**1**		+	+	
Juncus articulatus L. subsp. *articulatus*					1-2								
Juncus bufonius L.							1		2	1-2			1
Juncus bulbosus L.			1										
Juncus conglomeratus L.								2		2	2		1
Juncus effusus L.	x			x				2	2-3			1	
Juncus fontanesii J.Gay ex Laharpe		x		x									
Juncus heterophyllus Dufour		x	1			2							
Juncus maritimus Lam.	x												
Juncus pygmaeus Rich. ex Thuill.	x					1				2			

Table 2. continued.

	Numidia			Kroumiria									
	BM	K24	AB	CV	DF	AZ	S18	S18H	S18B	C18	ME	MO	PL
Juncus tenageia Ehrh. ex L.f.	x		+		1			2-3	1		1-2		2-3
Kickxia cirrhosa (L.) Fritsch (= *Linaria cirrhosa*)	x												
Kickxia commutata (Reichenb.) Fritsch (= *Linaria commutata*)									+				
Lotus hispidus Desf. ex DC.						3		1				2	
Lotus pedunculatus Cav.			+								2		
Ludwigia palustris (L.) Elliot (= *Isnardia palustris*)		x	1	x									
Lycopus europaeus L.	x	x											
Lythrum hyssopifolia L.						+						1	
***Lythrum junceum* Banks & Sol.** (= *L. graefferi*)	**x**		**1-2**		**+**	**+**		**1**	**+**	**1**	**+**		**2**
Lythrum portula (L.) D.A. Webb						3		+					
Lythrum salicaria L.	x		1										
***Mentha pulegium* L.**			**1-2**		**+**	**3**		**1**	**1**	**+**	**1**	**1**	**2-3**
Mentha suaveolens Ehrh. (= *M. rotundifolia*)			1										
Montia minor subsp. *chondrosperma* (Fenz) Walters						+							
Myosotis sicula Guss. (= *M. lingulata* subsp. *sicula*)						+							
Myrtus communis L. subsp. *communis*			3	x					1		+		1
Oenanthe fistulosa L.					+								
Oenanthe lachenalii C.C.Gmelin	x												
Oenanthe sp.				x									
***Osmunda regalis* L.**	**x**	**x**	**2**				**1**	**3-4**	**3**		**2**		**1**
Panicum repens L.						3							
Phillyrea angustifolia L.			2										
Phragmites australis (Cav.) Trin. ex Steud. (= *P. communis*)	x							1					
Plantago bellardii All.												1	
Poa annua L.						+						+	
Poa trivialis L.													+
Potamogeton nodosus Poir.			1										
***Potamogeton polygonifolius* Pourr.** (= *P. oblongus*)		**x**	**2-3**	**x**				**1**	**1-2**				
Potamogeton trichoides Cham. & Schltr.			1										
***Potentilla reptans* L.**			**1**	**x**	**1**		**+**	**1**		**3**			
Prunella vulgaris L.							+		1			1.2	+
Prunus avium (L.) L.			1-2										
Pteridium aquilinum (L.) Kuhn	x		1					1	1	2	1-2		
Quercus canariensis Willd. (= *Q. faginea*)			3-4										
Quercus suber L.			2-3										1-2
Ranunculus baudotii Godr. (= *R. peltatus*)						+						1	
Ranunculus flammula L.	x												

Table 2. continued.

