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Assessment of species diversity and state of *Stipa tenacissima* steppes

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Abstract: North African steppes are subjected to extreme degradation resulting in the reduction of their surface, genetic erosion of resources, and decrease in biodiversity. *Stipa tenacissima* steppes, which constitute one of the most representative vegetation types in the driest areas of the Mediterranean basin, are continuously degrading. With the aim of contributing to a better knowledge of the floristic composition and diagnosing the state of degradation of these steppes, we conducted a phytoecological analysis of 10 *S. tenacissima* sites in Tunisia. Floristic inventory compiled a systematic list of 46 vascular plant species belonging to 43 genera and 26 families. Species richness ranged from 4 to 18 species per 900 m^2. Total vegetation cover was moderate and fluctuated between 22.8% and 49.9%. Our results revealed also a decreasing trend in species richness with increasing elevation ($\rho = -0.585$). Indeed, species richness was negatively correlated with slope ($\rho = -0.19$) and positively correlated with sand content ($\rho = 0.262$). Biological types were dominated by chamaephytes; this chamaephytization is due to the phenomenon of aridization and overgrazing. Moreover, the low species cover and the appearance of nonpalatable species highlighted the vulnerability of these steppes to degradation.

Key words: Flora, *Stipa tenacissima* steppes, biodiversity, Tunisia, degradation, North Africa

1. Introduction

Biodiversity is rapidly declining all over the world. In fact, thousands of plant species are endangered and even threatened by extinction with the current trend of their exploitation and eradication (Butchart et al., 2010). The continuous decline of biodiversity over time has a dramatic effect on the functioning of ecosystems. The major causes of biodiversity decline include the loss of habitats, land clearing, overharvesting of biodiversity resources, the introduction of exotic species, and climate change. Thus, proper assessment of species diversity in an area is important for examining many relevant questions in ecology and for the development of management actions for conserving biodiversity (Engen et al., 2008).

North Africa is characterized by fragile zones generally subject to desertification, being estimated at about 121×10^6 ha threatened (Bounejmate et al., 2004). Among these fragile zones, steppe ecosystems are subjected to a strong tendency to degradation resulting in reduced biological potential and disruption of ecological and socioeconomic equilibrium, which leads to severe erosion of biodiversity and soil.

Stipa tenacissima steppes constitute one of the most representative vegetation types in the driest areas of the Mediterranean Basin, covering over 2.8×10^6 ha and resulting from the degradation of shrublands and Mediterranean open forests in Southwest Europe and North Africa, respectively (Le Houérou, 2001), by human activities such as grazing, harvesting, and repeated burning, which have been occurring in these steppes for millennia (Barber et al., 1997). For example, overgrazing has provoked changes in species composition and richness, and productivity has changed over the past decades (Wang et al., 2002). Indeed, grazing can influence structure and organization of plant communities in different ways (Noy-Meir et al., 1989). The impact of overgrazing is expressed by the rarefaction and even the disappearance of some useful plant species with high forage value, and the abundance and even the dominance of a few palatable species and the development of unpalatable species.

Stipa tenacissima steppes are mostly distributed in North Africa from Libya to Morocco and they occur between the 100–400 mm isohyets. These steppes have long been subjected to unsustainable exploitation, which led to their regression. Thus, this landscape has now declined by about 50% (Bounejmate et al., 2004). In central Tunisia, Ghrab (1981) estimated that for 60 years the Alfa steppes regressed 1% on average per year.

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With the aim of contributing to a better knowledge of the composition and structure of *Stipa tenacissima* steppes in Tunisia, we established floristic inventory data from 10 Alfa sites along an environmental gradient from central to southern Tunisia. We also discuss the degradation state and the changes in the floristic composition occurring in *Stipa tenacissima* steppes in North Africa.

2. Materials and methods

2.1. Study sites

Field investigation was conducted at 10 *Stipa tenacissima* sites located on south-facing slopes along a rainfall gradient in Tunisia from 6 governorates, Kasserine, Kairouan, Sidi Bouzid, Sfax, Gabès and Tataouine (Table 1). The sites surveyed encompass a wide range of human uses. The climate of the study areas is Mediterranean arid, with average annual precipitation ranging from 141 to 355 mm and an aridity index ranging from 0.09 to 0.3 (Table 1).

2.2. Vegetation sampling protocol

We sampled vegetation using a stratified random procedure as described by Maestre et al. (2012). Within each site, we established a plot of 900 m^2 (30 m × 30 m) representative of the vegetation present in that area and starting on the upper edge of the hill slope. Plots were established in areas with sparse vegetation containing plant patches and bare ground areas. In the upper left corner of the plot, we located a 30-m-long transect downslope. Three parallel transects of the same length (30 m), each 8 m apart across the slope, were added. In each transect we placed 20 consecutive quadrats (1.5 m × 1.5 m). Eighty quadrats were sampled per site. After recording all the names of the perennial plant species in quadrats, we measured the coverage of the population of each species. Species cover estimates were obtained by averaging the values registered in the 80 quadrats sampled in each site.

