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CONSERVATION ISSUES OF AN EXCEPTIONAL FRESHWATER MEDITERRANEAN WETLAND IN NORTHWEST TUNISIA: GARÂA SEJENANE

Maya ROUISSI[1,2], Serge D. MULLER[3], Imtinen BEN HAJ JILANI[2,4], Zeineb GHRABI-GAMMAR[2,4], Laila RHAZI[5], Laure PARADIS[3], Marion BOTTOLLIER-CURTET[6], Eric GERBAUD[7] & Amina DAOUD-BOUATTOUR[1,2*]

[1] Département de Biologie, Faculté des Sciences de Tunis, Université de Tunis El-Manar, 2092 Tunis, Tunisia
[2] UR99/UR/02-04 Biogéographie, Climatologie appliquée et Dynamique érosive, Faculté des Lettres, des Arts et des Humanités de Manouba, Université de la Manouba, 2010 Manouba, Tunisia
[3] Institut des Sciences de l'Evolution (ISE-M), Université de Montpellier/CNRS, case 061, 34095 Montpellier cedex 05, France
[4] Institut National Agronomique de Tunisie, Université de Carthage, 43, avenue Charles-Nicolle, 1082 Cité Mahrajène, Tunisia
[5] Laboratory of Botany, Mycology and Environment, Faculty of Sciences, University Mohammed V-Rabat, 4 avenue Ibn Battouta B.P. 1014 RP, Rabat, Morocco
[6] Les Ecologistes de l'Euzière, Domaine de Restinclières, 34730 Prades-le-Lèz, France
[7] Gap Sciences Animation 05, 8 route de Patac, 05000 Gap, France
* Author for correspondence. E-mail: daoudamina200@yahoo.fr

RÉSUMÉ.— *Enjeux de conservation d'une zone humide d'eau douce méditerranéenne exceptionnelle : la Garâa Sejenane (Tunisie septentrionale).*— Cet article a pour but d'évaluer les enjeux de conservation concernant la végétation hydrophytique de la plus grande zone humide naturelle d'eau douce de Tunisie, la Garâa Sejenane. Les 55 relevés phytosociologiques réalisés révèlent une richesse floristique exceptionnelle, avec 74 hydrophytes dont 26 sont à forte valeur patrimoniale. Des analyses multivariées (AFC, CHA) effectuées sur ces données distinguent trois types d'habitats : des cultures inondables, des marais temporaires, et des pelouses humides/mares temporaires. Leur cartographie montre une structure en 3 zones concentriques : une ceinture externe constituée de pelouses humides, de mares temporaires et de prairies fourragères sèches, une zone intermédiaire occupée par des marais temporaires et des prairies fourragères humides, et une zone centrale formée de cultures inondables. Un Indice de Rareté des Espèces très élevé, et des espèces à fort enjeu conservatoire (1 endémique stricte à la Garâa Sejenane, 5 espèces dont elle constitue l'unique localité tunisienne, et 2 espèces dont elle abrite les plus grandes populations nord-africaines) révèlent l'intérêt écologique et conservatoire majeur du site, et ceci malgré de fortes pressions anthropiques subies depuis les années 60. Dans le contexte actuel d'augmentation de la pression de perturbation, la conservation à long terme de cette biodiversité exceptionnelle nécessite la mise en place de mesures de gestion appropriées intégrant les populations locales.

SUMMARY.— This study addresses the conservation issues of the hydrophytic vegetation of Garâa Sejenane, the largest natural freshwater wetland in Tunisia. Fifty-five phytosociological relevés reveal the exceptional floristic wealth, including 74 hydrophytes of which 26 are patrimonial species. Multivariate analyses (CA, AHC) differentiate three types of habitats: flooded crops, temporary marshes, and wet lawns/temporary pools. Their mapping shows concentric zones, including an external belt of wet lawns, temporary pools and dry fodder meadows, an intermediate belt of temporary marshes and wet fodder meadows, and a central area of flood crops. A high Species Rarity Index and the occurrence of several species with high conservation values (1 strictly endemic species to the Garâa Sejenane, 5 others that exist in Tunisia only in this site, and 2 species whose local populations are the largest in North Africa) confirm the major ecological and conservatory interest of the site, despite anthropogenic pressures on the Garâa Sejenane since the sixties. In the present-day context of increasing human pressure, the long-term conservation of this exceptional biodiversity needs the implementation of targeted management measures integrating local populations.

Rising anthropogenic pressures have reduced Mediterranean wetlands over the last decades (Pearce & Crivelli, 1994; Médail *et al.*, 1998; Acreman, 2000). Conservation issues are uneven, particularly in the southern Mediterranean where industrial development and social instability

threaten natural environments in the short term. Wetlands, which count among the most sensitive ecosystems, are particularly impacted. The great diversity of wetlands in the Maghreb has long been recognized (Gauthier-Lièvre, 1931; Pottier-Alapetite & Labbe, 1951; Chevassut & Quézel, 1956; Hammada *et al.*, 2004; Ghrabi-Gammar *et al.*, 2009). Despite the fact that they elicit concerns for their conservation, North African wetlands continue to be disturbed, drained and polluted: today, most of them are degraded (Rhazi *et al.*, 2001, 2012; Belouahem-Abed *et al.*, 2011; Bouldjedri *et al.*, 2011; Daoud-Bouattour *et al.*, 2011) and several have simply disappeared (Chevassut, 1956; Samraoui *et al.*, 1992; de Bélair & Samraoui, 1994; Muller *et al.*, 2010, 2011).

