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Plant diversity and relationships with environmental factors after rangeland exclosure in arid Tunisia

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Abstract: On a broad scale, the extent of clearing and plowing of the crops in rangelands has brought a significant degradation in pasture species along with an invasion of weed species. This work evaluates the vegetation composition of an agriculture field after 15 years of exclosure and protection against clearing and plowing activities. Vegetation cover, density, richness, species dispersion, and diversity index were estimated through 12 permanent transects of 20 m in length and 23 quadrats of 1 m^2 over a 3-year period. Species diversity and its relationship with environmental factors (soil, canopy, elevation, and road effect) were analyzed by canonical correlation analysis. About 72 species were recorded across the study area. Plant species encountered were divided into three communities of steppic (45.8%), weed (44.4%), and steppic-weed (8.4%), with 1 cultivated species (1.4%). Raunkiaer classification showed a dominance of therophytes (73.6%) over the other groups. This work showed that exclosure of degraded arid lands can regenerate 16.6% of perennial plant cover that allowed to classify the experimental field as a low degraded zone.

Key words: Degraded rangeland, vegetation restoration, exclosure, steppic, weed, pasture

1. Introduction

In Tunisia's arid regions, climatic variability and land use changes have caused considerable degradation in the vegetation and the structure of ecological systems during the past 25 years. About 10% of the natural steppe areas have been replaced by agricultural field crops, shrinking them to a highly degraded vegetation (perennial plant cover of 5%) and resulting in the appearance and domination of unpalatable species (Hanafi and Jauffret, 2008).

However, agriculture activities such as clearing and plowing, harvesting, and wood cutting, accentuated by overgrazing, have resulted in the decrease of the Tunisian steppes that were overlapped by croplands and represent only 52% only of the total area of the natural vegetation (Le Floc'h et al., 1999; Hanafi and Jauffret, 2008).

The extent of clearing and plowing of crops in the rangelands causes not only a significant degradation in pasture area, but also an invasion by weed species and nonpalatable plants (Hanafi and Jauffret, 2008). As mentioned by Di Tomaso (2000), invasive weeds in pastures reduce forage quality and yield, impair animal performance, and increase costs associated with the use of herbicide.

One of the major procedures to restore natural vegetation in the degraded and disturbed field is to create exclosures. Establishment of exclosures, which are denoted as closed off from grazing for a specific period of time, is a well-known management tool to restore degraded rangeland ecosystems for both soil and plant cover (Bradd et al., 2011; Gómez et al., 2012). Regeneration of the natural vegetation had positive effects on biodiversity (Asefa et al., 2002; Abebe et al., 2006) and soil fertility (McIntosh et al., 1997; Mekuria et al., 2007); it reduced soil erosion (Descheemaecker et al., 2006) and increased water availability (Hongo et al., 1995) and also increased forage quality and productivity (Mseddi et al., 2004; Visser et al., 2008).

Rehabilitation can commonly start from relict vegetation or from the soil seed reserve (Mseddi et al., 2002). In severely degraded areas, autogenic recovery can be hampered by inadequate supply of seed, absence of suitable microsites for germination, and reduced soil functioning (Vandenberg and Kellner, 2005; Abebe et al., 2006). In these cases, ecosystem rehabilitation needs to be fostered through tilling, if necessary combined with planting and reseeding of indigenous plant species (Visser et al., 2004).

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Our research was conducted in a field area already degraded by annual plowing activities and grazing during a long period (approximately from 1960 to 1990). This work assessed the vegetation restoration patterns and their relationships with environmental factors on a protected agricultural field in Tunisian arid rangelands after 15 years of exclosure and protection against plowing (from 1990 to 2005).

The aims of this study were to examine the restoration and disturbance regime of arid land communities, analyze the ecological relationships between the vegetation restoration (communities and species) and the environment, and discuss the ecological relationships between species diversity and the environment by comparing canonical correlation analysis (CCA) with species composition and that with species diversity. Therefore, this work is hoped to provide valuable and innovative suggestions for restoration in Tunisian degraded rangelands.

2. Materials and methods

2.1. Study site

The fieldwork was conducted in an arid region of Sfax (34°45′54″N, 10°42′18″E) in a private field previously used for almond cultivation (Figure 1). The study area had been abandoned for a long time and most of trees were cut down or uprooted for firewood.

The surface of this field was likely about 3 ha. The field was protected by two constructed walls (north and south limits) and crossed by a track. The east and west sides were delimited by roads. Roads and track were mainly used by humans and not for livestock grazing.

The historic climatic factors were estimated as mean annual precipitation of 197 mm, a mean annual temperature of 18.9 °C, and a mean annual evapotranspiration of 962 mm (Floret and Pontanier, 1982). This type of climate is characterized as Mediterranean lower arid with a dry season during the summer and a rainy season spanning autumn to spring (Emberger, 1954). Climatic data during the study years show a mean precipitation of 258.8 ± 59.8 mm. These precipitations were higher than the estimated mean value of this region, which indicates a moisture period.

The annual precipitation recorded in 2005 (i.e. the first year of study) was 189.8 mm, which was considered as the nearest reading to the mean precipitation recorded for a long time period (197 mm). For the second and third years of the study (2006 and 2007) the mean precipitations were recorded as 290.7 mm and 269 mm, respectively. The mean temperature of 20.03 ± 0.20 °C was characteristic for this region (Table 1).

Before 1960, all the region of this field was considered as a *Rhanterium suaveolens* steppic land. After that the field was reserved for almond tree cultivation until 1990 (year of exclosure) and was exposed to plowing activity in autumn and then grazing by sheep in spring every year. For these purposes, mechanical methods, which had dramatic effects on sandy soils, were employed (Floret et al., 1992). Because of the rarity of protected land, this field seemed to be unique as an exclosure subject zone.