We did not include annual plants as they showed a high degree of intra- and interannual variability (Pake and Venable, 1996). We thus limited the study to perennial plants, which are instrumental in maintaining ecosystem functioning and preventing desertification in dry lands (Maestre et al., 2012).

2.3. Data analysis

Sand content was determined as described by Maestre et al. (2012). Species richness was calculated as the total number of species present at each site. Species cover estimates were obtained by averaging the values registered in the 80 quadrats sampled at each site. The sum of all species cover estimated the total vegetation cover in each plot.

Table 1. Main characteristics of the experimental sites.

Site location	Plot names	UTM coordinates	Elevation (m) [a]	Slope (°) [a]	Soil type [a]	Texture [a]	Sand content (%) [a]	Annual mean precipitation (mm)	Aridity index [a]
Bouhedma	P1	34°29′39″N, 9°38′49″E	172	4	Lithosols	Sandy loam	62.087	177	0.125
Chaambi	P2	35°10′03″N, 8°40′25″E	934	5	Calcic Cambisols	Sandy loam	56.713	355	0.261
Matmata	P3	33°31′17″N, 9°58′27″E	473	22	Lithosols	Sandy loam	65.873	221	0.160
Sbeitla	P4	35°09′36″N, 9°06′59″E	598	4	Haplic Xerosols	Sandy loam	59.808	274	0.194
Sidi Bouzid	P5	34°57′23″N, 9°43′04″E	447	18	Lithosols	Sandy loam	58.93	233	0.168
Tataouine	P6	32°59′00″N, 10°29′54″E	235	1	Lithosols	Loamy sand	81.167	141	0.096
El Gonna	P7	34°41′66″N, 10°30′22″E	104	3	Haplic Xerosols	Sandy loam	59.196	191	0.161
Gabès	P8	33°45.56″N, 10°01.69″E	94	1.5	Gipsy Yermosols	Sandy loam	69.144	171	0.131
Haffouz	P9	35°38′01″N, 09°41′27″E	288	2	Calcic Cambisols	Sandy loam	74.515	314	0.218
Jbel Halfa	P10	35°58′91″N, 10°29′88″E	221	1.5	Calcic Cambisols	Sandy loam	54.756	322	0.298

[a] Data come from Maestre et al. (2012).

We referred to Raunkiaer biological types (Raunkiaer, 1937) to establish the life form types of the plant species inventoried at the different experimental sites.

To quantify diversity, we used the Shannon diversity index (H') and the Simpson diversity index (D). We used the Hill diversity index (H) to assess multilateral species diversity and the Pielou index (J) to measure evenness.

The Shannon diversity index is sensitive to the diversity of common species (Weaver and Shannon, 1949); a higher value of H' indicates higher diversity (Kent and Coker, 1992): $H' = -\Sigma pi \text{ Ln } pi$, where pi is the relative abundance of species i within the community.

The Simpson index (D) measures the probability that 2 individuals randomly selected from an area will belong to the same species. It is sensitive to the diversity of dominant species (Simpson, 1949). The formula for calculating D is:

$D = 1 - \Sigma pi^2$, $pi = Ni/N$, where Ni is the abundance of the *i*th species in the sample and N is the total number of individuals.

We also used the Hill diversity index (H) (Hill, 1973) as a measure of the proportional abundance for associating the indices of Shannon and Weaver and Simpson: $H = (1/D)/e^{H'}$.

To measure evenness, we used the Pielou index (J): $J = H'/\text{Ln } S$; here, S denotes the total number of species (Pielou, 1969). The higher the value of J is, the more even the species are in their distribution within the treatment (Kent and Coker, 1992).

We used the Jaccard index, S_J (Jaccard, 1908), to assess degree of similarity between pairs of 900-m^2 plots based on the presence/absence species:

$S_J = a/(a + b + c)$,

where a is the number of species shared by plots, b is the number of distinct species in the first plot, and c is the number of distinct species in the second plot.

We consider plots with low similarity index (sharing few species) as ecologically distant and plots with high similarity index (sharing many species) as ecologically similar.

2.4. Statistical analysis

We used SPSS 17 for statistical analyses. Because most of the variables were nonnormally distributed, we conducted correlation analyses using the Spearman correlation coefficient (ρ) to analyze the relationship between species richness and abiotic parameters (elevation, slope, and sand content).

