1   **Livestock grazing-induced large-scale biotic homogenization in arid Mediterranean steppe rangelands**

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13  Running title: **Effects of livestock grazing on plant composition and diversity**

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27

28  **Abstract**

29  Despite many studies explored the effect of livestock grazing on plant communities, the response of species

30  composition and diversity to livestock grazing in arid rangelands remain ambiguous. This study examined the

31  effects of livestock grazing on plant communities in arid steppe rangelands of North Africa. Plant diversity of

32  annual species, perennial species and all species combined was measured and compared between grazed and

33  grazing-excluded areas. We also examined the relative importance of species turnover and community

34  nestedness. Moreover, the effects of livestock grazing on beta diversity at local among transects and landscape

35  among sites scales were examined using the multiplicative diversity partitioning. Results revealed that livestock

36  grazing significantly decreased the alpha diversity of all species combined and the diversity of annual plants.

37  Livestock grazing induced a shift in plant community composition where most of species composition variation

38  (~74%) was due to infrequent species replacement 'turnover' between the two management types rather than

39  nestedness (~26%). Results revealed also that among transects, beta diversity was higher in grazed steppes than

40  in grazing-excluded steppes. Whereas, among sites, beta diversity was lower in grazed steppes compared to

41  grazing-excluded steppes. These findings suggest that livestock grazing in arid steppe rangelands increases the

42  variation in plant species composition at a local spatial scale and engenders vegetation homogeneity at landscape

43  spatial scale. Therefore, the implementation of appropriate management practices such as short-term grazing

44  exclusion is mandatory to prevent these ecosystems from large scale biotic homogenization.

45  **KEYWORDS**: Mediterranean rangelands; ecological spatial-scaling; species composition dissimilarity; alpha

46  and beta diversity; species turnover; rangeland grazing; plant community.

47

## 1 | INTRODUCTION

Unsustainable livestock farming is considered the biggest driver of biodiversity loss and land productivity decline in drylands (Hanke et al., 2014). The impact of grazing on plant community structure and diversity, particularly in arid rangelands, is a major concern for range use and nature conservation (Fischer et al., 2019). Many studies carried out in these ecosystems have focused on the effects of grazing on alpha diversity which is an important focus because biodiversity is likely more affected at that scale. However other components of biodiversity, mainly beta diversity which is defined as the difference in species composition between communities, can also be altered due to grazing disturbances (Grman et al., 2018). For instance, de Bello et al, (2007) stressed that species beta diversity could respond to grazing intensity in different ways (positively, unimodal-response, or negatively) depending on climatic conditions (from arid to humid conditions).

Recent studies have revealed that livestock grazing behaviour could affect vegetation patterns in a distinct way across spatial scales (Limb et al., 2018). At a local scale, grazing disturbance might increase species diversity, by decreasing competitiveness and favouring the colonization of new species (Dorrough et al., 2007). On a broad scale, however, grazing could decrease diversity by eliminating species that are not adapted to grazing (Fischer et al., 2019; Limb et al., 2018). Furthermore, intense grazing could promote the expansion of certain plant species in a particular location. These species may have different functional roles, auto-ecological characteristics and adaptation strategies, including colonizer and invader species, ephemerals, ruderals, and even stabilizer species (such as the dominant species in semi-arid steppe rangelands of North Africa: *Macrochloa tenacissima* (L.) Kunth (syn. *Stipa tenacissima* L.), *Artemisia herba-alba* Asso, *Artemisia campestris* L., *Atriplex halimus* L. and *Stipagrostis pungens* (Desf.) De Winter. This leads to the selection of more similar species, which engenders compositional convergence, a process known as biological homogenization (Puhl et al., 2014). This process promotes the substitution of native species by widespread generalists that have greater ecological plasticity and wider ecological niche (Puhl et al., 2014). In arid and semi-arid rangelands, ruderals and therophytic plants govern the biotic homogenization in plant communities. Because the ecological plasticity of these plant categories allow species to cope with rapid environmental changes (Tarhouni et al., 2010; Kouba et al., 2021). Despite this broad conceptual context, a full understanding of how grazing affects the biodiversity of arid rangelands still lacking. The reason behind this is that most of the existing studies did not consider concomitantly different diversity measures and different spatial scales (Hanke et al., 2014).

