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in

Porqueddu C. (ed.), Ríos S. (ed.).
The contributions of grasslands to the conservation of Mediterranean biodiversity

Zaragoza : CIHEAM / CIBIO / FAO / SEEP
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 92

2010
pages 167-174

Vulnerability of Mediterranean grasslands to climate change: What can we learn from a long-term experiment?

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Abstract. Species diversity in Mediterranean grasslands could be seriously affected in the proximate future by significant changes in climate, as predicted by climate change models for the Mediterranean basin. These models forecast a reduction in precipitation, changes in seasonal rainfall distribution and a decrease in predictability. These changes can also affect the structure, production and composition of Mediterranean grasslands, particularly those that serve as rangelands. Here we present a long-term study (16 years) in Mediterranean grassland in Israel that aimed to evaluate the responses of plant species, plant functional groups and the plant community to different management regimes of cattle grazing. We examined the effects of precipitation change on the structure of the herbaceous community in order to understand the potential role of climate change. The results showed: (i) a decrease in peak standing biomass with decreasing annual rainfall; (ii) rainfall distribution and quantity played an important role in determining species composition –dry years favoured thistles and crucifers while wet years favoured legumes; (iii) grazing significantly reduced the cover of tall grasses; and (iv) that as yearly rainfall increased, stocking density had an additional negative effect on species diversity. Despite significant changes in rainfall amount and cattle grazing pressure along the studied period, the studied Mediterranean grassland showed a highly resilient response to all environmental variations. The perennial herbaceous component of these communities buffers against drastic changes in community structure and causes the eastern-Mediterranean grassland to become potentially less vulnerable to climate change.

Keywords. Cattle grazing – Management regimes – Rangelands – Species diversity.

La vulnérabilité des pâturages méditerranéens face au changement climatique : que peut-on apprendre d'une expérimentation à long terme ?

Résumé. *Selon les modèles calculés pour le bassin méditerranéen, la diversité des pâturages méditerranéens pourrait prochainement être sérieusement affectée par des changements significatifs de climat. Ces modèles prévoient une réduction des précipitations, des modifications de la distribution saisonnière des pluies et une prédictibilité moindre des phénomènes climatiques. Ces modifications pourraient affecter la structure, la production et la composition des prairies méditerranéennes, et en particulier de celles qui sont pâturées. Nous présentons une étude à long terme (16 ans) de pâturages méditerranéens en Israël dont l'objectif était d'évaluer les réactions d'espèces végétales, de groupes fonctionnels et de la communauté végétale à différentes méthodes d'élevage bovin. Nous avons examiné les effets des précipitations sur la communauté herbacée pour comprendre le rôle potentiel du changement climatique. Les résultats montrent que: (i) le pic de biomasse décroît quand les précipitations annuelles diminuent ; (ii) la distribution et le volume des précipitations ont un effet important sur la composition des espèces – les années sèches favorisant les épineux et les crucifères, les années humides favorisant les légumineuses ; (iii) le broutage diminue le pourcentage des herbes hautes ; et (iv) plus les précipitations augmentent, plus la densité de pâturage a un effet négatif sur la biodiversité. Malgré les changements significatifs au niveau des précipitations et de la densité de pâturage, le pâturage méditerranéen étudié ici a été très résistant face aux variations de l'environnement. Les herbacées pérennes constituent un tampon face aux changements structuraux extrêmes de la communauté et ainsi, les pâturages de l'est méditerranéen sont potentiellement peu vulnérables au changement climatique.*

Mots-clés. *Bovins en pâturage – Conduite du pâturage – Pâturages – Biodiversité.*

I – Introduction

Warmer and drier climatic conditions are predicted in the future around the Mediterranean basin (IPPC, 2001). In general, global and regional climate models for the region consistently predict a decrease in average water availability due to increasing temperatures and decreasing annual rainfall and an increase in the occurrence of climatic extremes (Bates *et al.,* 2008; Black, 2009; Kafle and Bruins, 2009). The Mediterranean basin is one of the regions where global circulation models agree with the prediction of decreasing precipitation (Bates *et al.*, 2008). In Israel, it was found that during the period of 1970 to 2002 the climate became more arid in most regions (Kafle and Bruins, 2009).