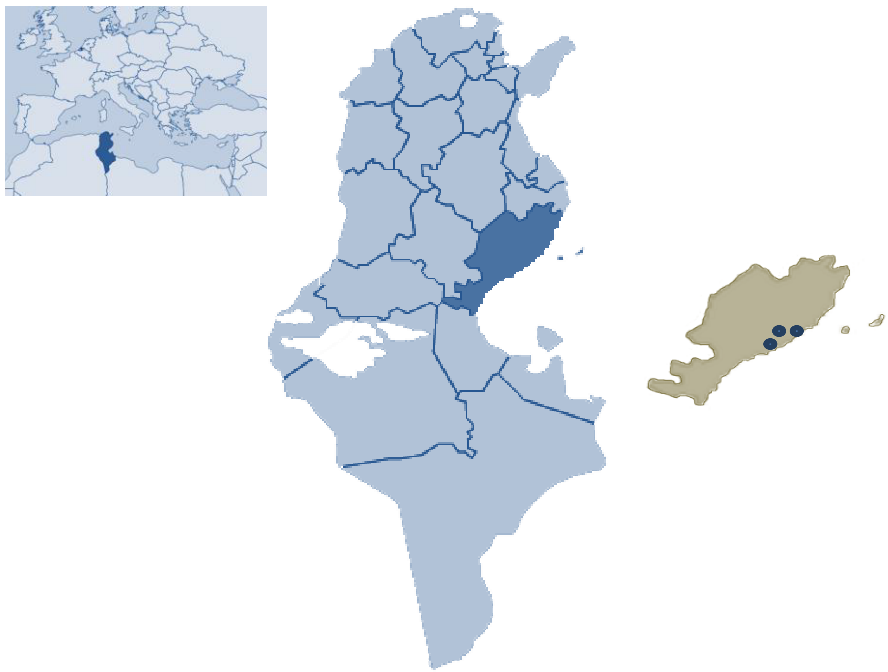

Figure 1. The study field and the control zones localization in the Sfax region (Tunisia).

Table 1. Climatic data during the study years. ±: standard deviation

Year	2005	2006	2007	Average
Precipitation (mm)	189.8	290.7	296	258.8 ± 59.8
Temperature (°C)	19.8	20.1	20.2	20.0 ± 0.2

2.2. Control zones

The evolution of the plant cover in the exclosure was compared with 2 control zones: a permanent plowed field and a natural protected steppe. The plowed field contained 18 weed species and neighbored the exclosure field, whereas the natural protected steppe (37 species) was situated 20 km from the study area (Jeddi and Chaieb, 2012). Only the plant lists of control zones were used in this study.

2.3. Sampling

We examined plant species composition of the study site over 3 years extending from 2005 to 2007 (i.e. 15 years after exclosure and protection against plowing and grazing). A total of 11 permanent transects, each 20 m long, were randomly located in the study area. Observations were made every 1 m, making a total of 20 points in the whole transect. The quadrat point method (Daget and Poissonet, 1971) was used to measure the floristic composition, the total percentage plant cover, and percentage cover of each herbaceous species sampled. The number of species per square meter was counted within 23 quadrats of 1 m^2 each placed randomly in the desired field.

Plants were classified into three communities, steppic, weeds, and pasture, according to Alapetite (1981) and Chaieb and Boukhriss (1998).

2.4. Index and data analysis

Richness, diversity, and dispersion indexes and their formulae are reported in Table 2. The high values of these indexes indicate high diversity and therefore a tendency toward equidistribution or regularity of various species numbers.

We used CCA (ter Braak, 1986) to examine the influence of environmental variables on species composition in the field. CCA is an ordination technique that can also be used to summarize the similarities and differences among plant communities, the relationships between sites and the environmental gradients. Four environmental factors were included in the CCA: 1) Soil types: S1, silt rocky; S2, sandy; S3, sandy gypsum; S4, loamy rocky; S5, sandy clayey; S6, silty salty; 2) Wall canopy: C1, protected by wall; C0, exposed to sunlight; 3) Elevation: L0, depression; L1, flat slope; L2, elevated; and 4) Distance from the quadrat/transect to the road: RD0, <5 m; RD1, 5 to 20 m; RD2, <20 m.

Table 2. Richness, diversity, and dispersion indexes and their formulae.

Index	Formula
Richness	S_0 = Species number
Jackknife estimator of species richness (Smith and Pontius, 2006)	$Jn(S) = S_0 + \frac{n-1}{n}\Sigma_{i=1}^{n} ri$ where S0 is the observed species count over all plots, ri is the number of species that are found only in plot i, and n is the number of plots
H: Shannon–Wiener index of species diversity (Shannon and Weiner, 1963)	$H = -\Sigma Pi \ln Pi$ *Pi* : the proportion of the *i*th species = abundance of $species_i$ / total abundance of all species ln p_i: the natural logarithm of p_i *S* = total species
Simpson's index of species diversity (Simpson, 1949)	$D = 1/\Sigma Pi2$
Pielou evenness index (Pielou, 1966)	$J = (-\Sigma Pi \ln Pi)/ \ln S$
Morisita index of dispersion: aggregative (Morisita, 1962)	$Md = nx \frac{\Sigma x^2 - \Sigma x}{\Sigma x^2 - \Sigma x}$ n: number of plot (quadrat/transect) x: number of individuals in the plot (quadrat/transect)

ANOVA and CCA analysis were conducted with SPSS 19.0.

3. Results

3.1. Richness, diversity, and dispersion

In this study, 72 species were recorded in this protected field with a density of 5 species/m^2. The specific richness index (jackknife estimator richness) was about 79.9. The Shannon–Weiner index of species diversity was 3.35 and Simpson's index was 18.8 (Table 3). Sixteen weed species were both found in the study site and the neighboring plowed field. *Diplotaxis harra* and *Sisymbrium irio* were found in the control-plowed field but not in the study field. However, no weed species were observed in the natural protected steppe.

The Morisita index of dispersion was estimated at 1.22, which indicated an aggregate dispersion of the species in the studied field. For all these values, no significant differences were shown among the 3 years of studies. No high differences were recorded in the precipitation registered during the study.