We applied multiple correspondence analysis (MCA) for comparisons between the 10 plots surveyed in terms of plant composition based on the absence/presence of species.

3. Results

Through the different floristic surveys, we identified 46 perennial vascular plants species belonging to 43 genera and 26 botanical families (Table 2). We detected nonpalatable indicator species of grazing such as *Atractylis serratuloides* in Matmata, Sidi Bouzid, Tataouine, El Gonna, and Gabès; *Lygeum spartum* in El Gonna and Gabès; *Astragalus armatus* in Gabès, Haffouz, and Jbel Halfa; and *Hammada scoparia* in Bouhedma.

Furthermore, the flora was characterized by the dominance of taxa belonging to the families Poaceae and Asteraceae (10.87%), followed by Cistaceae and Fabaceae (8.7%) and Lamiaceae (6.52%). Several other families were also present but at levels that remained low.

Biological types were dominated by chamaephytes, which ranged from 11.11% to 83.33%, followed by hemicryptophytes, which fluctuated between 11.11% and 44.44% (Figure 1).

Species richness, evenness, and diversity indices at the different experimental sites are given in Table 3. Species richness ranged from 4 to 18 species per 900 m^2; the lowest species richness was measured in Chaambi and the highest was measured in Gabès. Meanwhile, the lowest species evenness J and diversity index H' were measured in Sidi Bouzid. Hill index ranged from 0.66 in Sbeitla to 0.94 in Tataouine. Species richness was highly and significantly correlated with both Shannon index ($\rho = 0.982$, $P < 0.001$) and Simpson index ($\rho = -0.896$, $P < 0.001$).

On the other hand, species richness was negatively correlated with elevation ($\rho = -0.585$, $P = 0.075$). In fact, the highest value of species richness was recorded at the lowest elevation of 94 m, while the lowest species richness was recorded at 447 m. Moreover, species richness was negatively correlated with slope ($\rho = -0.19$, $P = 0.599$) and positively correlated with sand content ($\rho = 0.262$, $P = 0.464$).

The ratio of coverage of each species presented in the study areas is shown in Table 4. We noted a low species vegetation cover of almost all species (cover of <1%). Plant species with high cover were considered as dominant species. *Stipa tenacissima* had the highest rate of coverage, which ranged from 10.7% in Bouhedma to 40.8% in Sbeitla. The secondary dominant species were *Artemisia herba alba* in Chaambi, Tataouine, and Gabès; *Gymnocarpos decander* in Matmata and Tataouine; and *Rosmarinus officinalis* in Chaambi, Haffouz, and Jbel Halfa. Total vegetation cover was moderate and fluctuated between 22.7% and 49.9%.

The Jaccard index (Table 5) values demonstrated the high degree of dissimilarity between the surveyed sites, excluding plots 9 (Haffouz) and 10 (Jbel Halfa), which had Jaccard index of 0.54 and thus appeared the closest ecologically as compared to the other sites, which shared few species and thus appeared ecologically distant.

Dimensions 1 and 2 of the MCA ordinations accounted for 24.5% and 17% of the total variation, respectively. The MCA comparing the 10 plots surveyed based on

Table 2. Systematic list of plant species inventoried (+ existent species, - absent species). Note: Ch = chamaephytes, Th = therophytes, He = hemicryptophytes), Ph = phanerophytes), Nph = nanophanerophytes.

