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VEGETATION CHANGE IN VARIABLE RANGELAND ENVIRONMENTS: THE RELATIVE CONTRIBUTION OF DROUGHT AND SOIL TYPE IN ARID RANGELANDS

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Abstract

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The response of a plant community to protection from grazing, as a function of year and soil type, was studied in the arid rangelands of southern Tunisia between 2007 and 2009. The vegetation of rangelands is often altered under grazing pressure, but unfortunately, removing the grazing pressure often does not reverse the changes in the way the succession model predicts. Rainfall variability is a key driver of ecosystem structure and function in arid rangelands, and this arid area of North Africa is characterized by low and erratic rainfall and is prone to drought conditions which normally occur every two to three years.
Steppes are likely to exhibit strong and rapid structural and functional responses to these altered rainfall patterns. Although drought affects vegetation cover more in loamy soil than in all other soils, it affects diversity on all soils; particularly limestone and loam soils.

Key words: drought, soil type, management, arid rangeland.

Introduction

Natural disturbances and often previously unnoted human disturbances became a serious challenge to traditional succession, beginning as early as the 1940's (e.g., Stearns, 1949; Raup, 1975) but really solidifying in the 1970's. The increasing recognition of the pervasiveness of disturbances (White, 1979) led to the idea that ecological systems operated only in periods between disturbances.

Dynamic changes in vegetation level are controlled by the balance between climatic and anthropogenic factors. Human activity has greatly accelerated the rate at which species have disappeared from the earth (May et al., 1995). The anthropogenic origin of this phenomenon has been underlined by studies of demographic pressure, overgrazing and clearing of the ligneous family (Auclair et al., 1999).

According to Le Houérou (2009), the primary causes of vegetation destruction on arid land, and indirect causes of desertification, are clearing of land unsuitable for cultivation, prolonged overstocking and overgrazing and the destruction of woody species by excessive firewood collection. In addition to the anthropogenic factors, climate influences a variety of ecological processes (Stenseth et al., 2002). These effects operate through local weather parameters such as temperature, wind, rain, snow, and ocean currents; and the interactions occurring among them. There have been several recent studies on the impact of large-scale climatic forces on ecological systems.

The relationships between climate, soil, vegetation and other components of arid ecosystems have been described by many authors, including: Shreve (1942), Hassib (1951), Tadros (1953), Vernet (1955), Kassas (1955), Chapman (1960), Zohary (1962), Batanouny (1973), Younnes et al. (1983), Ayyad and El-Ghareeb (1984), Evenari et al. (1985), Zahran and Willis (2008) and Le Houréou (2009)

"Mediterranean bioclimates are characterized by winter rains and summer drought" (Le Houérou 2005a, b). However, droughts can occur anywhere, and this simple statement tells us nothing about what constitutes a drought (Allaby, 2003). In parts of North Africa, a drought occurs when no rain has fallen for at least two years. Perhaps, then, a drought can be defined as a period during which rainfall is insufficient to meet the needs of plants. Droughts meeting this definition have led to ongoing debates on desertification (Mainguet, 1995; Thomas, 1997).

Millions of people in rangelands depend directly on livestock for their livelihoods, but the management of these regions remains mired in controversy (Gillson, Hoffman, 2007). The sustainable management of natural resources demands controls negating land degradation and desertification (Ganry, Campbell, 1995). Although restoration models and practices have previously been applied to ecosystems, there is now a more recent focus on the "landscape perspective" of ecosystem restoration to improve nature conservation and management effectiveness (Moreira et al., 2006).

Among rare rehabilitation experiments, the one carried out by Le Floc'h et al. in 1999 in southern Tunisia enabled the reconstitution of a badly degraded steppe. In addition to this technique being generally beneficial to vegetation cover and species diversity (Gamoun et al., 2010a), it was found here that although sandy soil is more productive than limestone soil, the latter is more resistant to animal trampling (Gamoun et al., 2010b).

This study describes the effects of drought on the vegetation of the major rangeland soil types of the Dhahar from 2007 to 2009, with emphasis on cover, species richness and diversity.

Study area and data collection

This study was conducted over three years on four protected rangelands. This rangeland is localized in southern Tunisia, forming a collective steppe unit of the plate of Dhahar to the south of Tataouine (10°32'280 E and 32°8'760 N). The climate is characterized by hot dry summers and cool mild winters, so according to Emberger (1954), it has a Saharan superior Mediterranean bioclimate.