The combined warmer and drier climate conditions will considerably affect ecosystem services, such as fodder production, CO_2 sequestration, soil nutrient cycling and plant-insect interactions. Drier bio-climatic conditions due to warming would cause agricultural production in the semi-arid and dry sub-humid zones in the world to become more vulnerable (Kafle and Bruins, 2009). Life cycles that are strongly influenced by temperature and precipitation were found to be altered for some of the most abundant Mediterranean plants and birds (Peñuelas *et al*., 2002). Changes in the annual productivity of two Mediterranean shrubs under drier and warmer conditions were also detected (Llorens *et al.,* 2004; De Dato *et al.,* 2008). Shifts in plant distribution as species expand into newly favourable areas are also expected (Kelly and Goulden, 2008), while species diversity can be seriously affected.

Grazing is a very important factor in this process since its intensity has a strong impact on landscape productivity in the dryer regions (Kochy *et al*., 2008). Mediterranean regions represent the transition from mesic temperate to arid climate, therefore the effect of climate change on vegetation may be most pronounced in these regions (Lavorel *et al.*, 1998). Mediterranean rangelands are likely to suffer from this change and strategies for sustainably managing the scarce resources in these areas are needed.

The aims of this work were: (i) to evaluate the effects of yearly rainfall on the structure of the herbaceous community; and (ii) to investigate how Mediterranean grassland responds to different grazing management systems by evaluating the responses of individual key species and plant functional groups.

II – Materials and methods

1. Study site and experimental design

The study was conducted at the Karei Deshe experimental farm, located in the eastern Galilee in the north-east of Israel (long. 35º35'E; lat. 32º55'N; alt. 60-250 m a.s.l.) (Gutman *et al*., 1990, 1999). The topography is hilly, with slopes generally less than 20º (Seligman *et al*., 1989) covered with basaltic rocks with an average cover of 30% (Gutman and Seligman, 1979). The soil is a fertile brown basaltic protogrumosol of variable depth, but seldom deeper than 60 cm. The area has a Mediterranean climate, characterized by wet and mild winters with mean minimum and maximum temperatures of 7ºC and 14ºC, respectively. The average seasonal rainfall measured between 1963/4 and 2008/9 is 555 mm per year. The rainy season begins in October-November and ends in April. The vegetation is a rich hemicryptophytic grassland (Zohary, 1973) dominated by *Hordeum bulbosum* L., *Echinops* spp., *Bituminaria bituminosa* L. and many annual species, totalling about 200 plant species.

The study took place between 1994 and 2009 in twelve paddocks of 14 to 28 ha each. Treatments comprised two stocking rates, high (0.9 ha per cow) and moderate (1.8 ha per cow), and three forms of grazing management: continuous, seasonal (till no available forage is left on the plot) + early cattle introduction to the plots and seasonal + late introduction, with two replicates for each treatment. The paddocks were stocked with mature, medium-frame-size cows with an average body weight across seasons of 432±15 kg. In the "continuous" and "seasonal early" systems cattle were introduced to the range in mid-January. The early high stocking rate was maintained till mid-March, while the early moderate stocking rate was maintained till mid-May (Sternberg *et al*., 2000). The seasonal late grazing followed in similar paddocks. All paddocks were grazed till August at the high stocking rate and till November at the moderate one, when standing biomass reached less than 700 kg DM ha^{-1}.

2. Vegetation sampling and analysis

Sampling took place every year between 1994 and 2009 (16 years) during spring (in April, which is the period of maximum vegetation growth). Quadrates of 25 × 25 cm were randomly placed along permanent transects that crossed all paddocks and above-ground herbaceous biomass was harvested down to ground level. Twenty samples were harvested in each paddock, including two paddocks as control (without grazing), totalling 280 samples for each year of the study. The harvested plant material was oven-dried at 65°C and weighed.