Other studies have revealed that species diversity alone may not adequately reflect the shifts in vegetation composition and structure that occur in response to grazing disturbance in the dryland biomes, changes of the vegetation might be better reflected by trait-based diversity measures (Hanke et al., 2014, Puhl et al., 2014). This includes the exploration of aspects beyond taxonomic diversity patterns such as the measurement of $\alpha$, $\beta$, and $\gamma$ components of plant functional and phylogenetic diversity (Crist et al., 2003; Wang et al., 2019). As the timing of species establishment and possibly competitive outcomes are determined by functional traits linked to life-history strategies such as life longevity (Byun et al., 2013; Puhl et al., 2014). To understand community dynamics, it is critical to monitor shifts in the diversity of functional groups based on relevant traits (Puhl et al., 2014).

North African rangelands extend along the northern edges of the Sahara Desert, which makes these ecosystems subjected to severe effects of the hot-dry desertic climate. These climatic conditions promoted the existence of a specialized plant community (Slimani et al., 2010; Fatmi et al., 2020). Previous studies on plant communities carried out in these rangelands have mainly focused on the measurement of diversity using species richness, Shannon diversity, and evenness to explain the relationship between livestock grazing and plant diversity (e.g., Amghar et al., 2012; Merdas et al., 2017). However, little information is available on how livestock grazing affects species composition and beta diversity at multiple spatial scales in these arid ecosystems (Kouba et al., 2021).

In the present study, ten alfa steppes were selected in the arid high plains of Algeria, to investigate the response of plant community structure and diversity to grazing disturbance. We contrast freely grazed and grazing-excluded steppes to address the following questions: (i) does livestock grazing evenly affects rare, common, and dominant species (i.e., alpha diversities) of annual and perennial plants? (2) does the grazing-induced change in species composition due to species turnover (species restitution i.e. species eliminated by grazing and replaced) or community nestedness (refers to habitats with low richness host part of the species of richer habitats) or both of