Through our study, the studied rangelands can be divided into four different types designated since 2007; these rangelands are distributed as follows:

- Rangelands 1; is dominated by perennial grasses such as *Retama raetam*, *Hammada schmittiana*, and *Calligonum comosum* on wadi bed,
- Rangelands 2; the main dominant species are: *Hammada schmittiana* and *Anthyllis sericea* on limestone soil,
- Rangelands 3; dominated by *Helianthemum kahiricum* on loamy soil,
- Rangelands 4; the main dominant species are: *Stipagrostis pungens* and *Hammada schmittiana* on sandy soils.

These communal rangelands are exploited by individuals and although overgrazing can occur. they are largely composed of plants that have resisted or benefitted from grazing and drought (Gamoun, 2005). On this rangeland, each individual had an incentive to increase the number of animals and no individual was entitled to prevent access to others, (Hardin, 1968).

Since each rangelands, three 20-m long transects were set up to measure Total Plant Cover using the quadrat point method (Jauffret, Visser, 2003). Observations were made every 20 cm, providing a total of 100 points in each transect. The total plant cover is determined by the formula:

TPC = (n/N) x100 ; where n = the number of points where vegetation is present

and N = the total number of points in each transect (100 points in this case).

The Shannon's index of diversity H' (Shannon-Wiener, 1948) is used in ecology to measure the specific diversity (Margalef, 1958); it takes into account not only the floristic richness but also the proportion of each species in the herbaceous stratum. It is calculated from centesimal frequencies of species (fi): $H' = - \Sigma ((fi / N) * \log2 (fi / N))$,

Where ; fi = the number of i species in the samples, and N = the overall number of species.

H' varies between:

- H' = 0 : where the population consists of a single species;
- H' = log2 S : where the existing species have equivalent abundance.

The obtained data is subjected to several statistical analyses using SPSS for windows software v. 11.5 (SPSS Inc., 2002).

Results

Vegetation cover, diversity and species richness were assessed in March each year (2007, 2008 and 2009). The following classes of data were analyzed for each stratum: (1) cover, (2) species richness and (3) diversity.

Weather conditions

Rainfalls during the period from 1987 to 2009 averaged 75 mm/year (Fig. 1). The temporal rainfall distribution in Tataouine is eminently variable, with annual rainfall irregularly being either side of the norm. Various anomalies include: considerable reduction in rainfall in 1987, 1998, 1998, 1998, 1999, 2001, and 2009, and contrasting periods of excessive humidity (1990, 1994, 1995 and 2002).

From 2003, there was a marked tendency in annual rainfall to constantly remain lower than the average precipitation established over one long period.

These rainy events in southern Tunisia are characterized by their great variability and very irregular distribution. During the past twenty years, several droughts have affected the south and caused significant losses, mainly in agricultural sectors, and these have endangered farms specializing in livestock. The research community perceives the apparent desertification as a transient response to reduced rainfall (Tucker et al., 1991, 1994). A number of studies have shown that degradation to this land is reversible; with vegetation restored when rain returns.

Temperatures exceeded 30 °C for sixty days, and the maximum exceeded 40 °C for ten days. The average annual heat-under-shelter varied between 22 and 23 °C, while the winters were cold, registering between 11 and 12 °C in January.

The rains are spread over part of the year, with a relative variability of rainfall above 95% and a Martonne index of aridity of approximately 2 to 3. The most important rains generally fell in winter, spring and autumn, with the heaviest at 11.57 mm in October. The minimum rainfall of 0 mm has occurred in summer, in July (Fig. 2).

During summer, temperatures are pleasant with 32 °C in July and August and 30 °C in

June. Maximum temperatures are expected to increase with the growing season which is segmented into rain events separated by drought periods. If two successive years are dry, the probability of a third dry year in the south ranges from 14—17% (Benzarti et al., 2001).