In Tunisia, freshwater wetlands are located primarily in the northern part of the country. Although a small number of shallow lakes, more or less salty, exist in the limestone areas of the High Tell and Tunisian Ridge (Gammar & Karray, 1982, 1991), most of them are concentrated in the mountain regions of Kroumiria and Mogods (Gauthier-Lièvre, 1931). These wetlands, quite small and sparsely dispersed in mesic vegetation, are either isolated (temporary pools, heath peatlands, alder swamps) or linear, growing alongside rivers (riparian woods) (Pottier-Alapetite, 1952, 1959; Pottier-Alapetite & Labbe, 1951; Nègre, 1952; Ferchichi-Ben Jamaa *et al.*, 2010; Muller *et al.*, 2010). Majen Chitane Lake and Garâa Sejenane, the only two large sites, are both located in the Mogods Hills. While seriously degraded, their size (1.5 and 1200–1500 ha respectively) makes the stakes of their conservation high. First described by Pottier-Alapetite & Labbe, (1951) and extensively studied within the Cassarina Project (Flower, 2001; Ramdani *et al.*, 2001), Majen Chitane Lake is profoundly disturbed despite its protected status (Daoud-Bouattour *et al.*, 2011). The larger site, Garâa Sejenane, located in a sheltered depression near the village of Sejenane, was first explored at the end of the 19th century by E. Cosson, who discovered a new species of *Rumex*, named *R. tunetanus* by Murbeck (1899), which is strictly endemic to the site. In the 1930s, Gauthier-Lièvre (1931) and Bonniard (1934) described the site as a vast shallow lake partly covered by an extensive marsh. Pottier-Alapetite & Labbe (1951) and Pottier-Alapetite (1958) subsequently inventoried the lake's hydrophytic flora, and noted the presence of many rare species, some of which occur nowhere else in Tunisia. These studies are the only sources of information on the vegetation of the garâa before the great drainage works undertaken for agricultural holdings between 1958 and 1980. Today, Garâa Sejenane is a vast humid plain that is partly inundated in winter and includes a mosaic of wet habitats that are mostly cultivated and pastured. Ferchichi-Ben Jamaa *et al.* (2010) examined the vegetation of the garâa, in the context of a study of Mogods wetlands, and Ferchichi-Ben Jamaa *et al.* (2014) and Rouissi *et al.* (2014) subsequently studied the vegetation and fauna of some of the site's temporary pools. These studies revealed the presence of a rich and diverse flora, including two species that are new to Tunisia (*Crassula vaillantii*, *Pilularia minuta*; Muller *et al.*, 2008; Daoud-Bouattour *et al.*, 2009), and the strictly endemic *Rumex tunetanus*, discovered in 1898 (Murbeck, 1899) but never seen again until its rediscovery in 2008 (Z. Ghrabi-Gammar, unpublished data). These data, which highlight the major patrimonial interest of the Garâa Sejenane, motivated the current study in order to (1) describe and map the garâa's contemporary hydrophytic flora, and (2) estimate the patrimonial value of the site. Particular attention is given to patrimonial species to evaluate the potential of the area for their conservation, and to suggest some guidelines for their management locally and Tunisia-wide.

MATERIAL AND METHODS

STUDY SITE

The Garâa Sejenane covers an area of 12 to 15 km^2 in the Mogods region of northwest Tunisia (Fig. 1; 37°05' N, 09°12' E, 110 m a.s.l., i.e. above sea level) in the thermo-Mediterranean belt, a humid bioclimatic ambiance with mild winters (INRF, 1975). It is surrounded by low sandstone hills (no higher than 300 m a.s.l.) covered by degraded cork-oak

woods rich in *Cistus* spp., *Erica arborea*, *Myrtus communis*, *Pistacia lentiscus*, and belonging to the Numidian facies of the Maghrebian Oligo-Miocene flysh (Talbi *et al.*, 2008). Temporary streams crossing the hills surrounding Garâa Sejenane, home to *Isoetes histrix* (Ferchichi-Ben Jamaa *et al.*, 2010), feed the garâa, which is drained to its northwest by Wadi Sejenane that flows into Ichkeul Lake.

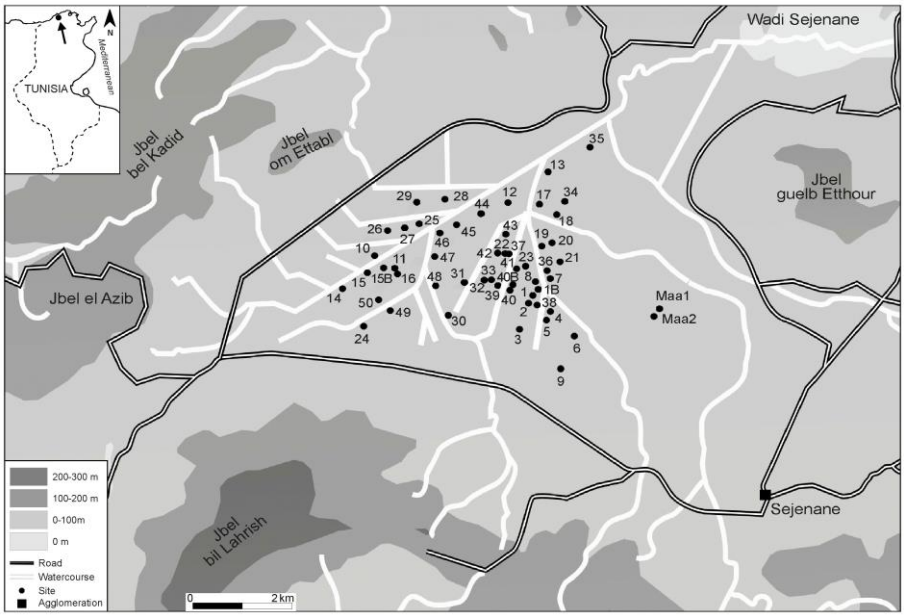

Figure 1.— Topography and geography of Garâa Sejenane and phytosociological relevés map.

VEGETATION STUDY

55 phytosociological relevés were carried out in the Garâa Sejenane between 2007 and 2014 (during the flooded phase; 15 April-15 May), using the Braun-Blanquet's method (1932) with an abundance/dominance scale from + to 5. The surface area of relevés was generally the site area, except for the largest habitats, where the phytosociological relevés were carried out on a minimum area. To cover the entire garâa and the diversity of its habitats, we identified homogeneous units by photo-interpretation of Google Earth satellite imagery, and carried out at least one relevé per unit.

Plants were identified according to Cuénod (1954) and Pottier-Alapetite (1979-1981), and plant nomenclature follows Le Floc'h *et al.* (2010). For each species, the life cycle (perennial, annual), rarity in Tunisia (Cuénod, 1954; Pottier-Alapetite, 1979-1981; Ghrabi-Gammar *et al.*, 2009), conservation status according to the IUCN Red List for freshwater biodiversity in North Africa (García *et al.*, 2010), and ecology were considered. For the last point, we distinguish among hydrophytes (aquatic, amphibious and helophytes), and opportunists (terrestrial) species (Médail *et al.*, 1998; Grillas *et al.*, 2004).

DATA ANALYSIS

A Correspondence Analysis (CA) and an Ascendant Hierarchical Classification (AHC), based on the Chord distance, were performed on the abundance coefficients of the phytosociological relevés. Taxa with fewer than 3 occurrences were eliminated because of their disproportionate influence on the analyses. Discrimination between types of habitats was performed by Monte Carlo test (1000 permutations). CA, AHC, and Monte Carlo tests were carried using PAST software (Paleontological Statistics; Hammer *et al.*, 2001).

A *Species Rarity Index* (SRI) was calculated for each habitat, by (1) giving each hydrophytic species a numerical value according to its distribution and conservation status (1, common; 2, infrequent; 4, rare; 8, very rare or near threatened; 16, vulnerable; 32, critically endangered), (2) summing all values for each habitat, and (3) dividing this sum by the number of species (Nicolet *et al.*, 2004). Analyses of variance (ANOVA, one-way) were performed using PAST to compare the SRI, and the habitat richness of the total species, annual species, hydrophytes, patrimonial species (defined here as very rare, rare, infrequent or with a conservation value), and invasive species.