96  them? (3) how livestock grazing affects plant beta diversity at different spatial scales (local scale vs. landscape
97  scale)? Based on the assumption that plant diversity responds negatively to grazing under resource-poor conditions
98  (Milchunas & Lauenroth, 1993), we expect negatives responses of alpha and beta diversities to livestock grazing in
99  these arid steppes. Furthermore, based on previous studies carried out in the arid high plains of Algeria (Aidoud et
100 al., 2006, Amghar et al., 2012, Kouba et al., 2021) we predict that livestock grazing will alter the composition of
101 plant assemblages mainly by inducing the loss and replacement of many native species.
102
103 **2 | MATERIALS AND METHODS**
104 **2.1 | Study area**
105     The study was conducted, approximately 150 km southeast of the capital Algiers, in the arid steppes located
106 in Central Algerian rangelands (Figure 1). The elevation ranges between 621 m a.s.l. in the high plateau region
107 and 980 m in piedmont near the Saharan Atlas, with a mean value of 842 m ($\pm$ 94.33). Soils of the study area are
108 dominated by Calcimagnesic, carbonated, and encrusted gypsum soils (Halitim, 1988).
109     The climate data obtained from the nearest meteorological station of Bou-Saâda (M'sila Province), for the
110 period of 1988–2014 showed that the climate is arid Mediterranean. The mean annual rainfall was 184 mm with
111 peaks in spring and fall. Only 103 mm of rainfall was recorded during the monitoring year (2014). The average
112 temperature was 32.30°C for July, indicating the hottest month, while January is the coldest month with 8.88°C.
113     The studied plant community is characteristic of the steppe vegetation of North Africa, where Halfah grass
114 *Macrochloa tenacissima* (syn. *Stipa tenacissima*) dominated. Other common species were shrubs (*Artemisia*
115 *herba-alba* Asso, *Artemisia campestris* L., *Helianthemum lippii* (L.) Dum. Cours., and *Noaea mucronata*
116 (Forssk.) Asch. & Schweinf.), forbs (*Anacyclus monanthos* subsp. *cyrtolepidioides* (Pomel) Humphries,
117 *Atractylis serratuloides* Sieber ex Cass., *Helianthemum salicifolium* (L.) Mill., and *Malva aegyptia* L.) and
118 grasses (*Stipa capensis* Thunb., *Koeleria pubescens* P. Beauv., *Stipa lagascae* Roem. & Schult., and *Poa bulbosa*
119 L.) (Le Houérou, 1995).
120     Lands of the study area are used mainly for livestock grazing where rangelands are subjected to free
121 continuous grazing (all around the year), principally by sheep. The pastoralists are semi-nomadic populations
122 (Slimani et al., 2010). The estimated stocking rate in the study area was 3.77 sheep units/ha, based on the data
123 provided by the agricultural services of M'sila Province; this represents a high-grazing intensity (Merdas et al.,
124 2017). All sampled sites within this region had similar topographic and climate conditions (Kouba et al., 2021).
125 Short-term grazing-exclusion is a management strategy implemented by the High Commission for the
126 Development of the Steppe (HCDS) to maintain the rangelands in a healthy state and avoiding land degradation.
127 The grazing-exclusion areas are open for grazing after pastoral carrying capacity assessment carried out by HCDS
128 technicians. The short-term grazing-exclusion is defined as a period of 3–4 years of protection from grazing
129 activity (Sullivan & Rohde, 2002; Amghar et al., 2012).
130
131 **2.2 | Data collection**
132     In spring 2014, during the period of peak vegetation growth (April–May), the vascular plant species were
133 sampled in ten sites dominated by the Halfah grass (*M. tenacissima*) in the rangelands of Central Algeria (see
134 Kouba et al., 2021 for details on characteristics of the sampled sites). Five sampled sites were freely grazed for
135 decades, whereas five other sites were protected from livestock grazing "grazing-excluded" for the last three years
136 (from 2011). Within each site, we performed vegetation surveys in three 200 m-long transects spaced 250 m
137 apart, which means 15 transects in grazed areas and 15 transects in grazing-excluded areas. Plant species
138 abundance, richness and composition were estimated for each transect using the line-point intercept method,
139 which consists of recording, at every 20 cm intervals (i.e., 1000 points located every 20 cm), the identity of all
140 individuals that are in contact with a vertical nail (Kouba et al., 2014). The abundance of each species in each
141 transect was estimated from the number of individuals recorded along the same transect. Plant species that could
142 not be identified with certainty in the field were collected, pressed, and brought to the herbarium for identification.

143  The plant nomenclature was based on the African Plant Database (www.ville-ge.ch/musinfo/bd/cjb/africa) and
144  the E-flora Maghreb website (https://efloramaghreb.org/).

145

146  **2.3 | Plant diversity estimation**

147  Measures of plant diversity, namely, alpha- and beta-diversity were quantified using Hill numbers ($^qD$).
148  Hill's $q$-metrics reflecting the sensitivity of the diversity index to relative abundances of species. The analysis
149  included the following $q$ values: (i) $q=0$ reflects species richness, which is not sensitive to species abundances
150  (ii) $q=1$ is equivalent to the exponential of Shannon entropy index; here, species are weighted in proportion
151  to their frequency in the sampled community, and therefore, it can be interpreted as the number of "typical
152  species" in the community, and (iii) $q=2$ is the equivalent of the inverse of Simpson's concentration index,
153  which can be interpreted as the number of "very abundant species" in the community (Chao et al., 2012).