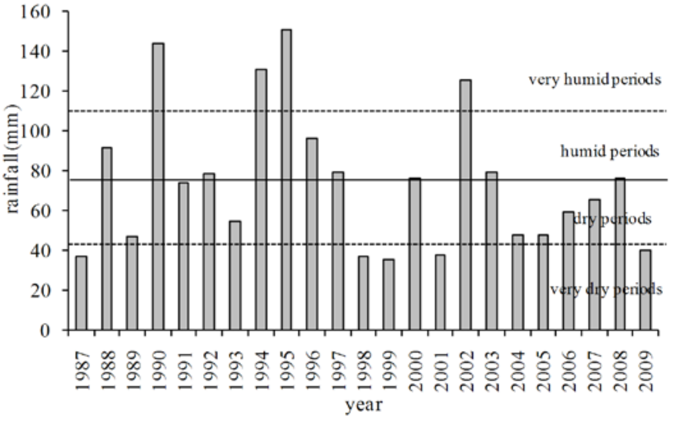

Fig. 1. Average rainfall distribution between 1987 and 2009 in Southern Tunisia (Remada).

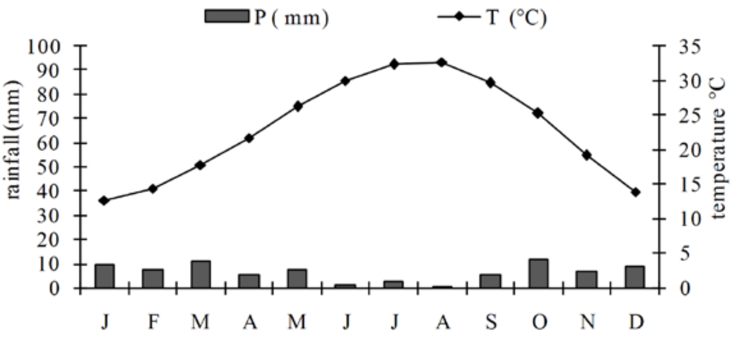

Fig. 2. Climatogram plans showing temperature and precipitation in Remada.

Vegetation cover

Plant cover depended on the edaphic gradient which differs from precipitation. Although the vegetation type exerted significant effects on vegetation cover ($F = 3.839$, $P = 0.043$), the annual effect was insignificant ($F = 4.853$, $P = 0.047$). The analysis of changes in vegetation cover revealed a highly significant interaction between vegetation type and season ($F = 6. 6$, $P < 0.001$). The existence of mutual interactions in the data is not surprising, because of the predictably strong effect of species composition.

The values recorded for vegetation types show that vegetation cover of species on limestone soil and in the wadi bed were the highest, followed by those on sandy soil and then those on loamy soil.

The vegetation cover increased from 50% in 2007 to 57% in 2008. In 2009, it decreased to 19% on loamy soil, highlighing the effect of the low precipitation in that year (Fig. 3).

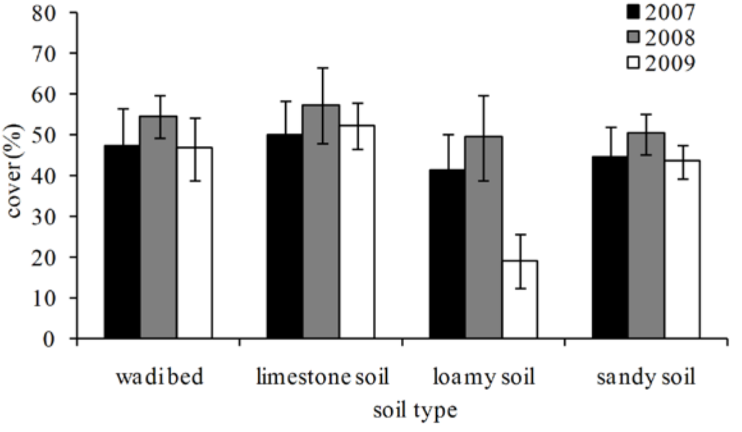

Fig. 3. Spatial and temporal variability in vegetation cover.

Species richness

The number of species under protection from grazing varied greatly between years ($F = 9.264$, $P = 0.001$), and there was also a significant difference between sites ($F = 6.044$, $P = 0.002$).

On average, each site is mostly dominated by 8 plant species. In the three year study period, rainfall changed plant community composition to a much greater extent in 2008 and to a much lesser extent in 2009. In 2007, species richness in loamy soil was consistently greater than at the remaining sites, while in 2008, which was considered a wet year, species richness