3.2. Families

The study site showed a richness of S_0 = 72 species, represented by 27 families. Asteraceae, Fabaceae, and Poaceae with respectively 16, 13, and 11 species were the most abundant families. Aizoaceae, Caryophyllaceae, and Plantaginaceae were represented each by 3 species. Geraniaceae and Papaveraceae were represented by 2 species and all the rest of the families (19 families) were represented by only one species for each family (Table 3).

3.3. Communities and life form

The studied field showed equilibrium between two groups of species: the restored and native steppic group and the invasive weed group. The steppic group was represented by 33 species (45.8%), of which 15 were pasture species. The weed group was represented by 32 species (44.4%), of which 10 were pasture species. Six species (8.4%) were considered as steppic-weed-pastoral plants. The field also included one cultivated species (1.4%) (Table 4).

The calculation of the average species cover during the study period showed that it ranged from 32.1% (*Bromus madritensis*) to 0.455% (*Scabiosa arenaria*). The most abundant species (9 plants) with a cover over 20% were annual plants, essentially belonging to the steppic community. Among them, *Argyrolobium uniflorum* (Co = 20.4%) and *Fagonia cretica* (Co = 20%) are perennial, whereas *Ononis sicula* (Co = 28.1%) and *Malva aegyptiaca* (Co = 25%) are weed species.

This study shows that the steppic community covers 34.9% of the green area, whereas weed and steppic/weed species cover 28.7% and 36.3%, respectively (Table 4). The recurrence of steppic species reflects a tendency toward the restoration of the study area's ecosystem.

The study of the annual variation of the coverage shows that species covers of the 2nd and the 3rd year were higher than the 1st year for almost all annual plants. These variations could be explained as a consequence of humidity fluctuations. The 1st year of the study, precipitation registered 189.8 mm, nearest to the long-term mean precipitation of the region, whereas the 2nd and 3rd years were considered as moisture periods with precipitations exceeding the region mean. For the perennial community no great differences were observed in cover values except in rare cases like *Launaea resedifolia*, *Launaea angustifolia*, and *Plantago albicans*, which were humidity-dependent. These results indicate that regenerated perennial species kept the same cover in a humidity range of 200 to 300 mm of rain. However, it was the size of plants that had changed.

Density data showed that steppic species covered 51.7% of the green surface with an absolute density of 8.5 plants/m^2. Weed species covered 29.2% with a density of 4.7 plants/m^2, whereas steppic-pastoral-weed species covered 19.1% with a density of 3.1 plants/m^2. Forage species were well represented by 31 pasture species, or 43% of total species.

Table 3. Richness, diversity, and dispersion index values in the study field and the control natural steppe (Jeddi and Chaieb, 2012).

Index	Study field	Natural steppe
Richness	72	-
Density	5.105 sp/m^2	7 sp/m^2
Jackknife estimator of species richness	79.9	-
H: Shannon–Wiener index of species diversity	3.3542	2.50
Pielou evenness index	0.7843	-
Morisita index of dispersion : aggregative	1.2219	-
Simpson's index of species diversity	18.817	-

Table 4. List of species names and codes found in the studied field. S/P/W: steppic/pasture/weed; LF: Raunkiaer life form; A/P/C: annual/perennial/cultivated; Cov: coverage; ReFri: relative frequency; Rdi: relative density; Di: total density. *: Species exist in the plowing control field; + : species exist in the natural protected steppe. ±: standard deviation