Every year of this study, vegetation composition was monitored during the peak season of primary production (early to mid-April). Plant cover and species composition were estimated using the step-point method, along permanent transects 200 to 700 m long that traversed the paddocks from fence to fence. Every two steps, a thin stick was placed vertically in the vegetation and the uppermost species in contact with the recording stick was recorded. The vegetation was classified into 10 functional groups according to life cycle, plant height and taxonomy (Noy-Meir *et al.*, 1989), including: tall perennial and tall annual grasses (>50 cm at maturity), short annual grasses (<50 cm), perennial and annual legumes, perennial and annual thistles, crucifers and "forbs" (all other dicots). Relative cover (%) was calculated from total plant cover, excluding rock and bare ground cover. Species nomenclature follows Feinbrun-Dothan and Danin (1991). In addition, the Shannon and Weaver (1949) species diversity index was calculated for species diversity for each paddock.

III – Results and discussion

1. Annual rainfall

Daily rainfall has been measured at the Karei Deshe experimental farm since the winter of 1963/4. A continued average decrease of 3 mm per year was found in the annual precipitation till the winter of 2008/9, along with CV of ~30%. The five year annual rainfall moving average at the Karei Deshe experimental farm showed a consistently decreasing trend of about 100 mm of rainfall in 46 years (Fig. 1).

2. Vegetation production – standing biomass

Annual fluctuations in standing biomass were found over the years of the study (Fig. 2a). The relationship between total annual rainfall and average peak standing biomass for the plots that were not exposed to grazing till spring was found to be positive but not very strong (R^2 = 0.1222) (Fig. 2b).

3. Vegetation composition – plant functional types

Tall annual grasses were highly affected by the different grazing management systems. Their cover decreased with the increase of grazing intensity (P = 0.001) (Fig. 3a). The reduction of cover by grazing was more salient in rainy springs (P = 0.024). Comparing timing (early *vs* late grazing), cover of tall annual grasses was higher in the late grazing treatments (Fig. 3b).

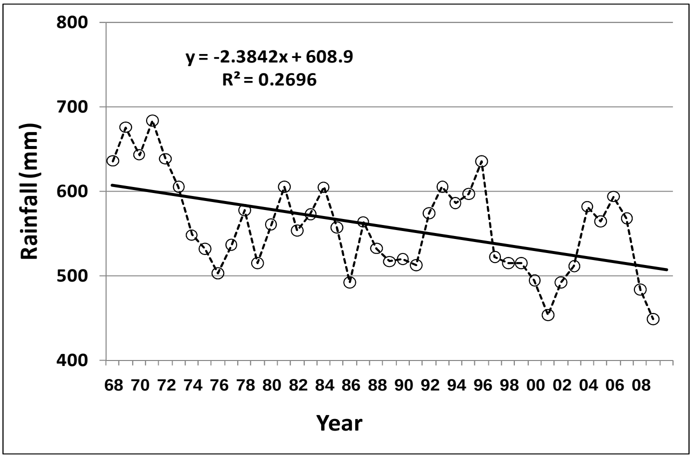

Fig. 1. Five year annual rainfall moving average at the Karei Deshe experimental farm between 1963/4 and 2008/9 seasons.

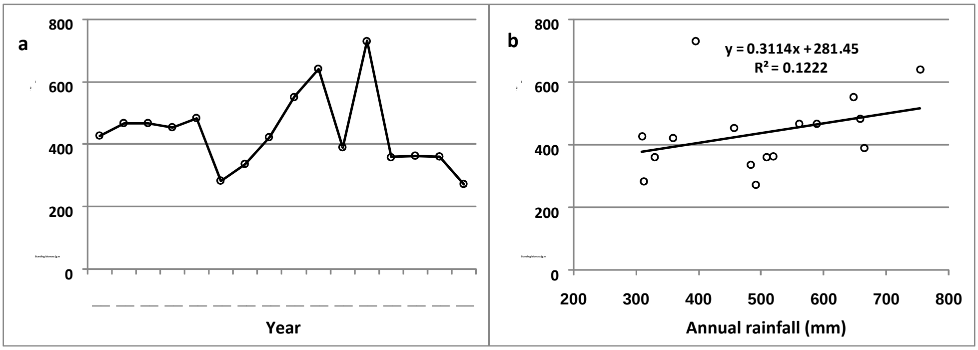

Fig. 2. Vegetation standing biomass in paddocks with no grazing between 1994 and 2009 (a) and the relationship between total seasonal rainfall and standing biomass during that period (b).