	Numidia			Kroumiria									
	BM	K24	AB	CV	DF	AZ	S18	S18H	S18B	C18	ME	MO	PL
Ranunculus macrophyllus Desf.						+							
Ranunculus sardous Crantz.												1	
Rubia peregrina L.			1										+
Rubus ulmifolius Schott	x		3				+	1	2-3	1	1-2		1
Ruscus hypophyllus L.			+										
Salix atrocinerea Brot. (= *S. cinerea* subsp. *atrocinerea*)	x						+		2				
Salix pedicellata Desf.			1-2										
Scabiosa succisa L. (= *Succisa pratensis*)	x	x											
Schoenoplectus lacustris (L.) Palla (= *Scirpus lacustris*, *S. lacuster*)	x												
Schoenus nigricans L.				x									
Selaginella denticulata (L.) Spring.											1		
Silene laeta (Aiton) Godr.			1	x		2		+	1			1	
Smilax aspera L.			1-2					1	+				
***Solenopsis bicolor* (Batt.) Greuter & Burdet** (= *Laurentia bicolor*)	**x**	**x**	**1**		**1**		**1**	**1**	+	+	**1**		+
Solenopsis laurentia (L.) C.Presl. (= *Laurentia michelii*)									+	1			
Trifolium nigrescens Viv.					1								
Viburnum tinus L.			2										
Viola riviniana Rchb. subsp. *riviniana*									+				
Vitis vinifera subsp. *sylvestris* (C.C.Gmel.) Hegi			+										
Vulpia myuros (L.) C.C.Gmel.								+					

Camps du 18e (36°45'15"N; 08°41'16"E; 666 m a.s.l., Tunisia, Fig. 1d). The Camps du 18e site is a shrubby wetland developed on a weak slope within the oak forest, located at a much lower altitude than the Sources du 18^{e} and close to a holiday camp. This site, which occupies a large 2 m-high peat mound bordered by a permanent stream, is dominated by a degraded community of *Alnus glutinosa* harbouring *Erica scoparia*, *Juncus conglomeratus*, *J. effusus* and *Pteridium aquilinum*. The herbaceous cover is composed of *Campylopus pilifer*, *Anagallis crassifolia*, *Bellis annua*, *Carex divulsa*, *C. punctata*, *Eleocharis multicaulis*, *Hypericum afrum*, *Juncus bufonius, J. pygmaeus, Lythrum junceum, Mentha pulegium*, *Potentilla reptans*, *Solenopsis bicolor* and *S. laurentia* (Table 2). The site moreover harbours populations of the rare *Isoetes duriei* and *Radiola linoides*. *Sphagnum* is relatively abundant in similar habitats than at Sources du 18^{e}, i.e. under *Juncus* tussocks and at the foot of *Erica* shrubs. The site is presently disturbed by several drainage ditches digged at its periphery and by wild boars.

Le Merij (36°45'03"N; 08°41'17"E; 614 m a.s.l., Tunisia, Fig. 1e). The mire of Le Merij is a small forest hollow, developed within a clearing in the mixed oak forest, dominated by *Quercus canariensis*, *Q. suber*, *Arbutus unedo*, and *Phillyrea latifolia*. The water supplying the mire originates from a capted spring located at the upper part of the site. The mire, surrounded by a dense belt of *Erica arborea*, *E. scoparia* and *Rubus ulmifolius*, is covered by a continuous, well-preserved carpet of *Sphagnum auriculatum*, in association to *Anagallis tenella*, *Athyrium filix-femina*, *Dittrichia viscosa*, *Eleocharis multicaulis*, *Juncus conglomeratus*, *Lotus pedunculatus*, *Osmunda regalis*, and *Solenopsis bicolor*. Despite its small extent, this site is the most preserved of all the sites visited during our prospections.

Le Mouajene (36°43'33"N; 08°42'32"E; 636 m a.s.l., Tunisia, Fig. 1f). Le Mouajene is a temporary pond installed in a vast depression within the mixed oak forest, above to the artificial lake of Beni M'Tir. The vegetation of the lake is relatively poor, compared to other similar habitats of the region: it comprises almost exclusively *Callitriche brutia*, *C. stagnalis*, *Juncus heterophyllus*, *Lythrum portula* and *Ranunculus baudotii*. However, a small (recent?) population of *Sphagnum auriculatum* has been discovered along the shore under *Erica arborea* shrubs, close to a relatively extended population of *Isoetes duriei*, another very rare plant in North Africa.