N	Species	Family	Code	S/P/W	LF	A/P/C	Cov1	Cov2	Cov3	Cov. Average	ReFri	Rdi	Di
1	*Aegilops geniculata* Roth	Poaceae	Po1	P/W	Th	A	0.809	1.364	1.918	1.364 ± 0.555	0.258 ± 0.015	0.417 ± 0.025	0.068 ± 0.003
2	*Aizoon canariense* L.*	Aizoaceae	Ai1	W	Th	A	3.889	4.545	5.000	4.478 ± 0.559	0.861 ± 0.043	0.472 ± 0.028	0.077 ± 0.003
3	*Anacyclus clavatus* (Desf.) Pers.	Asteraceae	Ast1	P/W	Th	A	0.455	0.909	1.364	0.909 ± 0.455	0.172 ± 0.056	0.056 ± 0.003	0.009 ± 0.000
4	*Anagallis arvensis* L.+	Myrsinaceae	My	W	Th	A	2.727	3.182	3.636	3.182 ± 0.455	0.603 ± 0.073	0.361 ± 0.022	0.059 ± 0.002
5	*Argyrolobium uniflorum* (Decne.) Jaub. & Spach+	Fabaceae	F1	S/P	Ch	P	20.455	20.000	20.909	20.455 ± 0.455	3.876 ± 0.223	5.028 ± 0.302	0.823 ± 0.033
6	*Aristida adscensionis* L.	Poaceae	Po2	S/P	H	P	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.016	0.028 ± 0.002	0.005 ± 0.000
7	*Arnebia decumbers* (Vent.) Coss. & Kral	Boraginaceae	Bo	S	Th	A	1.364	1.818	2.273	1.818 ± 0.455	0.345 ± 0.033	0.194 ± 0.012	0.032 ± 0.001
8	*Asparagus stipularis* Forsk.	Asparagaceae	Asp	S	G	P	2.727	2.273	3.182	2.727 ± 0.455	0.517 ± 0.028	0.222 ± 0.013	0.036 ± 0.001
9	*Asphodelus tenuifolius* Cav.+	Xanthorrhoeaceae	X	S/P	G	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.018	0.028 ± 0.002	0.005 ± 0.000
10	*Astragalus cruciatus* Link.	Fabaceae	F2	S/P	Th	A	10.000	11.364	11.364	10.909 ± 0.787	2.067 ± 0.095	1.611 ± 0.097	0.264 ± 0.011
11	*Atractylis flava* Desf.	Asteraceae	Ast2	S	Th	A	5.000	4.545	5.455	5.000 ± 0.455	0.947 ± 0.063	0.583 ± 0.035	0.095 ± 0.004
12	*Avena sativa* L.	Poaceae	Po3	S/P	Th	A	9.545	9.091	10.000	9.545 ± 0.455	1.809 ± 0.104	0.861 ± 0.052	0.141 ± 0.006
13	*Brachypodium distachyon* (L.) P.Beauv.	Poaceae	Po4	S/P	Th	A	29.091	35.000	32.727	32.273 ± 2.981	6.115 ± 0.140	10.417 ± 0.625	1.705 ± 0.068
14	*Bromus madritensis* L.+	Poaceae	Po5	S/P/W	Th	A	32.727	32.727	34.091	33.182 ± 0.787	6.288 ± 1.113	11.778 ± 0.707	1.927 ± 0.077
15	*Calendula aegyptiaca* Pers.	Asteraceae	Ast3	S	Th	A	23.182	27.273	28.636	26.364 ± 2.839	4.996 ± 0.921	4.306 ± 0.258	0.705 ± 0.028
16	*Centaurea dimorpha* Viv.*	Asteraceae	Ast4	W	Th	A	10.909	10.455	11.364	10.909 ± 0.455	2.067 ± 0.270	1.500 ± 0.090	0.245 ± 0.010
17	*Centaurea melitensis* L.	Asteraceae	Ast5	S	Th	A	1.818	1.364	2.273	1.818 ± 0.455	0.345 ± 0.013	0.167 ± 0.010	0.027 ± 0.001
18	*Chenopodium album* L.*	Amaranthaceae	Am	W	Th	A	3.636	4.545	5.455	4.545 ± 0.909	0.861 ± 0.055	0.250 ± 0.015	0.041 ± 0.002
19	*Chrysanthemum coronarium* L.	Asteraceae	Ast6	P/W	Th	A	13.182	15.455	16.364	15.000 ± 1.639	2.842 ± 0.037	3.111 ± 0.187	0.509 ± 0.020
20	*Convolvulus arvensis* L.*	Convolvulaceae	Co	W	Th	P	0.909	0.455	1.364	0.909 ± 0.455	0.172 ± 0.023	0.056 ± 0.003	0.009 ± 0.000
21	*Cleome arabica* L.	Cleomaceae	Cl	S	Ch	P	0.455	0.455	0.455	0.455 ± 0.000	1.981 ± 0.042	0.581 ± 0.035	0.061 ± 0.002
22	*Cynodon dactylon* (L.) Pers.*+	Poaceae	Po6	S/P/W	H-G	P	10.455	10.000	10.909	10.455 ± 0.455	1.981 ± 0.036	2.167 ± 0.130	0.355 ± 0.014
23	*Daucus carota* L.	Apiaceae	Ap	P/W	Th	A	8.636	10.909	11.818	10.455 ± 1.639	1.981 ± 0.023	1.056 ± 0.063	0.173 ± 0.007
24	*Dipcadi serotinum* (L.) Medik.	Hyacinthaceae	H	S	G	A	0.909	0.455	1.364	0.909 ± 0.455	0.172 ± 0.088	0.056 ± 0.003	0.009 ± 0.000
25	*Emex spinosa* (L.) Campd.*	Polygonaceae	Pol	W	Th	A	12.727	12.273	13.182	12.727 ± 0.455	2.412 ± 0.055	0.583 ± 0.035	0.095 ± 0.004
26	*Erodium glaucophyllum* (L.) Aiton+	Geraniaceae	G1	S/P	H	P	1.818	1.364	2.273	1.818 ± 0.455	0.345 ± 0.013	0.167 ± 0.010	0.027 ± 0.001
27	*Erodium triangulare* (Forssk.) Muschl.	Geraniaceae	G2	W	H	P	0.455	0.909	1.364	0.909 ± 0.455	0.172 ± 0.033	0.056 ± 0.003	0.009 ± 0.000
28	*Euphorbia terracina* L.*	Euphorbiaceae	E	W	Th	A	10.455	10.000	10.909	10.455 ± 0.455	1.981 ± 0.020	0.944 ± 0.057	0.155 ± 0.006
29	*Fagonia cretica* L.+	Zygophyllaceae	Z	S	Ph	P	20.000	19.545	20.455	20.000 ± 0.455	3.790 ± 0.011	2.750 ± 0.165	0.450 ± 0.018
30	*Filago germanica* (L.) Hudson	Asteraceae	Ast7	W	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.014	0.028 ± 0.002	0.005 ± 0.000
31	*Fumaria officinalis* L.*	Papaveraceae	Pa	W	Th	A	2.273	1.818	2.727	2.273 ± 0.455	0.431 ± 0.022	0.194 ± 0.012	0.032 ± 0.001
32	*Hippocrepis bicontorta* Loisel.+	Fabaceae	F3	S/P	Th	A	6.818	6.364	7.273	6.818 ± 0.455	1.292 ± 0.033	1.194 ± 0.072	0.195 ± 0.008
33	*Hordeum marinum* Huds.	Poaceae	Po7	S/P	Th	A	10.909	14.091	14.545	13.182 ± 1.981	2.498 ± 0.015	2.028 ± 0.122	0.332 ± 0.013
34	*Koeleria pubescens* (Lam.)+	Poaceae	Po8	S/P/W	Th	A	2.727	2.273	3.182	2.727 ± 0.455	0.517 ± 0.023	0.611 ± 0.037	0.100 ± 0.004
35	*Koelpinia linearis* Pall.	Asteraceae	Ast8	S/P/W	Th	A	0.909	0.455	1.364	0.909 ± 0.455	0.172 ± 0.054	0.111 ± 0.007	0.018 ± 0.001
36	*Launaea angustifolia* (Desf.) Kuntze	Asteraceae	Ast9	S/P	H	P	10.455	12.273	14.091	12.273 ± 1.818	2.326 ± 0.033	1.444 ± 0.087	0.236 ± 0.009
37	*Launaea nudicaulis* (L.) Hook.	Asteraceae	Ast16	S	Ch	P	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.009	0.581 ± 0.035	0.060 ± 0.002
38	*Launaea resedifolia* (L.) Kuntze+	Asteraceae	Ast10	S/P	H	P	13.636	14.545	15.455	14.545 ± 0.909	2.756 ± 0.015	1.694 ± 0.102	0.277 ± 0.011

Table 4. (Continued).