154

155  **2.4 | Statistical analysis**

156  Statistical analysis was carried out using the R software (R Core Team, 2020). First, variations in alpha
157  diversity metrics between grazed and grazing-excluded sites were analyzed using generalized linear mixed-effects
158  models (GLMM), for all plant species combined and for annual and perennial species, separately. The GLMMs
159  were performed using the function "lme" of the package {nlme}. To account for spatial dependencies, site
160  location "pseudo-replication" was included as a random effect in the models (Kouba et al., 2015), whereas steppe
161  grazing status "grazed vs. grazing-excluded" was the fixed effect. Normality and homogeneity of variance were
162  tested by examining the model residuals versus the fitted plots and the normal q-q plots of each model.

163  To test for a significant difference in plant species composition between grazed and grazing-excluded areas,
164  PERMANOVA analysis and non-metrical multidimensional scaling (NMDS) ordination were performed using
165  the functions "adonis" and "metaMDS" of the {vegan} package, respectively. NMDS was run based on Bray-
166  Curtis similarities using $4^{th}$-root transformation to reduce the weight of the most abundant species. Furthermore,
167  to assess whether the difference in plant species composition was due to species replacement or nestedness, the
168  additive partitioning of the total beta diversity method (Baselga, 2010) was performed using "beta.sample"
169  function of the package {betapart} (Baselga & Orme, 2012). In this analysis, the total beta diversity ($\beta_{SOR}$) is
170  defined as a Sørensen dissimilarity index which is additionally partitioned into $\beta$ Simpson ($\beta_{SIM}$) describing
171  species turnover and $\beta$ nestedness ($\beta_{SNE}$) which measures community subsetting [$\beta_{SOR} = \beta_{SIM} + \beta_{SNE}$].

172  The effect of grazing on beta diversity at multiple spatial scales was assessed using multiplicative diversity
173  partitioning (Jost, 2006). This method was mainly employed to quantify among-transects (Beta transects) and
174  among-sites (Beta transects) beta diversities for grazed and grazing-excluded steppes. At transect level (grain =
175  transect and extent = site), $\beta$-diversity measures reflect within sites variations (i.e., local variation in species
176  composition). At site level (grain = site and extent = management type {grazed/grazing-excluded}), $\beta$-diversity
177  measures reflect among sites within management type variation. Multiplicative diversity partitioning analysis was
178  performed using the "multipart" function from the {vegan} package.

179

180  **3 | RESULTS**
181  **3.1 | Species composition and relative abundance**

182  A total of 101 plant species were recorded (Appendix 1) and classified into 81 genera and 26 families. Most
183  species were annuals, *i.e.*, 62 species against 39 perennial species. The grazing-excluded steppes included more
184  species (*S*=93 species) compared to grazed sites (*S*=61 species). Plant species occurring exclusively in grazing-
185  excluded steppes were dominated by annual species (28 out of 40 species). Also, annual species represented 31
186  out of 53 for common species (shared species) whereas they represent 3 out of the 8 species exclusive of grazed
187  steppes (Figure 2). The most frequent species were *M. tenacissima* (33.25%), *Anacyclus monanthos*
188  *cyrtolepidioides* (11.50%), *Stipa capensis* (7.89%), *Malva aegyptia* (7.67%), and *Artemisia herba-alba* (5.58%).