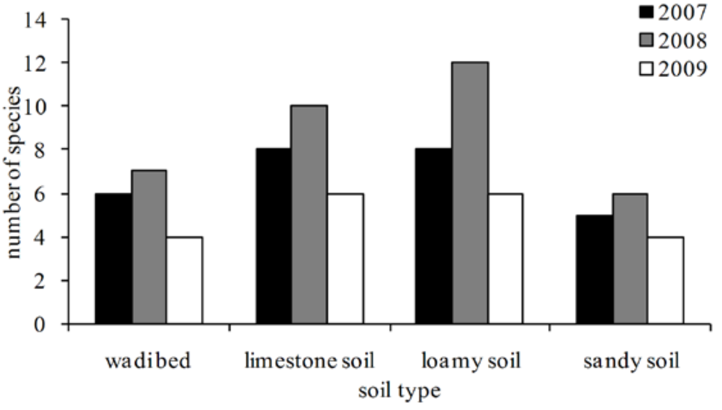

Fig. 4. Spatial and temporal variability in species richness.

had an increasing trend over time at all sites. This diversity then decreased to four species in 2009 due to that year's low precipitation (Fig. 4).

All sites on this gradient were dominated by perennial species which comprised 72% of the total species richness. Only *Hammada schmittiana* is present on all sites, while the presence of the other species varied according to soil type and year (Table 1).

T a b l e 1. Spatial and temporal species distribution.

	wadi bed			limestone soil			loamy soil			sandy soil		
	2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009
Anthyllis sericea	—	—	—	+	+	+	—	—	—	—	—	—
Anabasis oropediormum	—	—	—	—	—	—	+	+	—	—	—	—
Argyrolobium uniflorum	—	—	—	—	+	—	+	+	—	—	—	—
Atractylis serratuloides	—	—	—	+	+	+	+	+	+	—	—	—
Calligonum comosum	—	+	—	+	+	+	—	—	—	—	+	
Cutandia dichotoma	+	+	+	—	+	—	—	—	—	+	+	—
Daucus syrticus	—	—	—	+	+	+	—	—	—	—	—	—
Fagonia glutinosa	—	—	—	—	—	—	—	+	—	—	—	—
Gymnocarpos decander	—	—	—	—	—	—	+	+	+	—	—	—
Hammada schmittiana	+	+	+	+	+	+	+	+	+	+	+	+
Helianthemum sessiliflorum	—	—	—	—	—	—	+	+	+	—	—	—
Herniaria fontanesii	—	—	—	—	—	—	+	+	+	—	—	—
Koelpinia linearis	—	—	—	+	+	—	—	+	—	—	—	—
Launaea resedifolia	—	—	—	—	—	—	—	+	—	—	—	—
Plantago albicans	—	—	—	—	—	—	—	+	—	—	—	—
Polygonum equisetiforme	+	+	+	—	—	—	—	—	—	—	—	—
Retama raetam	+	+	+	—	—	—	—	—	—	—	—	—
Saesola vermiculata	—	—	—	—	—	—	—	—	—	+	+	+
Savignya parviflora	—	—	—	+	+	+	+	—	—	—	—	—
Schismus barbatus	+	+	—	—	—	—	—	+	+	+	+	+
Stipa lagascae	—	—	—	+	+	—	—	—	—	—	—	—
Stipagrostis pungens	+	+	—	—	—	—	—	—	—	+	+	+

Floristic diversity

Plant species diversity refers to the number of species and their relative abundance in a defined area. Diversity measurements incorporate species richness; where S = the number of plant species in a community. The spatial scale strongly influences biodiversity (Crawley, Harral, 2001; Symstad et al., 2003). Similarly, drought represents a determining component of arid ecosystem dynamics and biodiversity maintenance. Climate constitutes a crucial feature in arid rangelands, and drought often seriously affects the structure and diversity of vegetation communities, especially those on this steppe.

Although the overall ANOVA of floristic diversity with the year factored in was highly significant ($F = 43.284$, $P < 0.0001$), the vegetation type was not significant ($F = 1.070$, $P = 0.375$). However, vegetation and year registered significant dependence at $F = 4.016$, $P = 0.006$.

The current diversity period is mainly caused by drought impact. Patterns of land degradation, and presumably also biodiversity loss in this zone, have been greatly influenced by severe degradation events during drought. This diversity varied from 1.1 to 1.4 in 2007, and increased to 1.8 in 2008 in the wadi bed. There then followed a sharp decrease to 0.3 on limestone and loamy soil in 2009 (Fig. 5).