39	*Lobularia libyca* Webb & Berthel.	Brassicaceae	Br	P/W	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.022	0.028 ± 0.002	0.005 ± 0.000
40	*Lolium multiflorum* Lam.	Poaceae	Po9	P/W	Th	A	1.364	0.909	1.818	1.364 ± 0.455	0.258 ± 0.265	0.167 ± 0.010	0.027 ± 0.001
41	*Lotus pusillus* Viv.	Fabaceae	F4	S/P	Th	A	4.545	6.818	7.727	6.364 ± 1.639	1.206 ± 0.012	1.111 ± 0.067	0.182 ± 0.007
42	*Malva aegyptiaca* L.*	Malvaceae	Ma	P/W	Th	A	20.000	24.545	30.455	25.000 ± 5.242	4.737 ± 0.013	4.444 ± 0.267	0.727 ± 0.029
43	*Medicago laciniata* (L.) Miller	Fabaceae	F5	P/W	Th	A	1.364	0.909	1.818	1.364 ± 0.455	0.258 ± 0.065	0.167 ± 0.010	0.027 ± 0.001
44	*Medicago minima* L.+	Fabaceae	F6	P/W	Th	A	15.455	18.636	19.091	17.727 ± 1.981	3.359 ± 0.023	3.417 ± 0.205	0.559 ± 0.022
45	*Medicago truncVulata* Gaertn.	Fabaceae	F7	P/W	Th	A	4.909	5.455	7.364	5.909 ± 1.289	1.120 ± 0.022	0.889 ± 0.053	0.145 ± 0.006
46	*Melilotus sulcata* Desf.*	Fabaceae	F8	W	Th	A	3.182	2.727	3.636	3.182 ± 0.455	0.603 ± 0.034	0.306 ± 0.018	0.050 ± 0.002
47	*Mesembryanthemum crystallinum* L.	Aizoaceae	Ai2	S	Th	A	8.636	11.364	12.727	10.909 ± 2.083	2.067 ± 0.047	2.889 ± 0.173	0.473 ± 0.019
48	*Mesembryanthemum nodiflorum* L.	Aizoaceae	Ai3	S	Th	A	1.218	1.964	2.273	1.818 ± 0.542	0.345 ± 0.061	0.167 ± 0.010	0.027 ± 0.001
49	*Ononis natrix* L.	Fabaceae	F9	S	Ch	P	1.818	1.764	1.873	1.818 ± 0.055	0.345 ± 0.054	0.250 ± 0.015	0.041 ± 0.002
50	*Ononis serrata* Forssk.	Fabaceae	F10	W	Ph	P	9.091	8.636	9.545	9.091 ± 0.455	1.723 ± 0.014	1.694 ± 0.102	0.277 ± 0.011
51	*Ononis sicula* Guss.*	Fabaceae	F11	W	Th	A	24.182	27.727	32.636	28.182 ± 4.246	5.340 ± 0.014	9.028 ± 0.542	1.477 ± 0.059
52	*Oryzopsis miliacea* (L.) Asch. & Schweinf.	Poaceae	Po10	S/P	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.014	0.056 ± 0.003	0.009 ± 0.000
53	*Pallenis spinosa* (L.) de Cassini	Asteraceae	Ast11	S	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.033	0.056 ± 0.003	0.009 ± 0.000
54	*Papaver rhoeas* L.	Papaveraceae	Pa	S	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.027	0.028 ± 0.002	0.005 ± 0.000
55	*Paronychia arabica* L.+	Caryophyllaceae	Ca3	S	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.510 ± 0.031	0.043 ± 0.003	0.070 ± 0.003
56	*Phagnalon rupestre* (L.) DC.	Asteraceae	Ast12	W	Ch	P	1.364	1.409	1.318	1.364 ± 0.045	0.258 ± 0.024	0.111 ± 0.007	0.018 ± 0.001
57	*Plantago albicans* L.+	Plantaginaceae	Pl1	S/P	H	P	1.364	2.727	2.727	2.273 ± 0.787	0.431 ± 0.017	0.972 ± 0.058	0.159 ± 0.006
58	*Plantago lagopus* L.	Plantaginaceae	Pl2	S	Th	A	2.091	4.636	5.545	4.091 ± 1.791	0.775 ± 0.041	1.194 ± 0.072	0.195 ± 0.008
59	*Plantago ovata* Forssk.	Plantaginaceae	Pl3	S/P	Th	A	0.909	1.364	1.818	1.364 ± 0.455	0.258 ± 0.009	0.167 ± 0.010	0.027 ± 0.001
60	*Prunus amygdalus dulcis* (Mill.) D.A.Webb	Rosaceae	Ro	-	Ph	C	0.909	0.909	0.909	0.909 ± 0.000	0.172 ± 0.000	0.056 ± 0.000	0.009 ± 0.000
61	*Reseda alba* L.*	Resedaceae	Re	W	Th	A	3.182	5.000	5.455	4.545 ± 1.203	0.861 ± 0.014	0.417 ± 0.025	0.068 ± 0.003
62	*Scabiosa arenaria* Forssk.+	Dipsacaceae	D	W	Th	A	0.455	0.455	0.455	0.455 ± 0.000	0.086 ± 0.038	0.083 ± 0.005	0.014 ± 0.001
63	*Schismus barbatus* (Loefl. ex L.) Thell.	Poaceae	Po11	S	Th	A	28.182	27.727	28.636	28.182 ± 0.455	5.340 ± 0.056	6.944 ± 0.417	1.136 ± 0.045
64	*Scorpiurus muricatus L.* var. *muricatus*	Fabaceae	F12	W	Th	A	1.273	3.227	3.682	2.727 ± 1.280	0.517 ± 0.021	0.194 ± 0.012	0.032 ± 0.001
65	*Senecio gallicus* Chaix.*	Asteraceae	Ast13	W	Th	A	3.545	5.000	6.455	5.000 ± 1.455	0.947 ± 0.033	0.444 ± 0.027	0.073 ± 0.003
66	*Silene colorata* Poir.	Caryophyllaceae	Ca1	P/W	Th	A	9.273	11.818	14.727	11.939 ± 2.729	2.326 ± 0.022	2.278 ± 0.137	0.373 ± 0.015
67	*Solanum nigrum* L.*	Solanaceae	So	W	Th	A	1.318	1.864	2.273	1.818 ± 0.479	0.345 ± 0.021	0.111 ± 0.007	0.018 ± 0.001
68	*Sonchus orolaceus* L.*	Asteraceae	Ast14	W	Th	A	5.455	8.636	9.091	7.727 ± 1.981	1.464 ± 0.012	1.056 ± 0.063	0.173 ± 0.007
69	*Spergula flaccida* Asch.	Caryophyllaceae	Ca2	S	Th	A	4.545	4.091	5.000	4.545 ± 0.455	0.861 ± 0.077	0.611 ± 0.037	0.100 ± 0.004
70	*Urtica membranacea* Poiret*	Urticaceae	U	W	Th	A	0.909	3.182	2.727	2.273 ± 1.203	0.431 ± 0.530	0.250 ± 0.015	0.041 ± 0.002
71	*Vicia sativa* L.	Fabaceae	F13	S/P/W	Th	A	0.909	0.455	1.364	0.909 ± 0.455	0.172 ± 0.038	0.111 ± 0.007	0.018 ± 0.001
72	*Volutaria lippii* (L.) Maire	Asteraceae	Ast15	S	Th	A	21.455	25.000	25.909	24.121 ± 2.354	4.823 ± 0.210	3.778 ± 0.227	0.618 ± 0.025
				S: 33	Th: 54	A: 55				S: 34.9%	S:52.7%	S: 51.7%	S: 8.5/m²
		Total		W: 32	Oth: 16	P: 16				W: 28.7%	W:33.9%	W: 29.2%	W: 4.7/m²
				S/W: 6		C: 1				SW: 36.3%	SW: 13.4%	SW: 19.1%	SW: 3.1/m²
		ANOVA							Species	<0.001	<0.001	<0.001	<0.001
									Year	NS	NS	NS	NS