189

190  **3.2 | Alpha diversities**

191      When all species were included in the analysis, all measures of alpha diversity using Hill numbers ($^qD$) ($q=0$,
192   $q=1$, $q=2$) were significantly higher in grazing-excluded sites than in grazed areas. The same results were observed
193   for the annual species, except values of the inverse of Simpson concentration ($q=2$) which were not significantly
194   different between steppes. For the perennial species, estimates of plant diversity were not significantly different
195   between grazed and grazing-excluded steppes (Figure 3).
196
197   **3.3 | Beta diversities**
198      The PERMANOVA analysis revealed that plant species composition differed significantly between grazed
199   and grazing-excluded sites ($P<0.001$). Livestock management type (free grazing vs. grazing-exclusion) explained
200   almost 60% of the variation in the composition of plant communities in arid rangelands. The compositional
201   difference was clear in the plot determined using the NMDS analysis that revealed a clear separation between the
202   grazed and grazing-excluded sites (Figure 4).
203      Results indicated also that beta diversity generated from grazed and grazing-excluded sites contributed
204   greatly (54.2%) to the total diversity. Furthermore, the additive partitioning of the overall beta diversity ($\beta_{SOR}$)
205   indicated that 74.11% of the compositional dissimilarity was due to species turnover whereas 25.89% resulted
206   from nestedness. This result reflects that a large part of the compositional differentiation is due to species
207   replacement instead of plant community nestedness.
208      The multiplicative diversity partitioning also indicated that beta diversity measures expressed by values of
209   $q$-metrics were higher than expected by chance (Figure 5). Among transects, beta diversity (Beta transects) was
210   higher in grazed areas than in grazing-excluded areas. Whereas, among sites, beta diversity (Beta sites) was lower
211   in grazed sites compared to grazing-excluded areas. Furthermore, beta diversity decreased with the increasing of
212   $q$ values in both management types.
213
214   **4 | DISCUSSION**
215   **4.1 | Influence of grazing on over all diversity**
216      Finding from this study highlight the strong connection of plant community diversity to herbivore activity.
217   Plant species diversity of arid steppe rangelands of Algeria decreased significantly in grazed sites where it
218   declined by 30%. Shifts in plant species diversity due to grazing have been previously reported in steppe
219   rangelands of North Africa (Aidoud et al., 2006; Hirche et al., 2011; Kouba et al., 2021). Recently Gao & Carmel
220   (2020a) conducted a meta-analysis on the relationship between grazing and plant diversity and the results showed
221   that in arid environments, diversity responded negatively to grazing intensity. These findings strengthen the
222   assumptions of the generalized dynamic equilibrium model (Milchunas et al., 1988) where grazing intensity
223   decreases plant diversity in dry conditions. Livestock grazing can play a non-negligible role in the loss of
224   biodiversity and the collapse of ecosystem services under a changing climate especially when rangelands are
225   overloaded with livestock animals exceeding the carrying capacity (Hao et al., 2018; Oñatibia et al., 2020).
226   However, long-term grazing under moderate intensity has driven increases in plant species richness of temperate
227   grasslands with no losses of native plants and biodiversity (Puhl et al., 2014).
228      Although we found more perennial species in grazing-excluded areas, livestock grazing had no significant
229   effects on rare, frequent, and abundant perennial species. This is mainly because the recorded perennial species
230   were among the highly specialized and well-adapted species to the specific ecological conditions prevailing in
231   these environments, *i.e.*, recurrent drought events and continuous livestock grazing. Particularly, *M. tenacissima*,
232   which is considered a grazing-resistant species and barely palatable, was notably abundant in grazed areas in
233   Algerian steppe rangelands (Slimani et al., 2010) and Cabo de Gata Nijar, Spain (Saiz & Alados, 2012). The
234   effects of grazing on plant diversity differ from one climatic region to another (Milchunas & Lauenroth, 1993).
235   While the aridity and severe climatic conditions deepen the degradation of rangelands due to grazing in arid and
236   semi-arid regions (Oñatibia et al., 2020; Kouba et al., 2021); in temperate regions, moderate grazing can promote
237   plant diversity. According to Puhl et al. (2014), grazing in the mesophytic prairies increased local species richness
238   by 46% and regional richness by 28%.