Garâa Sejenane vegetation was mapped using ArcGIS 9.3 (QGIS Development Team, 2013) using both multivariate analyses (AHC, CA) and GIS (http://goto.arcgisonline.com/maps/World_Imagery on 30/05/2009) and Google Earth

satellite images (29/06/2010; 07/02/2014; 09/11/2014). The multivariate analyses allowed us to identify the different types of habitats in the site. Units of similar appearance representing homogeneous surfaces of vegetation were delimited by photo-interpretation before being interpreted for plant communities on the basis of floristic data.

RESULTS

A total of 185 species, including 74 hydrophytes, have been recorded in Garâa Sejenane (Tab. I). Hydrophytes comprise 41 annual species (55.4 %) mostly related to temporary pools, and 33 perennial species, including several large helophytes.

TABLE I

Characteristics of 185 species inventoried in 55 sites in Garâa Sejenane

Taxon	**Code**	**Life cycle**	**Ecology**	**Rarity status in Tunisia**	**IUCN conservation status**
Agrostis pourretii Willd.	Agpo	P	H		
Agrostis stolonifera L.	Agst	P	O		
Alisma lanceolatum With.	Alla	P	H		
Alopecurus bulbosus Gouan	Albu	P	O		
Ammi majus L.	Amma	A	O		
Anagallis arvensis L.	Anar	A	O		
Anagallis monelli L.	Anmo	P	O		
Anethum graveolens L.	Angr	A	O		
Anthoxanthum odoratum L.	Anod	A	O		
Antinoria agrostidea (DC.) Parl.	Anag	A	H	R	LC
Aphanes floribunda (Murb.) Rothm.	Apfl	A	O		
Asphodelus ramosus L. subsp. *ramosus*	Asra	P	O		
Avena sativa L.	Avsa	A	O		
Bellardia trixago (L.) All.	Betr	A	O		
Bellis annua L.	Bean	A	O		
Bolboschoenus glaucus (Lam.) S.G. Smith	Bogl	P	H		
Borago officinalis L.	Boof	A	O		
Briza maxima L.	Brma	A	O		
Briza minor L.	Brmi	A	O		
Bromus erectus Huds. subsp. *erectus*	Brer	P	O		
Bromus hordeaceus L. subsp. *hordeaceus*	Brho	A	O		
Callitriche brutia Petagna	Cabr	A	H		LC
Callitriche obtusangula Le Gall	Caob	A	H		LC
Carex divisa Huds. subsp. *chaetophylla* (Steud.) Nyman	Cadi	P	H		LC
Carlina corymbosa L. subsp. *corymbosa*	Caco	A	O		
Carthamus lanatus L.	Cala	A	O		
Centaurea calcitrapa L.	Ceca	A	O		
Centaurea solstitialis L.	Ceso	A	O		
Centaurium maritimum (L.) Fritsch	Cema	A	O		
Cerastium glomeratum Thuill.	Cegl	A	O		
Chamaemelum fuscatum (Brot.) Vasc.	Chfu	A	H		
Chara braunii S.G.Gmel.	Chbr	A	H	RR	
Chara connivens Salzmann ex A. Braun	Chco	A	H	RR	
Chara oedophylla G. Feldm.	Choe	A	H	RR	
Chara vulgaris L.	Chvu	A	H		
Chrysanthemum coronarium L.	Chco	A	O		
Cichorium intybus L.	Ciin	P	O		
Coleostephus myconis (L.) Cass. ex Rchb. f.	Comy	A	O		
Convolvulus althaeoides L.	Coal	P	O		
Convolvulus arvensis L.	Coar	P	O		
Convolvulus tricolor L.	Cotr	A	O		
Coronopus squamatus (Forssk.) Asch.	Cosq	A	O		LC
Corrigiola litoralis L.	Coli	A	H		LC

Cotula coronopifolia L.	Coco	A	H	Introduced	
Crassula decumbens Thunb.	Crde	A	H	Introduced	
Crassula helmsii Cockayne	Crhe	A	H	Introduced	
Crassula tillaea Lest.-Garl.	Crti	A	O		
Crassula vaillantii (Willd.) Roth.	Crva	A	H	RR	NT
Cressa cretica L.	Crcr	P	H		
Crypsis schoenoides (L.) Lam.	Crsc	A	H	R	LC
Cuscuta epithymum L.	Cuep	A	O		
Cuscuta planiflora Ten. subsp. *planiflora*	Cupl	A	O		
Cynodon dactylon (L.) Pers.	Cyda	P	O		
Cyperus longus L. subsp. *badius* (Desf.) Bonnier & Layens	Cylo	P	H		LC
Damasonium bourgaei Coss.	Dabo	A	H	IF	NT
Echium plantagineum L.	Ecpl	A	O		
Elatine macropoda Guss.	Elma	A	H	R	NT
Eleocharis multicaulis (Sm.) Desv.	Elmu	P	H	RR	NT
Eleocharis palustris (L.) Roem. & Schult.	Elpa	P	H		LC
Erodium cicutarium (L.) L'Hér.	Erci	A	O		
Eryngium pusillum L.	Erpu	P	H		LC
Euphorbia akenocarpa Guss.	Euak	A	O	IF	
Euphorbia exigua L.	Euex	A	O		
Euphorbia terracina L.	Eute	P	O		
Filago germanica (L.) Huds.	Fige	A	O		
Filago pygmaea L.	Fipy	A	O		
Galactites tomentosa Moench	Gato	A	O		
Galium murale (L.) All.	Gamu	A	O		
Gaudinia fragilis (L.) P. Beauv.	Gafr	A	O		
Geranium dissectum L.	Gedi	A	O		
Gladiolus byzantinus Mill.	Glby	P	O		
Glyceria notata Chevall.	Glno	P	H		LC
Glyceria spicata (Biv.) Guss.	Glsp	P	H	R	LC
Hedypnois rhagadioloides (L.) F.W. Schmidt.	Herh	A	O		
Hedysarum coronarium L.	Heco	P	O		
Heliotropium supinum L.	Hesu	A	H	IF	
Helminthotheca echioides (L.) Holub	Heec	A	O		
Helosciadium crassipes W.D.J. Koch ex Rchb.	Hecr	A	H	IF	
Hordeum murinum L.	Homu	P	O		
Hypochaeris achyrophorus L.	Hyac	A	O		
Hypochaeris radicata L.	Hyra	P	O		
Illecebrum verticillatum L.	Ilve	A	H	IF	LC
Isoetes duriei Bory	Isdu	P	H	RR	
Isoetes histrix Bory	Ishi	P	H		LC
Isoetes velata A.Braun	Isve	P	H	R	LC
Isolepis cernua (Vahl.) Roemer & Schultes	Isce	A	H		LC
Juncus acutus L.	Juac	P	H		LC
Juncus bufonius L.	Jubu	A	H		
Juncus capitatus Weigel	Juca	A	H		LC
Juncus heterophyllus Dufour	Juhe	P	H		NT
Juncus pygmaeus Rich. ex Thuill.	Jupy	A	H	R	LC
Juncus tenageia Ehrh. ex L. f.	Jute	A	H		LC
Kickxia commutata (Reichenb.) Fritsch	Kico	P	O		
Krubera peregrina (L.) Hoffm.	Krpe	A	O		
Lathyrus ochrus (L.) DC.	Laoc	A	O		
Lavatera cretica L.	Lacr	A	O		
Linum usitatissimum L.	Lius	A	O		
Logfia gallica (L.) Coss. & Germ.	Loga	A	O		
Lolium multiflorum Lam.	Lomu	A	O		
Lolium perenne L.	Lope	P	O		
Lolium rigidum Gaudin	Lori	A	O		
Lotus angustissimus L.	Loan	A	H		
Lotus conimbricensis Brot.	Loco	A	H	R	
Lotus hispidus Desf. ex DC.	Lohi	A	H		
Lythrum borysthenicum (Schrank) Litv.	Lybo	A	H	R	LC