The study showed that 19 species that have frequency Fi ≥ 2 were the most frequent, with a clear dominance of steppic weed species. From this list, 11 were forage species. The calculation of the relative density shows that given species occupied 79.3% of the green surface area.

Bromus madritensis (Fi = 6.29), *Brachypodium distachyon* (Fi = 6.12), *Schismus barbatus* (Fi = 5.34), *Calendula aegyptiaca* (Fi = 5.00), *Volutaria lippii* (Fi = 4.82), *Malva aegyptiaca* (Fi = 4.74), *Argyrolobium uniflorum* (Fi = 3.88), and *Fagonia cretica* (Fi = 3.79) were the most frequent steppic species. These species also have the highest densities in the field (Table 4).

Ononis sicula (Fi = 5.34), *Medicago minima* (Fi = 3.36), *Chrysanthemum coronarium* (Fi = 2.84), *Emex spinosa* (Fi = 2.41), *Silene colorata* (Fi = 2.33), and *Centaurea dimorpha* (Fi = 2.07) were the most frequent weeds in this protected field. In addition, these results prove that 28 species (38.9%) have a frequency of greater than 1; however, the rest of species (61.1%) have a frequency below 1. *Aristida adscensionis*, *Asphodelus tenuifolius*, *Filago germanica*, *Lobularia libyca*, *Oryzopsis miliacea*, *Pallenis spinosa*, *Papaver rhoeas*, and *Scabiosa arenaria* have very low frequency (0.01) with only one individual for each species.

Raunkiaer plant-life form classification clearly showed the dominance of herbaceous plants (therophytes) against degradation in shrublands. This was represented only by some dwarf shrubland species, and the absence of woody species except for almond (*Prunus amygdalus*), which was a cultivated tree. Thus, species distributed in the studied field included 53 therophytes, 5 chamaephytes, 7 hemicryptophytes, 5 geophytes, and 2 phanerophytes (Table 4).

Annual plants, with a proportion of 76.4% (55 species), dominated perennial plants at 22.2% (16 species). Perennial plant cover (PPC) was about 16.6%. This indicated low degraded land by the scale of Hanafi (2000). The comparison with the natural zone (control) that had similar ecologic characters and was located 20 km from our field (Jeddi and Chaieb, 2010, 2012) showed the presence of many regenerated species like *Launea residifolia*, *Scabiosa rhizhanta*, *Argyrlobium uniflorum*, *Medicago minima*, *Hippocrepis areolata*, *Erodium glaucophyllum*, *Fagonia cretica*, *Anagallis arvensis*, *Bromus madritensis*, and *Koleria pubscens*. However, the absence of many characteristic perennial species like *Artemisia campestris*, *Rhanterium suaveolens*, *Gymnocarpos decandrus*, and *Stipa* sp. in the study field (Jeddi and Chaieb, 2012) attests to the difficulty of regeneration for sensitive perennial species and therefore the necessity of human intervention (Jauffret and Visser, 2003).

3.4. Canonical correspondence analysis

Spatial distribution patterns of species were studied by detrended CCA and the environmental factors were separated into distinct groups along the CCA axis, which reflected the ecological relationships between species and their environments, and the distribution patterns of species in this field.

From Table 5, it is seen that botanical variables such as family, Raunkiaer classification, and life form were positively correlated to CCA axis I; however, environmental factors such as soil, elevation, and canopy and cover factors such as frequency and density were negatively associated with this axis. For axis II, soil and type of plant Ag defined the positive side of the CCA axis, whereas road, elevation, and canopy were negatively associated with this axis (Table 5).

