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30 Years of protection and monitoring of a steppic rangeland undergoing desertification

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ABSTRACT

Stipa tenacissima L., which has long been recognised as the typical dominant perennial plant in the North-African arid rangelands is currently going into extinction in the steppic High Plains of Algeria. The vegetation and soil dynamics were analyzed at an initially dense stand. The trend between 1976 and 2006 was investigated using five reference years. Sampling was performed along a grazing gradient including a grazed steppe and an exclosure. Between 1976 and 1993, the perennial cover and soil organic matter decreased outside the exclosure, while the composition of the dominant species remained unchanged. From 1993 to 2006, the plant cover, species composition and soil showed major changes both inside and outside the exclosure and *S. tenacissima* disappeared completely in 2006. These changes were primarily attributed to overgrazing by sheep. More frequent and intensive droughts exacerbated the grazing intensity in a context of common and uncontrolled land use. The exclosure, implemented as a remedy, temporarily played a positive role regarding vegetation and soil conservation. In addition to severe drought, the vegetation and soil degradation and sand encroachment even inside the exclosure, created conditions that were no longer able to support the pre-existing alfa-grass ecosystem.

1. Introduction

Until the early 20th Century, the nomadic pastoralists represented more than 80% of the population in the arid steppic rangelands in Algeria (Boukhobza, 1982). Extensive sheep and goat grazing was the main land-use for centuries as an opportunistic strategy coping with arid climate, variable precipitation and unpredictable natural forage production (Ellis and Swift, 1988).

The *Stipa tenacissima* L. (alfa-grass or alfa) steppe covered about 70% of the High Plains more than a century ago (Whal, 1897). Alfa is still described as the most representative dominant species in the arid High Plains of Algeria. However, due to desertification, the alfa steppe has virtually disappeared, and it only persists on mountain piedmonts bordering the high plains (Slimani and Aidoud, 2004; Aidoud et al., 2006).

The steppic rangelands of Algeria particularly suffered rapid degradation during the last three decades. Large portions of the Algerian arid rangelands have been protected from livestock using exclosures as one of the measures taken to restore degraded vegetation.

Most of the previous studies on the effects of exclosure on soil and vegetation (e.g. Valone and Sauter, 2005; Mekuria et al., 2006; Yayneshet et al., 2009) addressed rangelands that were already degraded. Few studies have focused on rangelands that were initially in an optimal environmental condition.

In order to attempt rangeland management options, knowledge about the pre-existing system is crucial to a better understanding of the interactions between land-use and climate changes. The targeted study site had been selected in the most favorable conditions of vegetation and soil for long-term environmental monitoring by collaborative national and international research projects. Research activities have focused on seasonal and inter-annual changes of biomass and diversity as a function of precipitation (Aidoud, 1989, 1992), resistance to water stress by *S. tenacissima* (Nedjraoui and Touffet, 1994) and soil seed composition (Hanifi and Touffet, 1989). A 12 ha exclosure was fenced in July, 1975 within an open rangeland grazed by sheep all the year-round. Eighteen years later, vegetation and soil analyses clearly showed that the original vegetation and soil conditions were maintained inside the exclosure, in contrast to the highly degraded land outside which had been subjected to uncontrolled grazing (Aidoud and Touffet, 1996; Aidoud et al., 1999; Slimani and Aidoud, 2004).

The types and causes of environmental changes and desertification in the arid zone of Algeria have been debated with two

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opposing main primary causes: land-use change and climate change. According to the UNCCD definition of desertification, the recurring droughts and various human overexploitation, mainly overgrazing (Le Houérou, 1996) were the two main driving factors that we focused on. Uncertainties still exist in the prediction of arid ecosystem responses to global climate change vs. land-use change (Lioubimtseva and Henebry, 2009). In many parts of Africa, especially in the arid zone, besides the decrease in rainfall, drought frequency and intensity have increased during the past three decades (IPCC, 2007). This trend towards more climatic instability and variability may constitute one of the most insidious manifestations of climate change (Hillel and Rosenzweig, 2002; Thomas, 2008).

The aim of this paper is to assess the impacts of grazing (exclosure vs. overgrazing) and climatic variability and change on vegetation and soil over a period of 30 years, based on data from five reference years. Specifically, we analyzed rainfall, the plant cover and key soil characteristics.