Species	Family	Life form type	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Pinus halepensis	Pinaceae	Ph	-	+	-	-	-	-	+	-	+	+
Gymnocarpos decander	Caryophyllaceae	Ch	-	-	+	-	-	+	+	+	-	-
Stipa tenacissima	Poaceae	He	+	+	+	+	+	+	+	+	+	+
Hammada schmittiana	Chenopodiaceae	Ch	+	-	-	-	-	+	+	-	-	-
Helianthemum sessiliflorum	Cistaceae	Ch	+	-	-	+	-	-	+	-	-	-
Artemisia herba alba	Asteraceae	Ch	-	+	-	-	+	+	+	+	-	-
Atractylis serratuloides	Asteraceae	Ch	-	-	+	-	+	+	+	+	-	-
Asparagus stipularis	Asparagaceae	Ch	-	-	-	-	-	-	+	+	+	+
Ononis natrix	Fabaceae	Ch	-	-	-	-	-	-	+	-	-	-
Lygeum spartum	Poaceae	He	-	-	-	-	-	-	+	+	-	-
Retama retam	Fabaceae	NPh	-	-	-	-	-	-	+	-	-	-
Erodium arborescens	Geraniaceae	Ch	-	-	-	-	-	-	+	-	-	-
Hammada scoparia	Chenopodiaceae	Ch	+	-	-	-	-	-	+	-	-	-
Lavandula augustifolia	Lamiaceae	Ch	-	-	-	-	-	-	+	-	+	+
Thymelia hirsuta	Thymelaeceae	Ch	-	-	+	+	+	-	+	-		-
Asteriscus pygmaeus	Asteraceae	Th	+	-	+	-	-	-	+	+	+	-
Echiochilon fruticosum	Boraginaceae	Ch	-	-	-	-	-	-	+	-	-	-
Digitaria commutata	Poaceae	He	+	-	-	-	-	-	-	-	-	-
Stipagrostis ciliata	Poaceae	He	+	+	+	-	-	-	-	-	+	-
Cenchrus ciliaris	Poaceae	H	+	-	-	-	-	-	-	-	-	-
Halimium halimifolium	Cistaceae	Ch	+	-	-	-	-	-	-	-	-	-
Acacia tortilis	Fabaceae	Ph	+	-	-	-	-	-	-	-	-	-
Sedum sediforme	Crassulaceae	He	-	+	-	+	-	-	-	-	-	-
Rosmarinus officinalis	Lamiaceae	NPh	-	+	+	+	-	-	-	-	+	+
Opuntia sp.	Cactaceae	NPh	-	+	-	-	-	-	-	-	-	-
Plantago albicans	Plantaginaceae	He	-	+	-	-	-	-	-	-	-	-
Anacyclus cyrtolepidoides	Asteraceae	Th	-	+	-	-	-	-	-	+	+	+
Fagonia cretica	Zygophyllaceae	Th	-	-	-	-	-	-	-	+	-	-
Reaumuria vermiculata	Tamaricaceae	Ch	-	-	-	-	-	-	-	+	-	-
Salsola kali	Chenopodiaceae	Ch	-	-	-	-	-	-	-	+	-	-
Anabasis articulata	Chenopodiaceae	Ch	-	-	-	-	-	-	-	+	-	-
Kickxia aegyptiaca	Scrophulariaceae	Ch	-	-	-	-	-	-	-	+	-	-
Astragalus armatus	Fabaceae	Ch	-	-	-	-	-	-	-	+	+	+
Polygonum maritimum	Polygonaceae	Ch	-	-	-	-	-	-	-	+	-	-
Deverra scoparia	Apiaceae	Ch	-	-	-	-	-	-	-	+	-	-
Echium arenarium	Boraginaceae	Th	-	-	-	-	-	-	-	+	-	-
Adonis vernalis	Ranunculaceae	Th	-	-	-	-	-	-	-	+	-	-
Rhus tripartia	Anacardiaceae	NPh	-	-	-	-	-	-	-	-	+	-
Periploca angustifolia	Asclepiadaceae	NPh	-	-	-	-	-	-	-	-	+	-
Helianthemum kahiricum	Cistaceae	Ch	-	-	+	-	-	+	-	-	-	-
Asteriscus ciliatus	Asteraceae	Th	-	-	+	-	-	-	-	-	-	-
Teucrim pollium	Lamiaceae	Ch	-	-	+	+	-	-	-	-	-	-
Fumana thymifolia	Cistaceae	Ch	-	-	-	+	-	-	-	-	-	-
Hernaria cinerea	Caryophyllaceae	He	-	-	-	+	-	-	-	-	-	-
Juniperus phoenicia	Cupressaceae	Ph	-	-	-	-	-	-	-	-	-	+
Globularia alypum	Globulariaceae	Ch	-	-	-	-	-	-	-	-	-	+

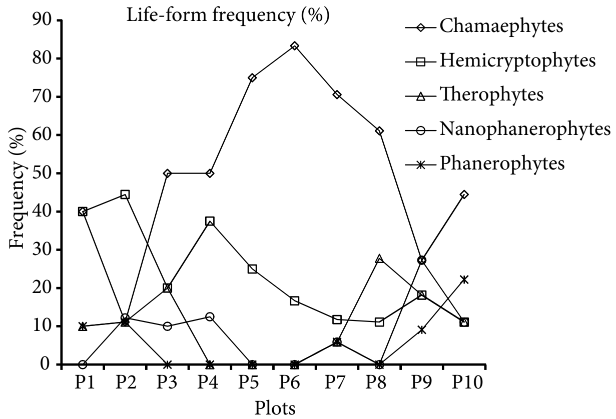

Figure 1. Life forms' percentage distribution for all data among the different experimental plots (%).

the absence/presence of species showed that these sites differed in terms of species composition (Figure 2) and so were inhabited by different assemblages of species.