The spatial distribution pattern of communities was recognized by CCA, and the communities were separated into 5 groups along the CCA axis, which reflected the ecological relationships between communities and their environments (Figure 2). Group 1 was the dominant group: it was represented particularly by steppic species like *Aegilops geniculata* (S/W), *Avena sativa* (S/P), *Brachypodium distachyon* (S/P), *Calendula aegyptiaca* (S), and *Sonchus orolaceus* (W). These species were the most frequent but were also well exposed to light and slowly elevated. They also accounted for the most frequent families, especially Poaceae and Asteraceae. Group 2 was the soil group: it included *Argyrolobium uniflorum* (S/P), *Chrysanthemum coronarium* (W/P), *Cynodon dactylon* (S/P/W), *Hordeum marinum* (S/P), and *Ononis natrix* (S), which were very much associated with their preferred soil.

Table 5. Correlation coefficient between each factor and each CCA axis. Significant correlation is indicated with an asterisk ($P < 0.05$). a: Cover factors (numeric factors): frequency and density. b: Environment factors (nominal factors): soil, elevation, canopy, and distance from road. c: Biological factors (nominal factors): family, Ag (steppic/weed/pasture). Rt: Raunkiaer life form.

	Component loadings	
	Axis 1	Axis 2
Freq[a]	–0.525*	–0.445*
Dens[a]	–0.660*	0.026
Soil[b]	–0.577*	0.329*
Ele[b]	–0.408*	–0.534*
Can[b]	–0.333*	–0.469*
Road[b]	0.145	–0.792*
Familly[c]	0.698*	0.138
Ag[c]	0.411*	0.389*
Rt[c]	0.339*	–0.579*

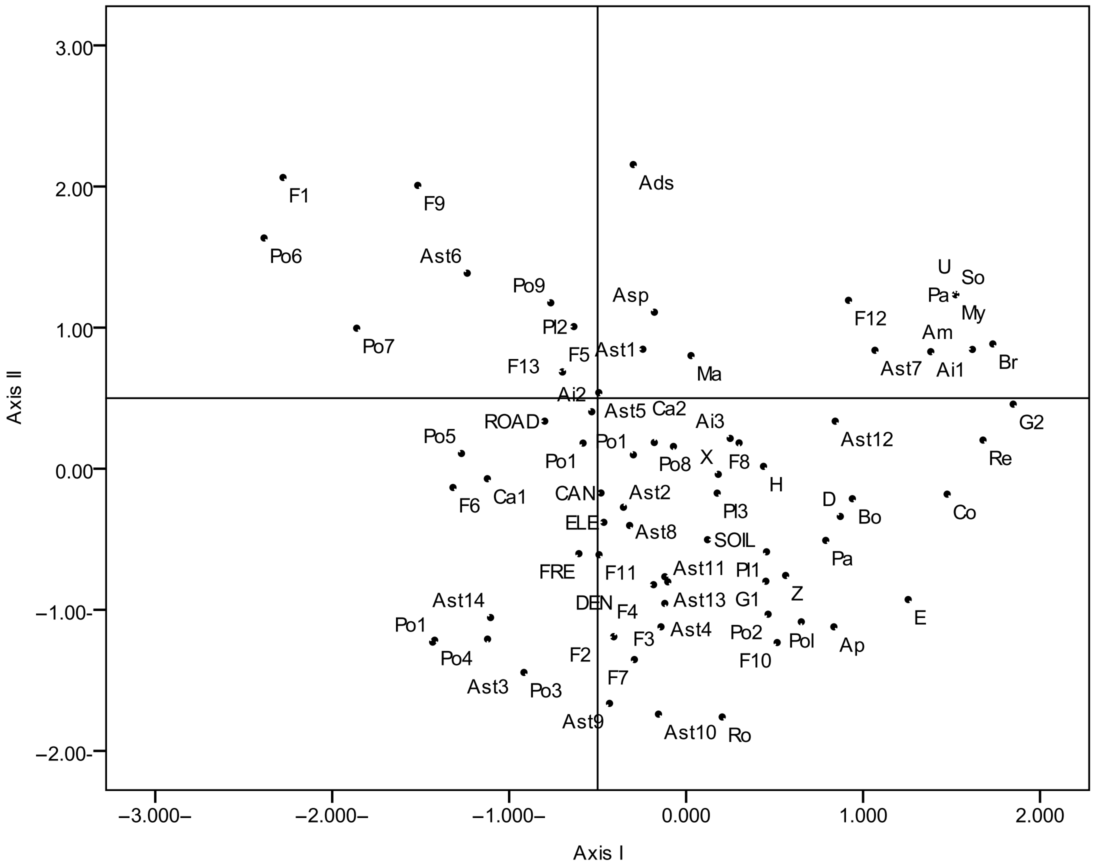

Figure 2. Canonical correlation analysis (CCA). Projection of plant species and environment factors. Plants are represented by letters and number codes. Letters indicate family and number the rank of species in the family. Environment factors: ROAD, SOIL, ELE (elevation), CAN (canopy). Numeric factors: DEN (density), FRE (frequency).

Because of their presence near the road, these species can resist and tolerate disturbance caused by the road. Group 3 was the road-avoidance group: it contained the species that cannot tolerate activities near roads (human disturbance) and grow far away from the road. The most common plants in this group wer: *Pallenis spinosa* (S), *Launaea resedifolia* (S/P), *Prunus amygdalus* (cultivated), *Centaurea dimorpha* (W), *Launaea angustifolia* (S/P), *Senecio gallicus* (W), *Hippocrepis bicontorta* (S/P), *Medicago trunculata* (W/P), *Ononis serrata* (W), *Emex spinosa* (W), *Daucus carota* (P/W), *Euphorbia terracina* (W) *Fumaria officinalis* (W), *Fagonia cretica* (S), and *Aristida adscensionis* (S/P). These species were closely associated with silt rocky soil. Group 4 included the rare communities, characterized by only 1 species per family and lower frequency. Weed plants dominated this group. Among them were *Anagallis arvensis* (W), *Chenopodium album* (W), *Erodium triangulare* (W), *papaver rhoeas* (S), *Filago germanica* (W), *Scorpiurus muricatus* (W), *Lobularia libyca* (W/P), *Reseda alba* (W), *Solanum nigrum* (W), and *Urtica membranacea* (W). These data indicate the beginning of the regression of weed species. Group 5 was the homogeneous group: it contains all the rest of the species located in the center of the graph. This group was characterized by medium values for all the variables measured and observed.