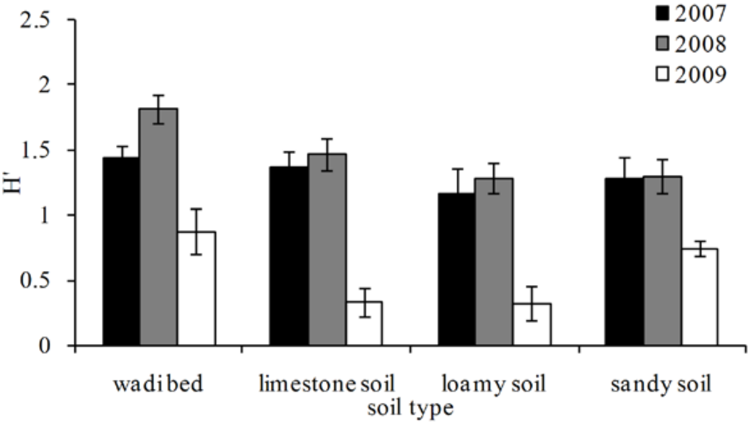

Fig. 5. Spatial and temporal variability in diversity.

Discussion

The effects of climate and soil type on vegetation have been studied by numerous researchers. Grime (1979) reported that the environment can control species richness in two distinct ways; by regulating the expression of dominance and by affecting the potential richness (pool of suitable species). Previous studies in southern Tunisia demonstrated relationships between vegetation soils (Floret, Pontanier, 1982), and rainfall (Le Houérou, Hoste, 1977). Variations in vegetation cover exhibited an overall tendency firstly to increase and then to decrease, but significant spatial contrast remained. While vegetation cover increased in 2008 with high precipitation, this then decreased in the low precipitation of 2009.

The dynamic variability of climatic parameters can also have significant implications for species richness, diversity and productivity. Changes in vegetation diversity can be considered one of the most sensitive indicators of climatic variability and they can be used to monitor the climate changes on different spatial scales. Hence, it is necessary to identify the different relationships existing between different climatic variables and vegetation dynamics. These relationships can have different patterns and magnitude on different spatial and temporal scales.

Soils in arid and semi-arid areas contain characteristics limiting ecosystems (Lundholm, 1976). As indicated by Whitford (2002), soil is the most important factor affecting vegetation structure in ecosystems. Sparsely distributed vegetation, results in a heterogeneous horizontal pattern of vegetation patches alternating with areas of bare soil (Noy-Meir, 1973).

This study shows that changes in vegetation are most affected by local climatic effects. It is reasonable to assume that these changes will manifest themselves in the frequency of warmer months and warmer seasons. In this study, the close relationship existing between vegetation and climatic variables are reflected in the impacts of the 2009 droughts. It also reveals that the dry season rainfall in this country decreases productivity in sandy soil by 25%. Results further indicate that these droughts have resulted in substantial declines in vegetation.

While the number of species is highest in loamy soil, and limestone soils reveal a slightly lower average, the lowest species numbers were recorded in the wadi bed and sandy soil.

The impact of species diversity on ecosystem functioning has generated considerable research and tremendous debate in view of the accelerated worldwide depletion in biodiversity (Singh et al., 2005). In particular, many recent advances have indicated that, on average, diversity can be expected to give rise to ecosystem stability (Wolfe, 2000; Chapin et al., 2000; Tilman, 2000; McCann, 2000).

Clearly, in these situations, the response to variation in species diversity cannot be separated from the response to environmental variation. This relationship is a central but contentious issue within ecology (Schmid, 2002).

Conclusion

This research tested whether particular patterns of variation in cover, diversity and richness can be applied generally to distinguish between mechanisms responsible for organizing vegetation.

Rangeland vegetation is highly dynamic due to climatic variability and extensive ecosystem degradation by increased population pressure from both humans and animals. The spatial scale strongly influences vegetation. Similarly, drought represents a determinant component of arid ecosystem dynamics and maintenance of vegetation biodiversity.

Our results indicate that changes in cover, species richness and species diversity depend on the spatial scale and rainfall. Drought affects the vegetation cover on loamy soil to a greater extent than on the other soils, and while diversity was affected by drought in all soils, this was particularly noted on limestone and loamy soils.

Water condition is a limiting factor for vegetation, and precipitation plays a key role in the ecological distribution of vegetation. When annual precipitation increased, vegetation cover improved, and conversely when annual precipitation decreased, the vegetation cover was degraded. Moreover, the relationship between precipitation and vegetation rapidly reached a significant level, and the steady retention of this level indicates that vegetation change is very sensitive to precipitation change. The soil type here was also shown to play an important part in species diversity.

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