4. Discussion

4.1. Biodiversity of *Stipa tenacissima* steppes: insights from Tunisian steppes

4.1.1. Effect of abiotic factors on species richness

The results of this research indicated that elevation, slope, and sand content had an influence on biodiversity and species richness. In fact, this study revealed a decreasing trend in species richness with increasing elevation along the studied plots. Similar results were found for decreasing species richness with elevation (Bachman et al., 2004; Jacquemyn et al., 2005). According to Rahbek (1995), there are 4 main trends in elevational species richness: a monotonic decline in species richness from low to high elevation, a hump-shaped pattern with a maximum at middle elevations, or essentially a constant from the lowlands to middle elevations, followed by a strong decline further upwards. The regionally observed patterns of species richness result from several interacting factors, such as geographical area, environmental variables, plant productivity, competition, historical or evolutional development, regional species dynamics, regional species pool, and human activity (Zobel, 1997; Criddle et al., 2003).

On the other hand, the negative correlation found between species richness and slope leads us to say that species richness decreases with increasing slope. In fact, it has been shown that soil on low slopes has more depth and greater fertility because of sediment accumulation compared to high-slope areas (Saeedi Goraghani et al., 2013). Indeed, competition in steep areas is lower due to lower depth, drainage, and more dryness (Noor Alhamad, 2006).

Furthermore, species richness showed a positive correlation with sand content. The pattern species richness-soil texture is still poorly studied as few studies have dealt with this issue. Saporetti-Junior et al. (2012) suggested that species richness will increase as fine sand percentage increases. Indeed, sandy soils having finer particles also have higher water retention rates than sandy soils with coarser particles (Mecke et al., 2002).

4.1.2. Floristic composition of Tunisian *Stipa tenacissima* steppes

The experimental sites have almost entirely different species compositions. In fact, almost all plots (excluding Haffouz and Jbel Halfa) shared few species and so appeared ecologically distant. We suppose that this was due to abiotic and biotic environmental differences.

Our results showed the dominance of chamaephytes in *Stipa tenacissima* steppes; this chamaephytization has its origin in the phenomenon of aridization (Floret et al., 1990). In fact, the highest percentage of chamaephytes was

Table 3. Species richness, evenness, and diversity indices.

Plots	Species richness	Shannon (H')	Simpson (D)	Pielou (J)	Hill (H)
P1	10	1.955	0.155	0.849	0.913
P2	9	1.642	0.234	0.747	0.827
P3	10	1.869	0.17	0.811	0.907
P4	8	1.422	0.366	0.684	0.658
P5	4	0.697	0.646	0.502	0.77
P6	6	1.549	0.226	0.864	0.939
P7	17	2.199	0.144	0.776	0.77
P8	18	2.248	0.134	0.777	0.788
P9	11	2.001	0.17	0.834	0.795
P10	9	1.727	0.228	0.786	0.779

Table 4. Mean ± standard error of species cover (%) at the different plots surveyed.