239

### 4.2 | Alpha diversity

240

241 This study showed that the richness of annual species in grazing-excluded areas is higher than in grazed
242 steppes. This result is consistent with previous studies carried out in arid Mediterranean rangelands, which
243 reported a high abundance of ephemeral herbaceous species inside the protected areas (Amghar et al., 2012).
244 Similarly, Neffar et al. (2018) stressed that the rehabilitation of arid steppe rangelands produces more herbage
245 under protection with a high frequency of therophytic annual plants. Overall, it is well acknowledged that the
246 species composition of the Mediterranean rangelands is mainly determined by annual plants with a few
247 numbers of high abundant perennial species such as *M. tenacissima* (Aidoud et al., 2006; Osem et al., 2007).

248 Many annual plants found in the protected areas (e.g., *Scorzonera undulata* Vahl, *Medicago laciniata* (L.)
249 Mill., *Lolium rigidum* Gaudin, *Medicago minima* (L.) L., *Hippocrepis multisiliquosa* L.) are considered as forage
250 species (Le Houérou, 1995), while non-protected areas exposed to free grazing were dominated by undesirable
251 plant species (Oñatibia et al., 2020). This could be attributed to the fact that sheep preferably consume the most
252 nutritious species, which reduces their abundance and even led to their disappearance (Tarhouni et al., 2010). In
253 line with this, Olff & Ritchie (1998) stressed that under the effect of herbivores, grazing-intolerant species can
254 disappear from the community resulting in low diversity.

255 Our findings revealed that livestock grazing changed significantly the composition of plant assemblages,
256 where the compositional divergence was mainly due to species replacement (74%) rather than community
257 nestedness (26%). Indeed, a total of 40 species (70% annuals and 30% perennials) present exclusively in grazing-
258 excluded steppes replaced the 8 exclusive species (37.5% annuals and 62.5% perennials) of grazed steppes. On the
259 other hand, our analysis indicated that transient species are the most affected by livestock grazing. Similarly,
260 Li et al. (2015) reported a decrease in the overall plant species richness because the majority of rare species
261 were highly grazed by animals. The data of this study indicated that the rarest species (frequency of occurrence in
262 samples ranged between 3.3–6.7%) that were absent in grazed steppes include 14 annuals (*Adonis dentata*,
263 *Ammoides verticillata*, *Avena sterilis*, *Centaurea omphalotricha*, *Ebenus pinnata*, *Echinaria capitata*, *Filago*
264 *germanica*, *Hippocrepis multisiliquosa*, *Lolium rigidum*, *Medicago minima*, *Papaver hybridum*, *Reseda luteola*,
265 *Rochelia disperma*, and *Spergularia diandra*) and 9 perennials (*Asparagus albus*, *Atractylis delicatula*, *Centaurea*
266 *incana*, *Centaurea tenuifolia*, *Erodium glaucophyllum*, *Genista microcephala*, *Peganum harmala*, *Salvia*
267 *verbenaca*, and *Thymelaea hirsuta*).

268

### 4.3 | Beta diversity

269

270 The analysis of diversity patterns at multiple spatial scales showed that beta diversity contributed significantly
271 to the overall diversity measure. All measures of beta diversity (*i.e.*, $q=0$, $q=1$, $q=2$) were significantly different
272 and greater than random estimates at both landscape and local spatial scales. This indicates that plant species were
273 not randomly distributed among and within scales, reflecting intraspecific aggregation (Crist et al., 2003). Our
274 analysis also showed that the most important portion of beta diversity is occurring at a broad scale (*i.e.*, among
275 sites) in both management types (free grazing vs. grazing exclusion). This may be explained as all the combinations
276 of transects beta diversity could be well represented at the site level could leading to a higher beta diversity (Beatty,
277 2014). Moreover, the fact that the values of beta diversity were the highest when more weight is given to rare
278 species reflects the great emphasis of rare species in patterning plant assemblages in arid steppe rangelands. In the
279 semi-arid Mediterranean rangelands, plant diversity was found to be considerably represented by rare species
280 (Osem et al., 2002). However, the protection from grazing increased the beta component of the exponential
281 Shannon diversity and the reciprocal Simpson diversity at broad scales (among sites). This can be attributed to the
282 prevention of negative competitive interactions and the establishment of associations between plant species
283 (Dorrough et al., 2007). The results also agree with previous studies that stressed the importance of grazing-
284 exclusion management practice for the conservation of biodiversity in dry areas (Gao & Carmel, 2020b; Kouba et
285 al., 2021). Such pattern of recovery in plant diversity is consistent with the theory of the high resilience of
286 Mediterranean rangelands with a long history of grazing (Perevolotsky & Seligman, 1998; Golodets et al., 2011).