2. Methods

2.1. Study area

The study area is located near the city of El Bayadh, on the "Rogassa plateau" in western Algeria. This area belongs to the 'Steppic high plains'; one of the three main eco-climatic regions in Algeria. It is named 'High Plains' due to its elevation, mostly higher than 1000 m in the western part, and the geomorphology consists of large sub-horizontal pediments or 'glacis'. The study site (33.56°N, 0.51°E) is located at an elevation of 1095 m on a gently sloped (<2%) pediment with a shallow sandy–silt soil, limited by a calcareous crust at depths of 20–30 cm. The climate is arid-Mediterranean, with a mean annual rainfall of 250 mm occurring mainly between autumn and spring, a dry period of 6–8 months and the mean annual temperature is 15 °C.

The pre-existing homogeneous steppe of about 30,000 ha (Aidoud, 1992), represented one of the best alfa-grass stands in North Africa. The mean plant cover was of 50%, dominated by up to 90% *S. tenacissima* perennial tussocks growing in a patchy pattern. Between the tussocks, ephemeral plants occurred. During dry years, a bare silty crust occupied nearly all of this interstitial space.

The main land-use was sheep husbandry carried out by semi-nomadic populations using seasonal transhumance. However, *S. tenacissima* itself is known to be barely palatable by sheep except for the young leaves and inflorescences that were grazed preferentially.

2.2. Data sampling and analyses

The long-term monitoring site was first established in 1975. Data on the vegetation and physical environment were collected over a period of 30 years. The site includes:

- a 12 ha exclosure (fenced since 1975) to exclude domestic herbivores, within an open rangeland grazed by sheep outside the fence.
- a 4300 m transect representing a grazing gradient starting within the exclosure (300 m) and continuing onto the open rangeland (4000 m). We analyzed the data from the grazed area as a whole i.e. regardless of the grazing gradient effects (Aidoud et al., 1999) that became imperceptible after 2000.

Practical field trip difficulties interrupted the monitoring program from 1994 to 1999. Therefore, we retained five years (1976, 1987, 1993, 2000, and 2006) that provided statistically reliable data. Sampling was carried out using the same protocol, with at least five samples, taken as pseudo-replicates, from the relatively homogeneous protected zone and ten samples taken from the grazed area.

We used the pin-point sampling technique to assess frequencies of plants and other soil surface elements. This technique was mostly used for low vegetation (Rozé and Lemauviel, 2004; Jauffret and Visser, 2003). The absolute frequency, Af_i, is the number of hits for a given plant species i, along a 20 m line transect consisting of 200 sampling points at 10 cm increments.

The relative frequency (Rf in %) of a given plant species was calculated as $Rf = Af_i/200 \times 100$, and was considered to be equivalent to plant species cover. Regarding the floristic composition, only the most frequent species, i.e. those identified along the line, were analyzed. The total plant cover was assessed regardless of the species composition, by subtracting the number of bare soil points from the total sampled points.

Soil analyses were initially performed in 1976, to describe the general soil characteristics at the study site. Analyses were carried out again in 1993, to identify possible changes in the soil components. At least ten samples were analyzed for each year to provide the particle size (clay, silt, and sand) and organic matter content. The particle size analyses were performed using the sedimentation method, sampling the fine fractions (silt and clay particles) by Robinson pipette and the larger fractions by sieving. The soil organic carbon content was measured using the Duchaufour (1970) method. Annual precipitation data for the Rogassa site were only available from 1975 to 1986. Therefore, we used data from the nearest (31 km) main weather station of El Bayadh for which rainfall data was available since 1875. A significant correlation ($p = 0.0296$) was found between rainfall data recorded at the two stations between 1975 and 1986.

Changes in plant cover and soil components both inside and outside the exclosure were tested using an ANOVA (Sokal and Rohlf, 1969) and Student's t-test.

Three data types were considered in the present paper:

a- Annual rainfall (September–August), which is the only water source;
b- Plant cover: individual species, perennials vs. ephemerals and total cover;
c- Soil characteristics: soil surface crust, sand cover and stone frequencies; soil texture and soil organic matter.

3. Results

3.1. Precipitation (1975–2006)

Due to its higher elevation, the El Bayadh station received more precipitation (29 mm yr^{-1} on average) than the Rogassa study site.

During the 1975–2006 period, annual rainfall showed important fluctuations (Fig. 1a); including three dry periods: 1978–1979, 1983–1985, and 1998–2003. The mean annual rainfall between 1975 and 2006 was 254 mm yr^{-1}. It was 14% lower ($p = 0.0158$) than the measured one (297 mm yr^{-1}) since 1875 with a mode of 240 mm yr^{-1}. This mode value (i.e. the most probable amount of rainfall) being less than the mean is a typical feature of arid climate (Hillel and Rosenzweig, 2002). Although the general trend during the 132-year-period showed a decrease in rainfall (Fig. 1b), we did not found a significant change using the Mann-Kendall test. However, the study period showed the higher number of multi-annual dry periods.