Species	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Pinus halepensis	-	1 ± 4.96	-	-	-	-	5.65 ± 18.86	-	1.56 ± 8.00	2.562 ± 13.69
Gymnocarpos decander	-	-	7 ± 6.83	-	-	7.7 ± 5.81	1.38 ± 2.19	0.82 ± 2.45	-	-
Stipa tenacissima	10.7 ± 12.46	32.68 ± 19.99	12.12 ± 12.13	40.81 ± 19.94	24.01 ± 8.53	11.45 ± 15.22	11.82 ± 20.57	17.18 ± 22.7	29.12 ± 39.03	19.037 ± 23.49
Hammada schmittiana	2,65 ± 4.62	-	-	-	-	1.32 ± 2.87	0.68 ± 1.64	-	-	-
Helianthemum sessiliflorum	3.85 ± 3.80	-	-	0.95 ± 2.307	-	-	0.062 ± 0.55	-	-	-
Artemisia herba alba	-	6.32 ± 8.27	-	-	0.03 ± 0.33	3.73 ± 5.30	0.25 ± 1.34	8.81 ± 7.93	-	-
Atractylis serratuloides	-	-	1.98 ± 3.97	-	0.1 ± 0.58	0.06 ± 0.55	0.12 ± 0.7	0.05 ± 0.31	-	-
Asparagus stipularis	-	-	-	-	-	-	0.88 ± 2.23	0.12 ± 1.11	1.08 ± 3.59	0.562 ± 2.37
Ononis natrix	-	-	-	-	-	-	0.06 ± 0.55	-	-	-
Lygeum spartum	-	-	-	-	-	-	0.93 ± 2.69	3.48 ± 11.71	-	-
Retama retam	-	-	-	-	-	-	0.37 ± 2.34	-	-	-
Erodium arborescens	-	-	-	-	-	-	0.15 ± 0.70	-	-	-
Hammada scoparia	9.93 ± 7.53	-	-	-	-	-	0.17 ± 0.89	-	-	-
Lavandula augustifolia	-	-	-	-	-	-	0.02 ± 0.22	-	1.28 ± 10.01	0.425 ± 1.74
Thymelia hirsuta	-	-	0.75 ± 2.67	0.21 ± 0.75	0.4 ± 0.88	-	0.08 ± 0.59	-	-	-
Asteriscus pygmaeus	0.96 ± 0.67	-	0.68 ± 1.21	-	-	-	0.06 ± 0.36	0.38 ± 0.81	1.3 ± 9.46	-
Echiochilon fruticosum	-	-	-	-	-	-	0.06 ± 0.55	-	-	-
Digitaria commutata	2.97 ± 4.24	-	-	-	-	-	-	-	-	-
Aristida ciliata	0.41 ± 3.09	1.5 ± 5.36	0.18 ± 0.18	-	-	-	-	-	-	-
Cenchrus ciliaris	0.82 ± 5.75	-	-	-	-	-	-	-	-	-
Halimium halimifolium	0.18 ± 3.53	-	-	-	-	-	-	-	-	-
Acacia tortilis	0.93 ± 17.67	-	-	-	-	-	-	-	-	-
Sedum sediforme	-	0.86 ± 1.79	-	0.46 ± 1.54	-	-	-	-	-	-
Rosmarinus officinalis	-	7.27 ± 10.03	2.58 ± 7.81	0.62 ± 2.89	-	-	-	-	4.37 ± 10.43	11.475 ± 16.74
Opuntia sp.	-	0.062 ± 0.55	-	-	-	-	-	-	-	-
Plantago albicans	-	0.125 ± 0.65	-	-	-	-	-	-	-	-
Anacyclus cyrtolepidoides	-	0.1 ± 0.64	-	-	-	-	-	2.287 ± 2.56	0.9 ± 3.03	0.062 ± 0.55
Fagonia cretica	-	-	-	-	-	-	-	0.987 ± 2.73	-	-
Reaumuria vermiculata	-	-	-	-	-	-	-	0.225 ± 0.805	-	-
Salsola kali	-	-	-	-	-	-	-	0.062 ± 0.55	-	-
Anabasis articulata	-	-	-	-	-			0.237 ± 1.03	-	-

Table 4. (Continued).

Kickxia aegyptiaca	-	-	-	-	-	-	-	0.025 ± 0.22	-	-
Astragalus armatus	-	-	-	-	-	-	-	1.375 ± 3.25	0.137 ± 0.72	0.912 ± 4
Polygonum maritimum	-	-	-	-	-	-	-	0.1 ± 0.64	-	-
Deverra scoparia	-	-	-	-	-	-	-	0.375 ± 1.72	-	-
Echium arenarium	-	-	-	-	-	-	-	0.075 ± 0.46	-	-
Adonis vernalis	-	-	-	-	-	-	-	0.025 ± 0.22	-	-
Stipagrostis ciliata	-	-	-	-	-	-	-	-	2.487 ± 6.51	-
Rhus tripartia	-	-	-	-	-	-	-	-	6.75 ± 22.19	-
Periploca graeca	-	-	-	-	-	-	-	-	0.062 ± 0.55	-
Helianthemum kahiricum	-	-	2.225 ± 2.84	-	-	2.387 ± 2.67	-	-	-	-
Asteriscus ciliatus	-	-	0.012 ± 0.11	-	-	-	-	-	-	-
Teucrim pollium	-	-	0.037 ± 0.33	0.325 ± 1.64	-	-	-	-	-	-
Fumana thymifolia	-	-	-	0.1 ± 0.64	-	-	-	-	-	-
Hernaria cinerea	-	-	-	0.462 ± 2.07	-	-	-	-	-	-
Juniperus phoenicia	-	-	-	-	-	-	-	-	-	12.125 ± 27.93
Globularia alypum	-	-	-	-	-	-	-	-	-	1.625 ± 3.93
Total vegetation cover	33.437	49.93	27.59	43.948	24.5	26.661	22.746	36.64	49.07	48.78

Table 5. Values of the Jaccard similarity index.