287  This study demonstrated that livestock grazing in arid rangelands of Algeria increased the compositional
288  divergence in plant communities. This result supports the notion that increased intensity of grazing may surge the
289  spatial variation in species assemblages at the local scale (Zhang et al., 2013). Besides, Golodets et al. (2011)
290  stressed that herbivores increase small scale heterogeneity of soil nutrients (impact of excreta), which may
291  increase plant diversity. Interestingly, our results revealed that livestock grazing reduces compositional
292  divergence and contributes to vegetation homogenization at the landscape scale. This finding is in line with other
293  studies that reported a generalization of vegetation homogenization as a result of overgrazing (Dorrough et al.,
294  2007; Li et al., 2015), in particular in arid Mediterranean ecosystems (Alados et al., 2004). This plant
295  homogenization can result in the loss of biodiversity and ecosystem functions (Mori et al., 2018).

296

## 297  5 | CONCLUSION

298  This study highlights the effects of livestock grazing on plant community composition and diversity in arid
299  steppe rangelands. Our findings suggest that increasing livestock grazing intensity in arid rangelands could
300  decrease plant alpha diversity and induces a shift in plant community composition because of the spatial turnover
301  of less frequent species. Our analysis indicates also that livestock-induced changes in beta diversity are scale-
302  dependent: at a local scale, these changes are characterized by the increasing variation in species composition,
303  while at the landscape scale they are represented by a large-scale biotic homogenization. We recommend that the
304  improvement of the grazing management system in arid steppe rangelands is mandatory to prevent further land
305  degradation due to biodiversity loss and large-scale biotic homogenization. The implementation of "short-term
306  grazing exclusion" in many sites at the same time and the application of appropriate sheep stocking rates in the
307  surrounding areas could enhance the ecological value of protected steppes.

308

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424

425 **FIGURE LEGENDS**
426
427 **FIGURE 1.** Location of the study area in the central steppe rangelands of Algeria. Orange solid points (●) indicate
428 locations of sampled sites in grazed steppes and green solid points (●) represent grazing-excluded sites
429
430 **FIGURE 2.** Plant relative abundance (in%) and species richness for perennials and annuals in grazed and grazing-
431 excluded steppe rangelands of arid lands of Algeria.
432
433 **FIGURE 3.** Comparing alpha diversities for all plant species combined, perennials and annuals, between grazed and
434 grazing-excluded "ungrazed" areas of the steppe rangelands of Algeria. Results of GLMMs tests are included in the figure
435 as an asterisk (*) indicating significant differences ($P > 0.05$), and (ns) no significant differences
436
437 **FIGURE 4.** Non-metrical multidimensional scaling (NMDS) ordination based on Bray-Curtis similarities using 4th-
438 root transformation. Each symbol-point represents a 200-m transect used in plant sampling.
439
440 **FIGURE 5.** Comparing beta diversities between grazed and grazing-excluded in the arid steppes rangelands of Algeria.
441 Diversity was quantified using the Hill numbers, with $q = 0$ (all species are given equal weight), $q = 1$ (greater weight is
442 given to common species), or $q = 2$ (greater weight is given to dominant species). "Beta transects GS" and "Beta transects
443 GES" refer to among transects beta diversity (grain = transect and extent = site) in grazed and grazing-excluded steppes,
444 respectively; "Beta sites GS" and "Beta sites GES" refer to among sites beta diversity (grain = site and extent =
445 management type) in grazed and grazing-excluded steppes, respectively.
446