4. Discussion

In arid and semiarid Tunisia, many wild and natural landscapes have been transformed into agricultural fields. The Sfax region in central-eastern Tunisia is considered an important zone for olive and almond tree cultivation in the country and about 95% of the wild landscape is used for this purpose. Steppe clearing (i.e. total biomass destruction and the highest degree of disturbance) was considered as the prime cause of the disappearance of the North African steppe (Visser et al., 1997). Moreover, in the Tunisian arid lands, total destruction of vegetation is happening under continued grazing. As a result of this disturbance, wild steppes and natural landscapes have almost disappeared in the Sfax region but are still resisting elsewhere in very restricted protected zones like El-Gonna Park (Jeddi and Chaieb, 2012).

To date, no research activities have been conducted on the ecosystem structure and biodiversity evaluation for this area. That is why this field study was designed to answer many core questions: What is the floristic structure of the degraded land after protection against all agricultural and grazing activities? What is the degree of plant diversity that can be reached after exclosure? What are the relationships between the flora and the environmental conditions of this protected zone? What are the forage scale and the grazing level that could be adapted after regeneration?

Exclosure strategy was reported to be excellent for the restoration of degraded rangeland and the increasing of biodiversity (Asefa et al., 2002; Abebe et al., 2006). In this work, the exclosure for 15 years of a degraded rangeland allowed the rehabilitation of 72 species with a density of 5 species/m^2. The jackknife index value of 79.9 indicates a high species biodiversity. Allred et al. (2012) reported that richness index of 70 and Shannon diversity index of 2.47 indicated a very low degraded land. These findings can be proven by 16.6% PPC, which also indicates a low degraded land on the Hanafi scale (Hanafi, 2000; Hanafi and Jauffret, 2008).

Biodiversity benefits included higher species richness and amplified abundance of native grasses, many of which have become locally rare under increased grazing pressure and clearing (Bradd et al., 2011). In this work, we have shown that pasture species were highly represented by a cover of 43% of the total coverage. Therefore, we suggest that this field can be exploited for controlled and low grazing.

Annual and herbaceous species (therophytes) were the most regenerated at 76.4%, whereas perennial and dwarf shrubs (chamaephytes) existed at a rate of 16.6%. This result is supported by Verdoodt et al. (2010), who reported that rangeland enclosure promoted the regeneration of annual and perennial grasses and considerably increased grass cover and standing crops.

The regenerated field showed that steppic species were the most abundant group with a cover of 45.8%, followed by weed plants (44.8%). From all these species 43% were pasture plants. In the long term, Tracy et al. (2004) reported that the evenness at which forage species were distributed in pastures might help reduce aboveground weed abundance. Weeds can affect and reduce the quality of field palatability (Tracy et al., 2004). The “long life” of weeds can be explained by the neighboring field effect, considered for weed seed dispersion enhanced by their small size.

CCA showed five plant groups: 1- abundant plants; 2- plants associated with their preferred soil; 3- road-avoidance plants; 4- rare communities, and 5- a homogeneous group. Disturbance by roads was highly discussed by Daisuke et al. (2012), who showed a qualitative variation in roadside weed vegetation along an urban–rural road gradient. Expansion and integration of road networks, which accompany urbanization, can cause fragmentation and extinction of plant populations and communities (Jantunen et al., 2006), floristic homogenization (Wittig and Becker, 2010), facilitation of invasion by aggressive nonnative species into neighboring plant communities (Christen and Matlack, 2006, 2009), and alteration of landscape spatial patterns (Forman and Alexander, 1998).

Despite the high density of weeds (29.2%), CCA showed that the ‘rare’ group was represented especially by weedy species. This result shows the beginning of the decrease of weed species. Increased forage plant diversity in grazed pasture communities might be related to reduced weed abundance, both in the aboveground vegetation and the soil seed bank (Tracy et al., 2004). Maintaining an evenly distributed mixture of forage species may help suppress weeds as well (Tracy et al., 2004).

CCA showed that *Argyrolobium uniflorum*, *Chrysanthemum coronarium*, *Cynodon dactylon*, and *Hordeum marinum* were closely associated to their preferred soil. In fact, soil texture (sand vs. clay content) also affects the frequency of grasses and shrubs on sandy soils, which are more favorable to shrubs because they can simply reach the water table (Lauenroth et al., 2008).

After 15 years of exclosure and protection against plowing and grazing, ecological analyses based on transects and quadrats methods followed by CCA using correlations between environmental factors and species distribution permit the following conclusions: 1) The efficiency of the exclosure as a good method to regenerate the green cover with high diversity (72 species); 2) the beginning of the decline of weed species that reduce palatability; 3) difficulty of regeneration of perennial species and especially small woody shrubs, which shows that they need more time for regeneration and may also need human intervention; 4) CCA shows that any ecological factor (soil, for example) and disturbance factor (roads, for example) can affect the distribution and the diversity of species; 5) despite the results that we have found, we suggest that keeping field exclosure for longer periods can help land approach its natural state, while human intervention by seeding “difficult” plants (like *Rhus tripartita*, *Deverra tortuosa*, *Artemisia campestris*, and *Artemisia herba-alba*) can accelerate the rehabilitation process and greatly enhance forage quality of the field; 6) the considered field can be used for controlled grazing since 43% of existent species were pastoral species.

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