Plots	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	1									
P2	0.117	1								
P3	0.176	0.187	1							
P4	0.125	0.214	0.285	1						
P5	0.076	0.166	0.272	0.2	1					
P6	0.142	0.153	0.333	0.076	0.428	1				
P7	0.227	0.13	0.227	0.136	0.235	0.277	1			
P8	0.115	0.125	0.166	0.043	0.157	0.2	0.25	1		
P9	0.105	0.25	0.157	0.157	0.071	0.062	0.227	0.208	1	
P10	0.055	0.285	0.125	0.133	0.083	0.071	0.181	0.173	0.538	1

shown in Tataouine, characterized by a lower aridity index of 0.096, while lower percentages of chamaephytes were shown in Haffouz (18.18%) and Chaambi and Jbel Halfa (both 33.33%), characterized by aridity indexes of greater than 0.2. Moreover, chamaephytes adapt better to summer drought and light (Danin and Orshan, 1990). Grazing can also promote chamaephytes being rejected by herds (Kadi-Hanifi, 1998). In grassland formations, Le Houérou (1992) emphasized the increase of woody chamaephytes due to overgrazing by cattle and sheep.

It is possible to note the important percentage of taxa belonging to the family Poaceae as an indicator of grazing.

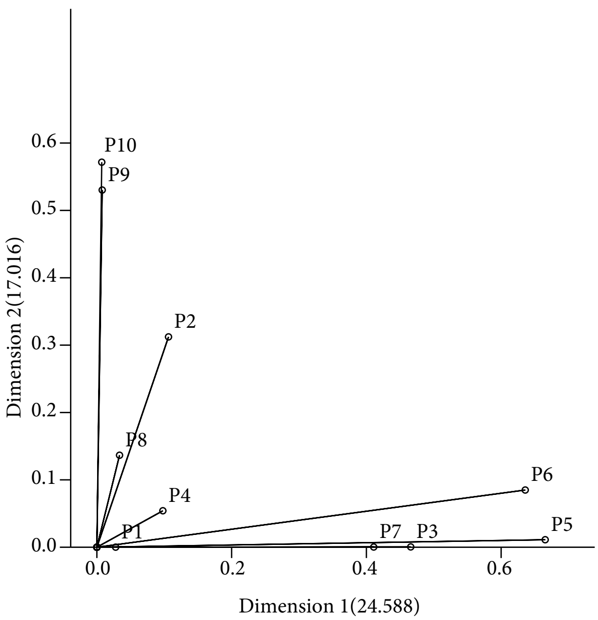

Figure 2. Multiple correspondence analysis (MCA) comparing the 10 plots surveyed in terms of species composition based on the absence/presence of species.

In fact, Catorci et al. (2011) mentioned that grazing promotes grasses, especially Poaceae species. Many of the grasses belonging to Poaceae show remarkable increases during grazing disturbances, contributing to the enhancement of the pastoral value (Sebastia et al., 2008).

The relatively low vegetation cover may also represent proof of overgrazing, which caused rapid regression of *Stipa* steppes and accelerated the dune installation process and contributed greatly to rangeland degradation.

An important cover of *Artemisia herba alba* was remarkable in some plots. This species was generally related to the degradation of *Stipa* steppes in central and southern Tunisia. One study reported that these steppes are permanent but they are not resilient; once destroyed, they do not reestablish themselves (Le Houérou, 1981). On the contrary, an older study found the steppes stable as they are both permanent and resilient and reported that they may be considered a 'neoclimax' (Le Houérou, 1969).

In addition, we noted a predominance of nonpalatable species among the different experimental sites. In fact, the regressive evolution of *Stipa tenacissima* steppes resulted in stages where this climax species was replaced by less preferred livestock species reflecting overgrazing, such as *Lygeum spartum*, *Atractylis serratuloides*, *Hammada scoparia*, and *Astragalus armatus*. Indeed, the overexploitation of pastoral resources caused genetic erosion of the most productive species and evolution of potential and biodiversity to a nonproductive dynamic with installation and development of ruderal unpalatable species.

Through the floristic surveys, we identified the 2 sites that were the most vulnerable to degradation. The first site was Sidi Bouzid (P5) with the lowest evenness, diversity, and species richness (only 4 species; 2 of these species, *Atractylis serratuloides* and *Thymelia hirsuta*, are nonpalatable indicator species of overgrazing). The other site was Bouhedma (P1), where the cover of *Hammada scoparia* was 9.93% against 10.7% of *Stipa tenacissima*, which underlined that *Stipa* will be replaced over time by this nonpalatable species if restoration measures are not introduced. Restoration ecologists should devote further attention to these degraded steppes in accordance with the magnitude of this problem.