Lythrum hyssopifolia L.	Lyhy	A	H		LC
Lythrum junceum Banks & Sol.	Lyju	P	H		LC
Lythrum tribracteatum Salzm. ex Spreng.	Lytr	A	H		LC
Medicago polymorpha L.	Mepo	A	O		
Melilotus indicus (L.) All.	Mein	A	O		
Melilotus sulcatus Desf.	Mesu	A	O		
Mentha pulegium L.	Mepu	P	H		LC
Mibora minima (L.) Desv.	Mimi	A	H	RR	
Myosotis sicula Guss.	Mysi	A	H	R	
Nasturtium officinale R.Br.	Naof	P	H		
Nitella opaca (C.Agardh ex Bruzelius) C.Agardh	Niop	A	H	IF	
Oenanthe fistulosa L.	Oefi	P	H	IF	LC
Oenanthe globulosa L.	Oegl	P	H		LC
Oenanthe silaifolia M. Bieb.	Oesi	P	H		LC
Oenanthe virgata Poir.	Oevi	P	H		
Ononis alba Poir. subsp. *alba*	Onal	A	O		
Ornithopus compressus L.	Orco	A	O		
Parentucellia viscosa (L.) Caruel	Pavi	A	O		
Paronychia echinulata Chater	Paec	A	O		
Persicaria amphibia (L.) Gray	Peam	P	H	RR	VU
Persicaria salicifolia (Willd.)	Pesa	P	H		LC
Petrorhagia prolifera (L.) P.W. Ball & Heywood	Pepr	A	O		
Phalaris aquatica L.	Phau	P	O		
Phragmites australis (Cav.) ex Steud.	Phau	P	H		LC
Pilularia minuta Durieu	Pimi	A	H	RR	CR
Plantago afra L.	Plaf	P	O		
Plantago coronopus L.	Plco	A	O		
Plantago crassifolia Forssk.	Plcr	A	O		
Plantago lagopus L.	Pllag	A	O		
Plantago lanceolata L.	Pllan	P	O		
Poa annua L.	Poan	A	O		
Poa bulbosa L.	Pobu	P	O		
Polycarpon tetraphyllum (L.) L.	Pote	A	O		
Polygonum aviculare L.	Poav	A	O		
Polypogon monspeliensis (L.) Desf.	Pomo	A	O		LC
Pulicaria arabica (L.) Cass.	Puar	P	H		LC
Pulicaria sicula (L.) Moris	Pusi	A	O		
Ranunculus baudotii Godr.	Raba	A	H		
Ranunculus ficaria L.	Rafi	P	O		LC
Ranunculus ophioglossifolius Vill.	Raop	A	H	RR	LC
Ranunculus sardous Crantz.	Rasa	A	H		LC
Rapistrum rugosum (L.) All.	Raru	A	O		
Rumex bucephalophorus L.	Rubu	A	O		
Rumex conglomeratus Murray	Ruco	P	H		LC
Rumex crispus L.	Rucr	P	O		LC
Rumex pulcher L.	Rupu	P	O		LC
Rumex tunetanus Barratte & Murb.	Rutu	P	H	RR	CR
Sagina apetala Ard.	Saap	A	O		
Schenkia spicata (L.) Mansion	Scsp	A	H		
Schoenoplectus lacustris (L.) Palla	Scla	P	H		LC
Scilla autumnalis L.	Scmu	P	O		
Scorpiurus muricatus L.	Scve	A	O		
Scorpiurus vermiculatus L.	Shar	A	O		
Sherardia arvensis L.	Siga	A	O		
Silene gallica L.	Sila	A	O		
Silene laeta (Aiton) Godr.	Situ	A	H		
Silene tunetana Murb.	Siar	A	O		
Sinapis arvensis L.	Sola	A	O		
Solenopsis laurentia (L.) C.Presl.	Spbo	A	H		LC
Spergularia bocconi (Scheele) Graebn.	Sthi	A	O		
Stachys hirta L.	Taga	A	O		
Tamarix gallica L.	Toba	P	O		

Tolpis barbata (L.) Gartn.	Tran	A	O		
Trifolium angustifolium L. subsp. *angustifolium*	Trca	A	O		
Trifolium campestre Schreb.	Trcu	A	O		
Trifolium filiforme L.	Trfi	A	O		
Trifolium nigrescens Viv.	Trni	A	O		
Trifolium pratense L.	Trpr	P	O		
Trifolium resupinatum L.	Trre	A	O		
Trifolium subterraneum L.	Trsub	A	O		
Trifolium suffocatum L.	Trsuf	A	O		
Trifolium tomentosum L.	Trto	A	O		
Triglochin laxiflorum Guss.	Trla	P	H		
Typha domingensis (Pers.) Poir. Ex Steud.	Tydo	P	H		
Valerianella discoidea (L.) Loisel.	Vadi	A	O		
Veronica anagallis-aquatica L.	Veana	P	H		LC
Veronica anagalloides Guss.	Vean	A	H		LC
Vicia lutea L.	Vilu	A	O		
Vicia sativa L.	Visa	A	O		
Vulpia myuros (L.) C.C.Gmel	Vumy	A	O		

Life cycle: P, Perennial; A, Annual. Ecology: H, hydrophyte; O, opportunist species. Rarity status in Tunisia: RR, very rare; R, rare; IF, infrequent (cf. Maire, 1952-1987; Cuénod, 1954; Quézel & Santa, 1962-1963; Pottier-Alapetite, 1979-1981; Ghrabi-Gammar *et al.*, 2009). IUCN conservation status for North Africa: CR, critically endangered; VU, vulnerable; NT, near threatened; LC, least concern (cf. García *et al.*, 2010).