Piste de Lebga (36°45'11"N; 08°41'22"E; 608 m a.s.l., Tunisia, Fig. 1g). The peaty hollow of Piste de Lebga is developed on a steep slope, along a stream, in the mixed oak forest. This small wetland (*ca*. 200 m^2) is dominated by *Sphagnum auriculatum*, *Athyrium filix-femina*, *Carex remota*, *Eleocharis multicaulis*, *Juncus tenageia* and *Osmunda regalis*, and bordered by a belt of *Erica arborea*, *Myrtus communis* and *Rubus ulmifolius*. *S. auriculatum* occurs in small patches growing among rocks and tussocks of *E. multicaulis*. The site is disturbed by wild boars.

Aïn Bergougaïa (36°50'58"N; 08°35'25"E; 306 m a.s.l., Algeria, Fig. 1h). The Aïn Bergougaïa site is a degraded mixed carr of *Alnus glutinosa* and *Quercus canariensis*, locally associated to *Erica arborea*, *E. scoparia*, *Frangula alnus*, *Myrtus communis*, *Quercus suber* and *Salix pedicellata*. For the last ten years, the ecosystem, initially rich and

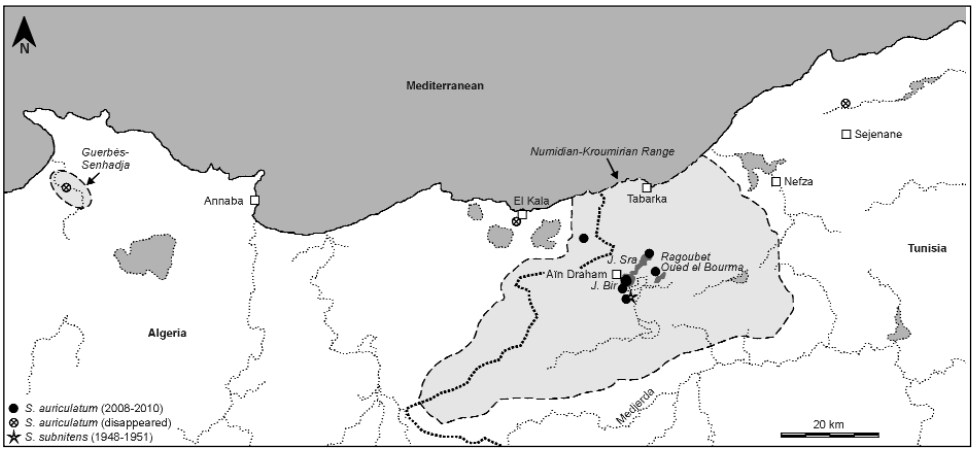

Fig. 3. Distribution of *Sphagnum auriculatum* and *S. subnitens* in the Numidian-Kroumirian range and adjacent regions (Cosson 1885; Nègre 1952; Braun-Blanquet 1953; Pottier-Alapetite 1954; this study).

relatively well preserved, has been progressively degraded by cutting, burning, overgrazing and illegal dumping (Belouahem & al. 2010). Today, the ecosystem is highly damaged and restricted to five old alders and seven young ones surviving on an herbaceous carpet composed of *Anagallis crassifolia*, *Athyrium filix-femina*, *Callitriche stagnalis*, *Carex remota*, *Hypericum afrum*, *Juncus bulbosus*, *J. heterophyllus*, *Ludwigia palustris*, *Lythrum junceum*, *Osmunda regalis*, *Solenopsis bicolor* and *Pteridium aquilinum* (Table 2). *Sphagnum* occurs under *Juncus* tussocks, at the foot of *Erica* shrubs and as loose carpets on bare organic wet soils.