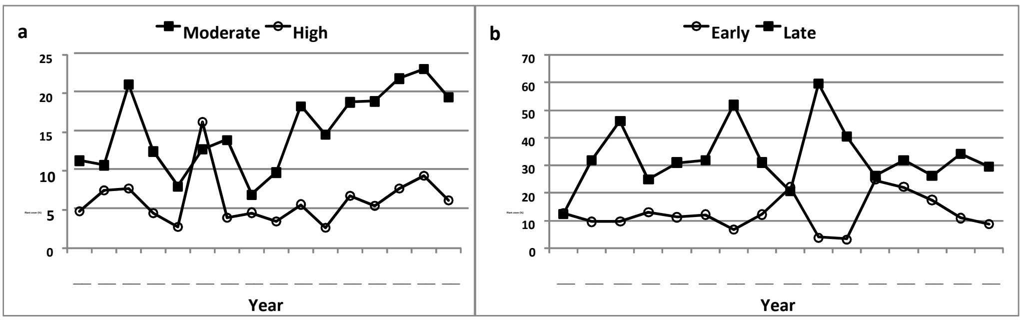

Fig. 3. Cover (%) of tall annual grasses at moderate (1.8 ha/cow) and high (0.9 ha/cow) stocking rates (a) and under early and late grazing (b).

As found for tall annual grasses, the cover of tall perennial grasses was consistently higher in paddocks with continuous grazing at lower pressure as well as in treatments with late grazing. In addition, differences in rainfall between years had a significant effect on their cover. Short annual grasses showed a significant increase in cover from year to year (2.6% to 17%) (P = 0.008). The cover of annual legumes increased significantly during high rainfall years (Fig. 4a). On the other hand, cover of perennial thistles (Fig. 4b) and crucifers (Fig. 4c) increased in low rainfall years.

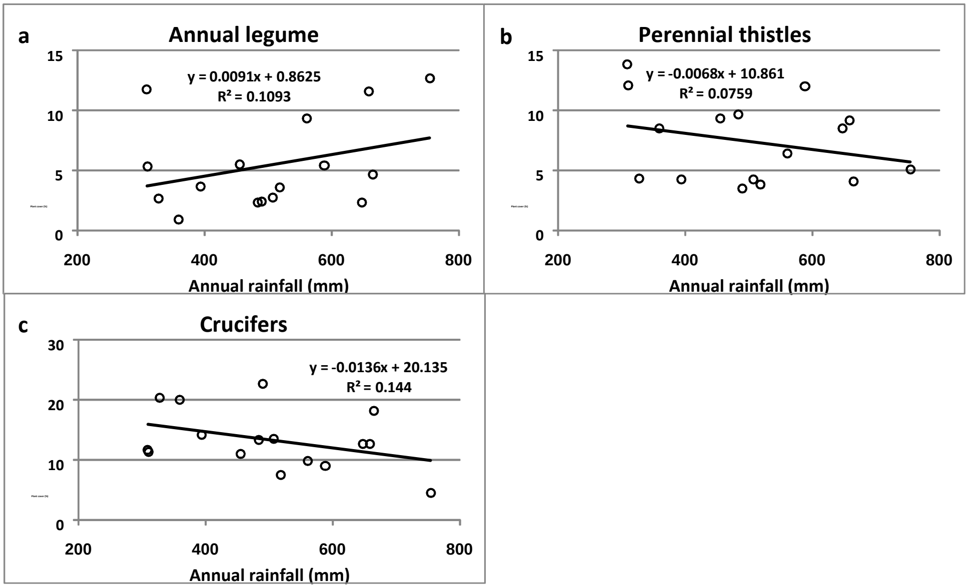

Fig. 4. Cover (%) of annual legumes (a), perennial thistles (b) and crucifers (c) in all management treatments combined, in relation to annual precipitation between 1994 and 2009.

4. Species diversity

Analyses show that in general, species diversity was relatively higher in grazed paddocks (Fig. 5a *vs* 5b). Significant differences were found in species diversity among years and their interaction with grazing treatments (P = 0.001 and P = 0.0214, respectively). Species diversity was affected by rainfall conditions in the grazing season (P = 0.022). Species diversity under grazing decreased with increased rainfall; however, due to the lack of significant differences, we cannot conclude that drier conditions will lead to higher diversity (Figs 5b,c and d).