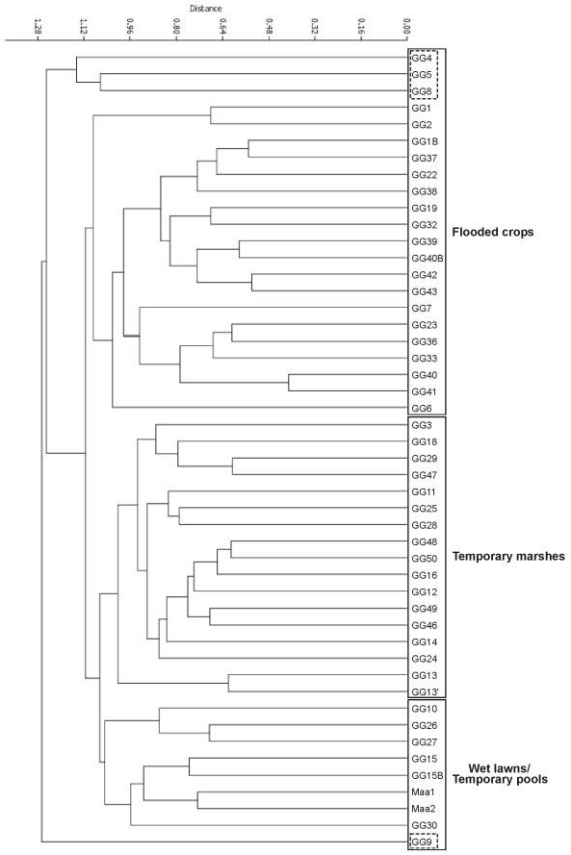

Figure 2.— Dendrogram obtained by AHC (Ascendant Hierarchical Classification) of the phytosociological relevés of 47 wetlands (Chord distance).

CHARACTERIZATION OF VEGETATION

Multivariate analyses (performed on 55 sites and 100 species) discern the drained driest areas occupied by fodder meadows with *Avena sativa*, *Bromus* spp., *Hordeum* spp., *Lolium* spp. and *Trifolium* spp., and reveal the strong influence of human activities that trigger the complete replacement of the natural hydrophytic vegetation with artificial herbaceous habitats. In order to focus on the natural wet habitats, the 8 phytosociological relevés corresponding to these dry meadows were excluded from the subsequent analyses (performed on 47 sites and 80 species). The AHC (Fig. 2) then distinguished 3 types of habitats: (1) temporary marshes, (2) flooded crops, and (3) a group including wet lawns and temporary pools. Temporary marshes covers relatively extended areas, and are dominated by helophytes about 1 meter high (*Bolboschoenus glaucus*, *Phragmites australis*, *Schoenoplectus lacustris*), which develop in spring in water ranging from 30 to 50 cm depth. Flooded crops are home to sparse low vegetation including *Coronopus squamatus*, *Crassula vaillantii*, *Damasonium bourgaei*, *Elatine macropoda*, *Lythrum tribracteatum*, *Pilularia minuta* and *Ranunculus ophioglossifolius*. Wet lawns that serve as grazing pastures for cattle and sheep have short vegetation primarily of *Isoetes histrix*, accompanied by *Bellis annua*, *Crassula tillaea*, *Juncus capitatus*, *J. pygmaeus* and *Rumex bucephalophorus*. They are scattered with small depressions occupied by temporary pools with *Isoetes velata*, *Eryngium pusillum*, *Lythrum borysthenicum* and *Myosotis sicula*.

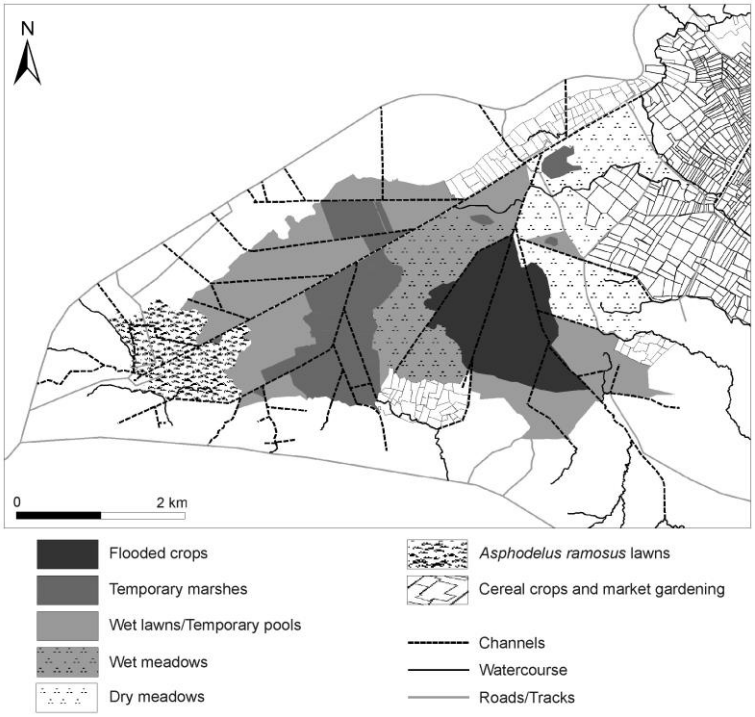

Figure 3.— Garâa Sejenane habitat mapping.

HABITAT MAPPING

Figure 3 maps the different habitats shown by the AHC. Flooded crops occupy the less drained soils in the central zone of the garâa, in the middle of which a small area harbors some individuals of *Persicaria amphibia*. This central zone is surrounded by wet fodder meadows and

temporary marshes, in turn bordered by wet lawns, temporary pools and dry fodder meadows. Some areas on the periphery of the garâa are cultivated for market gardening. The western extremity is the driest zone, invaded by stress-tolerant communities dominated by *Asphodelus ramosus* and *Scolymus hispanicus.* Strong human impact not with standing, the spatial organization of the vegetation of Garâa Sejenane in three concentric belts going from the central area flooded until early summer to the margins that are a transition zone between hydrophytic and meso-xerophytic habitats.