Distribution of Sphagnum species in the Numidian-Kroumirian range

Sphagnum subnitens was collected two times in the valley of Merij, close to Aïn Draham, in Kroumiria (Table 1; Fig. 2). This site, not recovered despite our repeated investigations in the zone, was probably its unique locality in the Numidian-Kroumirian range. In the present-day state of our knowledge, *S. subnitens* should therefore be considered as possibly extinct from the region, although its survival in small forest peaty hollows of the Aïn Draham region seems possible. In North Africa, the species seems to be now restricted to a unique locality in northwestern Morocco (Muller & al. in preparation).

Sphagnum auriculatum is more abundant in North Africa. Its distribution encompasses northern Morocco, northeastern Algeria and northwestern Tunisia (Cosson 1885; Braun-Blanquet 1953; Nègre 1952; Pottier-Alapetite 1954; Dahlgren & Lassen 1972; Fig. 3, Table 1). Daniels & Eddy (1985) indicate 'Atlas mountains' for characterising the North African distribution of *Sphagnum auriculatum*. Based on the general map they give for the distribution of the genus around the world, they probably only refers to Rif.

Besides our findings, located in the vicinity of the artificial lake of Beni M'Tir in Kroumiria, and between Oum Tebboul and Aioun in Numidia (Fig. 1), *S. auriculatum* has been mentionned in a few adjacent zones. First, Pottier-Alapetite & Labbe (1951) and

Pottier-Alapetite (1958) mentioned the existence of a "*petite mare à Sphaigne*" at the edge of Garâa Sejenane, a formerly inundated plain presently drained and cultivated, in the Mogods Hills, east of Kroumiria. This pool, developed in a small *Quercus coccifera* stand, certainly constituted the easternmost locality of *Sphagnum auriculatum* (reported as *S. obesum* by Pottier-Alapetite & Labbe 1951) in North Africa. The site, not recovered despite our repeated investigations of the zone since 2006 (Muller & al. 2008; Daoud-Bouattour & al. 2009; Ferchichi-Ben Jamaa & al. 2010), is considered to have disappeared. Second, it had also been found in the Senhadja region (Table 1), at Demet marsh near El Kala (Table 1), and at Bou Merchen (also called Demnet Errihane; Gauthier-Lièvre 1931; P. Ozenda, pers. comm. 1989). Despite the investigations conducted for tens of years in these zones by G. de Bélair (pers. comm. 2010) and two of us (D. Belouahem-Abed and M. Benslama), none of these plain populations has been recovered.

These considerations suggest a strong decline of *Sphagnum auriculatum* throughout the Numidian-Kroumirian range, marked by the probable extinction of its peripheral lowland populations. This species is thought to be now restricted to a zone centred on Aïn Draham, and encompassing a few mountains apart from the Algero-Tunisian boundary (Fig. 3).

Ecological and phytosociological significance of Sphagnum in North Africa

Since we have no information about the plant communities associated with *Sphagnum subnitens* in Kroumiria, the following discussion deals only with *S. auriculatum*. However, because we found both species associated in northern Morocco (Muller & al., in preparation), we suspect that their ecological requirements would be relatively similar, with a possible lower ecological range for the rarer *S. subnitens*. The North Moroccan wetlands with *Sphagnum*, described in detail by Dahlgren & Lassen (1972), appear as treeless poor fens, wadies and ponds. The situation is different in Numidia and Kroumiria, where *Sphagnum auriculatum* occurs within more diversified plant communities, ranging from forest hollows and alder carrs to peaty heathlands dominated by *Erica scoparia*. The treed communities were mostly developed in the Numidian coastal lowlands, whereas the shrubby ones are rather located in the Kroumirian mountains. Very few evidence is available for assessing the ecological significance of both communities. However, the pollen records of Dar Fatma (Ben Tiba 1980; Ben Tiba & Reille 1982; Stambouli-Essassi 2002; Stambouli-Essassi & al. 2007) show that the present local hydrophytic shrubby and herbaceous communities originate from full-glacial carrs of *Alnus glutinosa*, *Salix* and *Osmunda regalis*, organised in mosaic with open water bodies harbouring *Myriophyllum* and *Sparganium*. The occurrence of some scattered individuals of *Alnus glutinosa*, *Salix pedicellata* and *S. atrocinerea* in the other investigated sites suggests that their present-day vegetation also constitutes the damaged remnants of former treed communities. Human-induced disturbances have been reported from Sources du 18^{e} haut (Pottier-Alapetite & Labbe 1951; Pottier-Alapetite 1959) and Aïn Bergougaïa (Belouahem & al. 2010). The observed vegetation gradient from shrubby to treed communities then appears as a gradient of disturbance, where poor fens with *Erica scoparia* and *Juncus* spp. would represent a regression stage of alder carrs. This view agrees with Nègre (1952), who considers the community with *Sphagnum auriculatum* and *Carex punctata* (*Cariceto-Sphagnetum plumulosi* Labbe & Nègre 1952) as the first stage of the hydroseral succession leading to the community of *Erica scoparia* and *Osmunda regalis* (*Osmundo-Ericetum scopariae* Nègre 1952), then to