4.2. Degradation state and floristic changes occurring in North African *Stipa tenacissima* steppes

At the end of the 19th century, the North African *S. tenacissima* steppes covered about 12 × 10^6 ha; they have now declined by about 50% (Bounejmate et al., 2004). Le Houérou (1981) underlined that they covered about 5.5 × 10^6 ha (Algeria: 3 × 10^6; Morocco: 1.5 ×10^6; Tunisia: 0.6 × 10^6; Libya: 0.4 × 10^6). Overgrazing has constituted the principal cause of this severe degradation by reducing perennial plant cover and as a result increasing erosion, and reducing the number of palatable species, which can be replaced by unpalatable plant units resulting from a dynamic degradation with less functional performances such as *Hammada scoparia*, *Hammada schmittiana*, *Atractylis serratuloides*, and *Astragalus armatus*. Indeed, the clearing of *S. tenacissima* steppes for agriculture is one of the most important causes of degradation, loss of species, and ecosystem dysfunction.

In Tunisia, Azaiez (2001) proved that rangelands have been degrading since the 1960s. In fact, comparison of the state of rangelands between 1978 and 1999 showed a decline in the steppe area estimated at approximately 9.6% (Bounejmate et al., 2004). In central Tunisia, Ghrab (1981) estimated that for 60 years the *Stipa* steppes had regressed 1% on average per year. Moreover, Le Houérou (1986) highlighted a decrease in the area of *S. tenacissima* steppe estimated to an average of 10,000 ha per year since the beginning of the century.

Moroccan rangelands have also deteriorated. Comparison between rangeland conditions of 1988 and 2000 showed that overall degraded area increased from 53,541 ha to 72,228 ha due to the clearing of *Stipa tenacissima* and *Artemisia herba alba* steppes (Mahyou et al., 2001). According to these authors, degraded *Stipa tenacissima* steppe increased from 54,149 ha to 56,188 ha and the *S. tenacissima* steppe in good condition decreased from 22,457 ha to 15,929 ha. Furthermore, in eastern Morocco, Bounejmate et al. (2004) suggested an irreversible degradation of *S. tenacissima* steppes into shrub steppes.

In Algeria, *S. tenacissima* steppes showed over time a severe degradation and progressive regression. In fact, the esparto-covered surface decreased hugely from 4.5 × 10^6 ha (Boudy, 1950) to only 3 × 10^6 ha (Ghebalou, 2001).

On other hand, Le Houérou (1981) suggested that once Alfa grass has been removed it never comes back. Indeed, he showed that when Alfa steppe is deteriorated, steppic shrubs represented mainly by *Artemisia herba alba*, *Atractylis serratuloides*, *Hammada scoparia*, and *Thymelia hirsuta* tend to replace the Alfa grass. The thinned and degraded *Stipa tenacissima* steppe then slowly gives way chamaephytic steppe. Our results showed the predominance of chamaephytes and nonpalatable species among the different experimental sites, reflecting the regressive evolution of *Stipa tenacissima* steppes.

After a few years of total protection, chamaephytic steppes are dominated by palatable perennial grasses such as *Stipa lagascae*, *S. parviflora*, *Stipagrostis ciliata*, and *Cenchrus ciliaris*. This corroborates field investigations in long-term enclosures (5–15 years) in Libya, Tunisia, Algeria, and Morocco (Le Houérou, 1969).

The development of restoration ecology through the restoration, rehabilitation, and reallocation approach (Aronson et al., 1995) is designed to understand the dynamic processes of degradation as the reconstruction of ecosystems (Aïdoud et al., 2006).

In North Africa, the regeneration of steppe rangelands was, during the last 4 decades, the challenge for many development and restoration actions (Aïdoud et al., 2006). A comparison of surface conditions and vegetation showed the effectiveness of protection (Floret, 1981). In fact, the exclosure of a degraded steppe promotes regeneration of perennial plants that trap sand and organic matter (Floret and Pontanier, 1982) and allow the infiltration of rainwater. This causes increased vegetation cover and its maintenance during erosion risk (Floret, 1981). In Tunisia, several studies have evaluated the effect of rangeland protection on the *Stipa tenacissima* cover (Floret, 1981) and the improvement of its nutritive value (Genin et al., 2007).

4.3. Concluding remarks and ecological significance

This floristic survey showed that beyond the apparent homogeneity of *Stipa tenacissima* steppes, there is relatively high biodiversity. However, the low number of species and total vegetation cover, the predominance of chamaephytes, and the installation and development of ruderal unpalatable species due to overgrazing represent an extreme threat to the resilience of this ecosystem. These results, in combination with those related to abiotic factors and biodiversity (i.e. species richness declined with increasing elevation and slope and increased with increasing sand content), show the vulnerability of these steppes to degradation.

Protection of *Stipa tenacissima* steppes and the establishment of a seed bank can help to restore these ecosystems and to improve their resilience to environmental change. Experience showed that restoration procedures are not useful unless they are included within an institutional set-up providing the required policy related to grazing rights, empowerment of herders, and better access to marketing (Bounejmate et al., 2004).

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