STRUCTURE AND COMPOSITION OF VEGETATION

Axis 1 (11.88 % of variance) of the CA (Fig. 4) opposes wet lawns/temporary pools and flooded crops, ranking sites based on their water depth and showing the preeminent role played by hydrology. Axis 2 (10.41 % of variance) isolates temporary marshes contrasting overgrazed (wet lawns and temporary pools) and cultivated (flooded crops) areas with weakly disturbed temporary marshes, showing the secondary importance of disturbances, already shown by Fig. 3. Discrimination between types of habitats is highly significant ($p < 0.0001$).

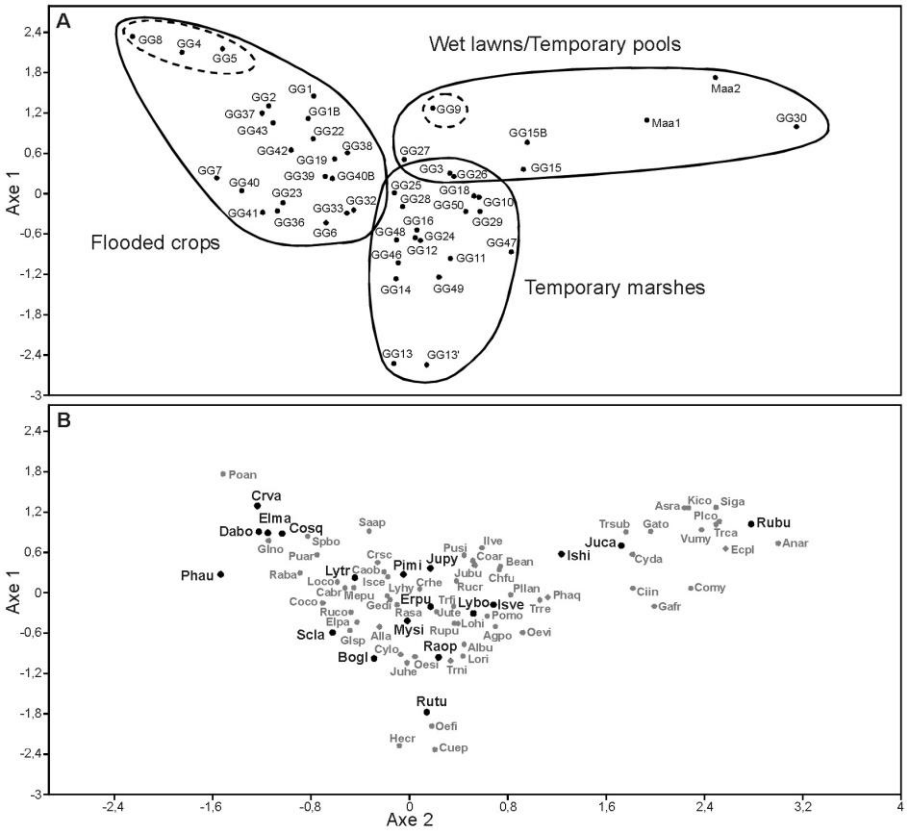

Figure 4.— Scatterplot of first two CA (Correspondence Analysis) axes of 47 phytosociological relevés of wetlands (A) with 80 species (B). *Notes*: Inertia percentages of axes 1 and 2 are 11.88 and 10.41 respectively. See Table I for signification of abbreviated species name.

We found 26 patrimonial, hydrophytic species (*i.e.* 35.1 % of the hydrophytes) of high conservation value for Tunisia, including 10 rare and 9 very rare species (Tab. I). Among these 26

species, 8 are included in the IUCN Red List of North Africa (García *et al.*, 2010): 2 are considered to be critically endangered (*Pilularia minuta*, *Rumex tunetanus*), 1 vulnerable (*Persicaria amphibia*) and 5 near threatened (*Crassula vaillantii*, *Damasonium bourgaei*, *Elatine macropoda*, *Eleocharis multicaulis*, *Juncus heterophyllus*).

TABLE II

Variance Analysis (1-way ANOVA) of Species Rarity Index and Mean species richness by habitat (FC, flooded crops; TM, temporary marshes; WL, wet lawns). Bold characters identify values significantly different from others

Habitat	FC	TM	WL	Garâa		
Species Rarity Index					*F*	*p*
	3.27	3.13	2.82	3.07	0.65	ns
Mean species richness						
Total species	18.55	19.76	**32.44**		7.69	**
Annual species	11.77	10.00	**22.22**		7.00	**
Hydrophytes	16.00	14.65	17.56		1.19	ns
Patrimonial species	4.55	4.41	5.56		1.00	ns
Invasive species	0.59	**0.18**	0.67		3.47	*

Note: * $p < 0.05$; ** $p < 0.005$; ns: not significant

Table II shows that wet lawns present significantly higher richness of total species and annual species than either flooded crops or temporary marshes and that invasive species colonize significantly more wet lawns and flooded crops than temporary marshes. However, the wealth of hydrophytes and patrimonial species does not vary significantly by type of habitat. Finally, the SRI, calculated for the different wetland habitats, is relatively similar for flooded crops, temporary marshes, wet lawns and across the garâa.

DISCUSSION

HYDROPHYTIC VEGETATION IN GARÂA SEJENANE

Almost all plant communities described by Ferchichi-Ben Jamaa *et al.* (2010) in the Mogods are present in Garâa Sejenane. Such diversity is clearly related to the heterogeneity of habitats, in particular to water depths and hydroperiods. The major role of hydrological factors is a well-known element of the ecology of Mediterranean temporary wetlands, typically including several concentric belts (Rhazi *et al.*, 2001; Winter & LaBaugh, 2003; Grillas *et al.*, 2004; Deil, 2005). The recent habitat mapping of Garâa Sejenane (Fig. 3) shows this zonal difference, and reveals its persistence over the last 65 years despite strong human disturbances. Indeed, Pottier-Alapetite & Labbe (1951) and Pottier-Alapetite (1958) described a vast helophytic marsh, surrounded by a 100-meter wide external belt of *Isoetes velata* and associated plants. This large concentric spatial structure has, to our knowledge, no equivalent in North Africa, or even, perhaps, in the western Mediterranean Basin. Similar areas in North Africa (*e.g.*, the Loukkos marshes near Morocco's Atlantic coast and the great lakes of northeastern Algeria) present far more homogeneous structures without extensive peripheral zones (Géhu *et al.*, 1993; Samraoui & de Bélair, 1997; Stevenson *et al.*, 1988; Bouldjedri *et al.*, 2011).