the community of *Alnus glutinosa* (*Rusco hypophylli-Alnetum glutinosae* Géhu, Kaabeche & Gharzouli 1994). These three stages are thought to constitute the hydroseral series of the alliance *Alnion glutinosae* Malcuit 1929, order *Alnetalia glutinosae* R. Tx. 1937, class *Alnetea glutinosae* Br.-Bl. & R. Tx. 1943 (Géhu & al. 1994). These peat-forming carrs, developed on permanently water-logged and anoxic substrates, differ from riparian alder forests developed on well-oxygenised soils submitted to seasonally alternating floods and droughts, which are classified into the alliance *Osmundo-Alnion* Drske. & Riv.-Mart. 1975, order *Populetalia albae* Br.-Bl. 1931, class *Querco-Fagetea* Br.-Bl. & Vlieg. 1937 (Bensettiti & Lacoste 1999; Belouahem & al. 2010).

While representing different stages of a regressive hydroseral succession, the studied plant communities harbour a number of species regularly associated with *Sphagnum auriculatum*. These species are, on the first hand, *Carex punctata*, *Danthonia decumbens*, *Eleocharis multicaulis* and *Potentilla reptans*, which are rarely encountered without *Sphagnum*, and on the second hand, *Anagallis crassifolia*, *Bellis prostrata*, *Hypericum afrum*, *Lythrum junceum*, and *Solenopsis bicolor*, which occur in most North Tunisian wetlands installed on organic soils (Table 2). Most of these species were considered by Nègre (1952) as characteristics of its association *Cariceto-Sphagnetum plumulosi*, which should be renamed as *Cariceto-Sphagnetum auriculati*. To these species, we can add *Holcus lanatus* and *Potamogeton polygonifolius*, and maybe also *Galium palustre* subsp. *elongatum*, *Isolepis cernua* and *Mentha pulegium*, although these ubiquitous species occur in a wide range of wetlands (Table 2). Most of these species are common between the Numidian-Kroumirian range and northern Morocco (Dahlgren & Lassen 1972). However, the North African endemics *Bellis prostrata*, *Hypericum afrum* and *Solenopsis bicolor* are lacking in North Moroccan wetlands, which, in turn, are characterised by the occurrence of the Atlantic species *Carex echinata*, *Erica ciliaris*, *Genista anglica* subsp. *ancistrocarpa*, *Isolepis setacea*, *Lobelia urens*, *Pinguicula lusitanica* and *Potentilla erecta*.