Mediterranean grasslands are characterized by high rainfall variability both between years and within the rainfall seasons (Sternberg *et al.*, 2000). Consequently, yearly changes related to these inter-annual climatic conditions were found in standing biomass and vegetation composition. A summary of our main results shows that: (i) lower standing biomass was found in drier years; and (ii) in relatively wet years the cover of legumes increased and the cover of perennial thistles and crucifers decreased.

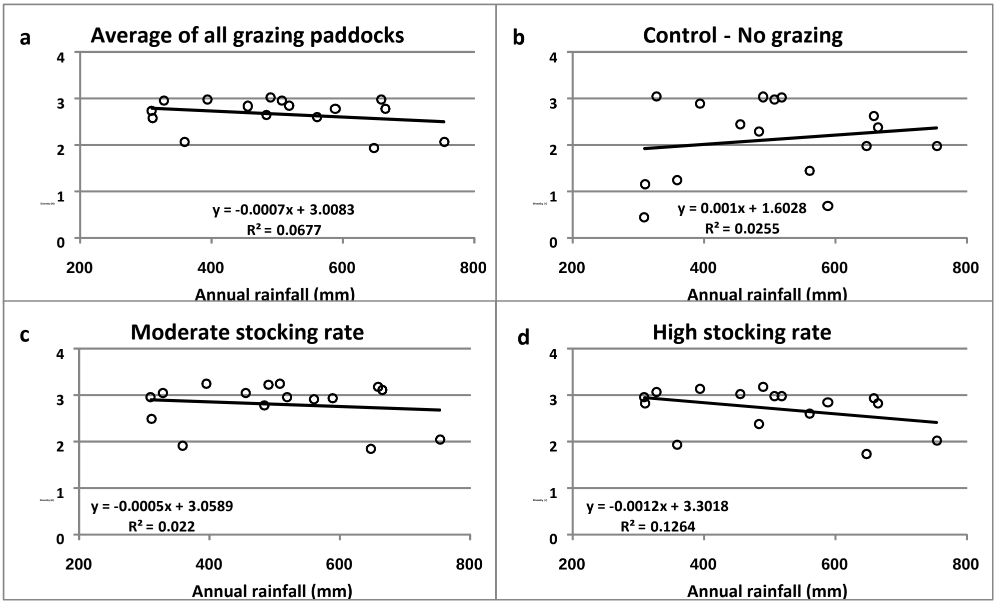

Fig. 5. Species diversity (H) in all grazed treatments combined (a) with no grazing (b) and under continuous moderate (c) and high (d) stocking rates in relation to annual rainfall between 1994 and 2009.

As shown, the resilience of the system is very high. Differences in vegetation composition as expressed in plant functional types are manifested every year according to the annual precipitation characteristics. It is clear that change in climate conditions plays an important role in determining the vegetation structure, but in the long run, most species are very resilient, and those whose presence decreased drastically in a certain year increased in the following year with the change in rainfall. It is therefore common to find in Mediterranean grasslands many species that are well adapted to long dry spells and grazing, and manifest a high degree of resilience following extensive climatic variability and defoliation (Perevolotsky and Seligman, 1998). In systems with high dominance of grasses and annual species, the rapid changes in plant species composition that occurs following grazing cessation were associated with a fast recovery of the potential for biomass production to levels found in long-term protected plots (Golodets *et al.*, 2009).

Dry seasons had a major effect on the dynamics of the plant community, whereas grazing played a secondary role. These results are consistent with observations from other studies that have attempted to relate changes in vegetation to rainfall and grazing intensity (Lauenroth and Sala, 1992; Koukoura *et al.,* 1998).

IV – Conclusions

Despite significant yearly changes in productivity and vegetation composition related to variations in rainfall amount and cattle grazing pressure along the studied period, Mediterranean grasslands appear to be highly resilient in response to environmental variations.

The perennial herbaceous component buffers against drastic changes in community structure and makes the eastern-Mediterranean grassland less vulnerable to climate change.

Acknowledgments

The study was funded by grants from the Israeli Range Management Advisory Board, Northern R & D, and the Jewish National Fund. The authors gratefully acknowledge the assistance of Tzadock Cohen and the many people who participated in field work through the years.

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