The 74 hydrophytes of Garâa Sejenane represent nearly 58 % of the species inventoried in the Mogods (Ferchichi-Ben Jamaa *et al.*, 2010). More than 1/3 of these have a patrimonial value. This exceptional richness was first noted by Gauthier-Lièvre (1931), and later by Pottier-Alapetite & Labbe (1951), Labbe (1953) and Pottier-Alapetite (1958), who emphasized the presence of some very rare species, including the Algero-Tunisian endemic *Armeria spinulosa*, and *Mibora minima*, *Myriophyllum alterniflorum*, *Oenanthe fistulosa*, *Nymphaea alba*, *Persicaria amphibia* and *Utricularia vulgaris*. Our study revealed some of these species and discovered four species that are

new to Tunisia: *Chara braunii*, *Crassula vaillantii*, *Nitella opaca* and *Pilularia minuta* (Daoud-Bouattour *et al.*, 2009; I. Soulié-Märsche & S.D. Muller, unpublished data).

THREATS

Four main types of disturbances were identified in Garâa Sejenane. The oldest one was the draining and fragmentation of the former lake (Fig. 3), which began in the 1960s and lead to the local disappearance of several rare species: *Alternanthera sessilis*, *Armeria spinulosa*, *Butomus umbellatus*, *Exaculum pusillum*, *Myriophyllum alterniflorum*, *Nymphaea alba* and *Utricularia vulgaris* (Gauthier-Lièvre, 1931; Labbe, 1953; Cuénod, 1954; Pottier-Alapetite, 1979-1981). Since the 1980s, it was possible to drain the central part of the garâa so as to extend agro-pastoral activities in the entire area, including farming (tobacco, peppers and melons), cattle grazing, mowing, and sheep grazing (Ferchichi-Ben Jamaa *et al.*, 2010). By creating very temporary wetlands at the periphery of the garâa, these hydrological changes certainly helped to favour pioneer and heliophilous amphibious communities (Daoud-Bouattour *et al.*, 2009, 2014).

Grazing, in the Maghreb, is known as a major control on the composition and structure of plant communities of wet temporary habitats, by compacting the soil, favoring the development of annual dwarf species (Bouahim *et al.*, 2010; Ferchichi-Ben Jamaa *et al.*, 2014), and reducing the wealth and abundance of species characteristic of temporary pools (Bouahim *et al.*, 2014). Our data suggest these effects by showing that wet lawns present significantly more annual species than the other types of habitats (Tab. II). The lesser competition induced by domestic herbivores could constitute a tool for the management and conservation of biodiversity, so as to maintain open areas favourable to the patrimonial therophytic communities of wetlands (Gordon *et al.*, 1990). At Garâa Sejenane, grazed fields do appear to contain significantly more species than temporary marshes and flooded crops (Tab. II; Ferchichi-Ben Jamaa *et al.*, 2014).

The third disturbance is the cultivation of areas flooded in winter. The current location of flooded crops and wet fodder meadows (Fig. 3) suggests that these agricultural activities have been developed at the expense of the helophytic marshes that covered the central part of the garâa, before the 60's (Pottier-Alapetite & Labbe, 1951; Pottier-Alapetite, 1958). This appears to be confirmed by the similar richness in total species and annual species of marshes and flooded crops (Tab. II) that share a number of species, but are distinguished by the higher impact of invasive species in the disturbed crops (Tab. II). However, cultivation strongly affects the structure of plant communities by reducing the coverage of the dominant helophytic species, disrupting seed bank (Devictor *et al.*, 2007) and creating water eutrophication (Rhazi *et al.*, 2001, 2006). However, as Bouahim *et al.* (2014) observed, some amphibious hydrophytes, such as *Crassula vaillantii*, *Damasonium bourgaei* or *Lythrum tribracteatum*, seem to benefit from these new conditions, probably because their pioneering ecological requirements made them more resilient to this particular disturbance.

Finally, three introduced species (*Cotula coronopifolia*, *Crassula helmsii*, *C. decumbens*) were observed in different habitats, but only the first two are known as having an invasive behaviour (Costa *et al.*, 2009; Le Floc'h *et al.*, 2010; Delbart *et al.*, 2011). The Garâa Sejenane, where we discovered *Crassula helmsii* in 2008, is to our knowledge the only site on the African continent where this species exists. It may have been introduced by the clover seeds imported from Australia in the 1970s (Jaritz & Schulke, 1972; Le Floc'h *et al.*, 2010). Yet despite the possible disruption of ecological equilibrium provoked by these invasive species, the richness of the patrimonial species remains significantly higher here than in temporary marshes (Tab. II).

CONSERVATION ISSUES

Patrimonial species (*i.e.* very rare, rare and infrequent) tend to be localized in the southern half of Garâa Sejenane (Fig. 5), where they occur in the three types of wetland habitats (wet lawns,

flooded crops and temporary marshes). Each houses several patrimonial species, more or less specific, lending them similar conservation values.

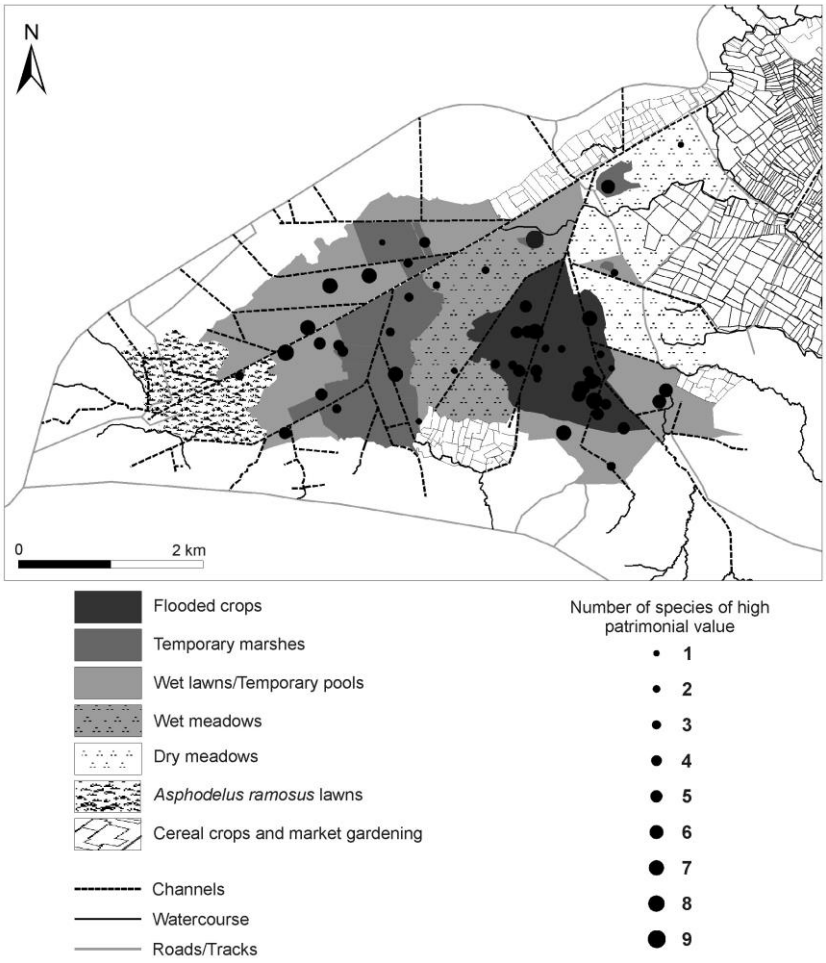

Figure 5.— Distribution of patrimonial species richness in Garâa Sejenane.