Conclusions

The present study attests the past occurrence, within the Numidian-Kroumirian range, of only two species (*Sphagnum auriculatum* and *S. subnitens*). It moreover highlights the strong decline of both species: *S. subnitens*, not recovered since 1951, is considered as regionally extinct, and *S. auriculatum*, probably disappeared from Guerbès-Senhadja and El Kala regions in Numidia, and from Sejenane region in Mogods, only persists in a few wetlands of the Kroumirian mountains. These wetlands, generally extended on a few tens of meters square and dominated by *Juncus* and *Erica*, seem more disturbed than the Numidian alder carrs, whose surface areas commonly attain hectares. However, the lowland wetland complexes of Numidia experienced strong anthropogenic pressures for several decades (Stevenson & al. 1988; Samraoui & al. 1992; de Bélair & Samraoui 1994; Samraoui & de Bélair 1997; Belouahem & al. 2010), which probably induced the recent extinction of their *Sphagnum* populations. The ongoing regional decline of wetlands is also evidenced in Sejenane region (Mogods), where several species of conservatory interest, including *Sphagnum auriculatum*, have recently disappeared (Muller & al. 2008; Ghrabi-Gammar & al. 2009; Ferchichi-Ben Jamaa & al. 2010). This worrying situation, in regard

to the increasing human pressure in the concerned regions, implies the urgent implementation of conservatory measures in order to preserve the last *Sphagnum* populations and the remarkable associated plant communities. In particular, tree cutting, pollution and overgrazing should be imperatively forbbiden in these fragile habitats. We recommend the strict restriction of public access to the most extended peat-forming wetlands of Kroumiria (e.g., Sources du 18^{e} haut, Camps du 18^{e}), as well as to some of the marshes and alder carrs of Numidia, which present rich plant communities likely to harbour residual *Sphagnum* populations (e.g., Demnat Ataoua, Sidi Freitis, Bou Merchen, Righia, Aïn Bergougaïa).

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Addresses of the authors:
Serge D. Muller,
Université Montpellier-2 - CNRS, Institut des Sciences de l'Evolution de Montpellier (ISE-M), Case 061, Place Eugène Bataillon, 34095 Montpellier cedex 05, France. E-mail: smuller@univ-montp2.fr

Amina Daoud-Bouattour, Semia Ben Saad-Limam, Hafawa Ferchichi-Ben Jamaa,
Département de Biologie, Faculté des Sciences de Tunis, Université Tunis El Manar, Campus le Belvédère, 2092 Tunis, Tunisie ; U.R. Biogéographie, Climatologie Appliquée et Dynamique Erosive, Faculté des Lettres, des Arts et des Humanités de Manouba, Université de la Manouba, Tunisie. E-mail: daoudamina200@yahoo.fr, samiabensaad@yahoo.fr

Djamila Belouahem-Abed,
Institut National de Recherche Forestière, Station de Recherche, El Kala (El Tarf), Algérie. E-mail: belouahem_djamila@yahoo.fr

Imtinen Ben Haj Jilani,
Ecole supérieure d'Agriculture de Mateur, 7030 Mateur, Tunisie ; U.R. Biogéographie, Climatologie Appliquée et Dynamique Erosive, Faculté des Lettres, des Arts et des Humanités de Manouba, Université de la Manouba, Tunisie. E-mail: imtinenbhj@yahoo.fr

Mohamed Benslama,
Laboratoire de Biologie Végétale et Environnement, Université Badji Mokhtar, BP 533, 23000 Annaba, Algérie. E-mail: m.benslama@univ-annaba.org

Laïla Rhazi,
Université Hassan II Aïn Chock, Faculté des Sciences, Laboratoire d'Ecologie Aquatique et Environnement, BP 5366, Maarif, Casablanca, Maroc. E-mail: rhazi-laila@yahoo.fr

Zeineb Ghrabi-Gammar,
Institut National Agronomique de Tunisie (INAT), 43 Avenue Charles Nicolle, 1082 Cité Mahrajène, Tunis, Tunisie ; U.R. Biogéographie, Climatologie Appliquée et Dynamique Erosive, Faculté des Lettres, des Arts et des Humanités de Manouba, Université de la Manouba, Tunisie. E-mail: zghrabi@yahoo.fr