The calculated SRI are very high in comparison with the values obtained by Nicolet *et al.* (2004) for temporary pools in England and Wales (mean: 1.17 ± 0.29; maximum: 2.50). In addition, the garâa constitutes a priority for the preservation of certain species.

First, it hosts the world's sole population of *Rumex tunetanus*, which is divided into several subpopulations scattered among the temporary marshes in the northwest of the flooded plain. The largest subpopulation, comprising several hundred individuals with an approximate density of 150 plants/ha (Z. Ghrabi-Gammar, unpublished data), seems to be viable in the long term, but *in-situ* conservation measures are urgently needed. These should aim at sustaining the current uses of the area that appear compatible with the ecological requirements of *Rumex tunetanus*, and may involve a partnership with the landowner or the acquisition of the parcel by state services. It is also urgent to develop, through national and international organizations (botanical gardens, conservatories, universities, gene banks, etc.), an *ex-situ* cultivation program for this highly threatened plant endemic to Tunisia.

Garâa Sejenane is the sole Tunisian locality where several rare or very rare species exist on such a scale: *Chara braunii*, *C. connivens*, *C. oedophylla*, *Crassula vaillantii*, *Mibora minima* and *Persicaria amphibia*. *P. amphibia* is undoubtedly the most endangered species of the area. Its population has been reduced to a few individuals located in the central part of the garâa, in the deepest flooded crops. The conservation of this species, classified as vulnerable throughout North Africa according to IUCN criteria (García *et al.*, 2010) and threatened by extinction in the short term in Tunisia, requires that protective measures be urgently undertaken in collaboration with landowners and local authorities.

The three species of Characeae were collected in artificial and disturbed habitats: *Chara braunii* in flooded crops fits with the known ecology of the species in other Mediterranean countries, where it develops mainly in cultivated wetlands (Mouronval *et al.*, 2015); *C. connivens* and *C. oedophylla* occur in drainage ditches and pits dug along side paths. If the two first species are typical of this kind of environment in the Mediterranean region, *C. oedophylla* is much rarer: it was found only once in Tunisia, in Wadi Tinja (near Bizerte), by L. Gauthier in 1923, a collection later used by Feldmann (1946) to describe the species that is occasionally considered to be a variety of the cosmopolitan species *C. vulgaris* (*e.g.*, Mouronval *et al.*, 2015). Outside northern Tunisia, *C. oedophylla* is presently known only in a few localities in Spain and in southern France (Comelles, 1981; Soulié-Märsche, 2003; Cirujano *et al.*, 2007).

Mibora minima reaches the eastern limits of its African distribution in Sejenane, and was observed recently only once on the southern edge of the garâa. This apparent rarity could be due to its vernal phenology, which makes it difficult to find during fieldtrips that usually took place in April or May, when wetland communities reach their optimal development. *Crassula vaillantii* has only been found in flooded crops, where it develops in very open areas with *Damasonium bourgaei*, *Elatine macropoda*, *Heliotropium supinum*, *Lythrum tribracteatum* and *Ranunculus ophioglossifolius*. Although very localized in the garâa, this dwarf annual species presents several relatively abundant populations.

Finally, two other species of Garâa Sejenane present a high conservation value: *Pilularia minuta* and *Elatine macropoda* are respectively classified on the IUCN Red List as Critically Endangered and Near Threatened at the scale of North Africa (García *et al.*, 2010). In Tunisia, both species are only found in one other site (Majen el Ma, Kroumiria; Pottier-Alapetite, 1979-1981; Daoud-Bouattour *et al.*, 2009). The size of their populations at Sejenane clearly makes the garâa a priority for preservation in the Mediterranean (Daoud-Bouattour *et al.*, 2009).

CONCLUSION

The biodiversity of Garâa Sejenane is comparable to that in the great emblematic wetlands of North Africa, such as the Lake Sidi Bou Rhaba (Flower, 2001; Ramdani *et al.*, 2001; Rhazi *et al.*, unpublished data) and the marshes of Loukkos (Bennig, 2004) in Morocco, Beni-Belaid Lake (Bouldjedri *et al.*, 2011), the wetland complex of Guerbès-Senhadja (Samraoui & de Bélair, 1997) and El Kala National Park (Stevenson *et al.*, 1998) in Algeria, and Lake Majen Chitane in Tunisia (Pottier-Alapetite & Labbe, 1951; Daoud-Bouattour *et al.*, 2011). However, unlike these protected sites (Ramsar, nature reserve, national park, etc.), Garâa Sejenane is totally ignored by authorities and environmental organizations. This can be attributed to a lack of scientific knowledge and the economic interest of the area for local populations.

While highly disturbed, the garâa still displays a singular zonal structure for an environment of this size. Each of its three concentric belts has distinct plant communities: wet lawns, temporary pools and dry fodder meadows in the external belt; temporary marshes and wet fodder meadows in the intermediate belt, and flooded crops in the centre. With the exception of fodder meadows, the

other habitats all present exceptional conservation values, integrating both a great wealth of patrimonial species (26 very rare, rare and infrequent) and extremely rare species with special conservation issue (1 strict endemic, 5 species for which the garâa is the only Tunisian locality, and 2 species constituting their largest North-African populations). Contrary to what is observed for the temporary pools of Morocco (Rhazi *et al.*, 2001, 2006 ; Bouahim *et al.*, 2010, 2014), the extensive human activities in Garâa Sejenane seem compatible with the conservation of habitats and species of patrimonial value. Such conservation can be sustainable only if agro-pastoral practices are rationally managed, which means that local populations and authorities must ensure the maintenance of extensive and traditional usage.

Land users must be aware of the interest and fragility of the concerned habitats as a necessary precondition for the implementation of targeted protective measures (Bouahim *et al.*, 2015). In Garâa Sejenane, these should include (1) the protection of areas including populations of species where conservation issues are most critical (*Rumex tunetanus*, *Persicaria amphibia*); and (2) the establishment of management agreements with landowners and/or users, defining modalities of use that are compatible with the maintenance of target species and likely to elicit financial compensation for induced losses. Both types of measures could, if necessary, be accompanied by the government's acquisition of some plots to control the various anthropogenic and natural factors and favour the most threatened plant communities. While the situation today in Tunisia does not favour the implementation of an ambitious management policy, minimal management measures are urgently needed to ensure the protection of the most threatened species.

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