Landscape changes of desertification in arid areas: the case of south-west Algeria

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Abstract This study aims to monitor the arid Algerian High Plateaus, a key region for pastoral activities which has suffered harsh and widespread degradation from the eighties. This area is not sufficiently known by the international scientific community. For this purpose, we considered phytoecological inventories and thematic maps that have been carried out during 30 years. Available data for the study are vegetation maps derived from aerial photographs (1975–1978) and from satellite imagery (2006). The parameters considered include vegetation, flora, and soil surface properties. The study area is part of the ROSELT/OSS (ROSELT: Réseau d'Observatoires de Surveillance Ecologique à Long Terme (Long Term Ecological Monitoring Observatories Network); OSS: Observatory of the Sahara and the Sahel) network observatory (OSS 2008). To assess land degradation, we used landscape ecology parameters. These include the number and surface area of vegetation units, synthesized by the large patch index and the Shannon landscape diversity index. All parameters reflect an increase in landscape heterogeneity. The largest decline is observed for *Stipa tenacissima* vegetation units constituting 2/3 of the landscape in 1978 and occupied just 1/10 in 2006. Vegetation units linked to degradation, such those dominated by *Salsola vermiculata*, inexistent in 1978, now dominate the steppe. Another result of the ongoing landscape degradation on the plateaus between 1975 and 2006 is the decrease of vegetation cover. In 1978, 1/3 of rangelands only had low vegetation covers, inferior to 15%. Presently 9/10 present the same class cover. This can be explained by severe spells of drought combined by an exponential rise of livestock during the last 30 years. This has in

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turn greatly undermined the fodder potential of the steppe. Results suggest that the "greening-up" described by several authors in the Sahel over the last 40 years is not observed in the Algerian, nor in the North African steppes. On the contrary, the desertification is still ongoing and the threshold of irreversibility seems to be imminent.

Keywords Change detection · Heterogeneity · Landscape ecology · Desertification · Remote sensing

Introduction

Land degradation, long an important environmental issue in arid and semi-arid lands, is now acute in Algeria's high plateaus. The Algerian steppes are the most widespread rangeland of the North African countries. They occupy a pivotal position between the hilly and humid north, called the Tell, composing 5% of Algeria's surface, and the south formed by the Sahara covering 86% of the nation's territory. The Sahara is the largest desert of the planet (Tucker et al. 1991). Nevertheless, relatively few scientific works had been edited in English up to now (Benhouhou et al. 2003). Early studies based on remote sensing data and techniques undertaken with the objective of monitoring land conditions found no evidence for extensive degradation in the Sahelian region (Helldén 1984, 1991; Prince et al. 1998; Tucker and Nicholson 1999; Rasmussen et al. 2001). On the contrary, recent studies of the Sahelian vegetation based on remote sensing data even emphasize "the greening-up" of the Sahel (Anyamba and Tucker 2005; Helldén 2008; Helldén and Tottrup 2008). At the North African area, the results are globally in contradiction with these results. The aim of this study is to contribute some elemental reflections to this issue by evaluating qualitatively and quantitatively the phenomenon of land evolution in a representative area in the south Oran steppe (about 10 million hectares). The study area covers approximately 400,000 ha and the time horizon considered is 30 years. Data analyses are based on indices borrowed from landscape ecology: the large patch index (LPI), the Shannon landscape diversity index (SHDI), and the use of geographic information systems (GIS) and remote sensing tools. The interest of the approach is to consider potential landscape heterogeneity as the result of land degradation.

In 1975, the Centre de Recherches sur les Ressources Biologiques et Terrestres (CRBT) carried out a major vegetation monitoring program in the south Oran steppe producing thematic maps of the entire area. Also, permanent observation sites have been set up to collect more accurate data. The latter have been gathered for 30 years of observations.

Results from similar studies will provide a general overview for the North African countries and it would be possible to carry out rigorous comparisons with landscape changes within the Sahelian region. Researchers of both the Sahelian and North African regions collaborate presently in the same major research project, "DeSurvey", which constitutes an ideal framework to exchange scientific data and experiences.
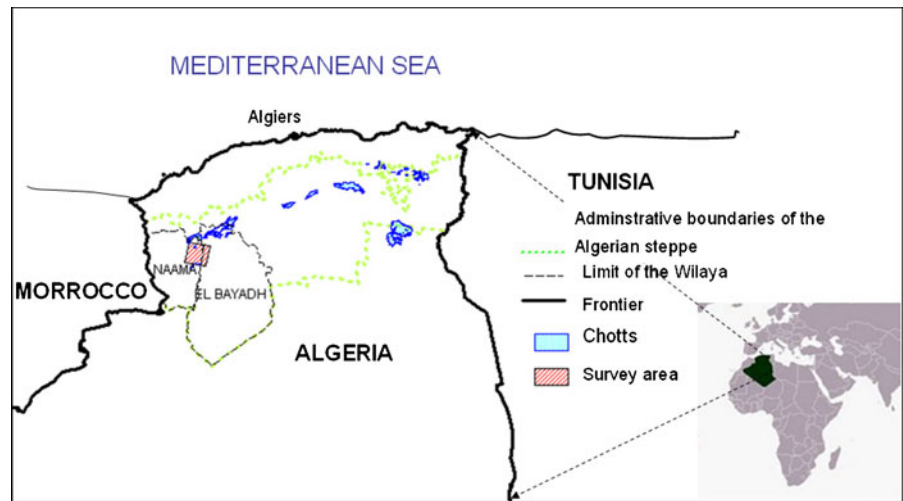
Material and methods

The study area

The study area occupies two thirds of Algeria's south-western High Plateaus. It is administered by the wilaya of Nâama (Fig. 1). The average altitude is around 1,000 m and it is primarily occupied by Quaternary polygenic glacis. It includes saline depressions such as Chott Chergui. The area is surrounded by chain of mountains such as the Antar djebel which culminates at 1,700 m.

Climate

Climatic data was gathered from the National Meteorology Office and cover a long period from 1907 to 2004 (ONM 2008). The climate is characterized by low annual rainfall with averages ranging from 263 mm in Mecheria (the center of the study area) to 287.5 mm in El Bayadh (a mountainous area surrounding the north-east). The distribution of rainfall is very irregular. The coefficient of variability reached 43.2% in Mecheria and 31.3% in El Bayadh. Winters are cold and harsh while summers are hot and dry.
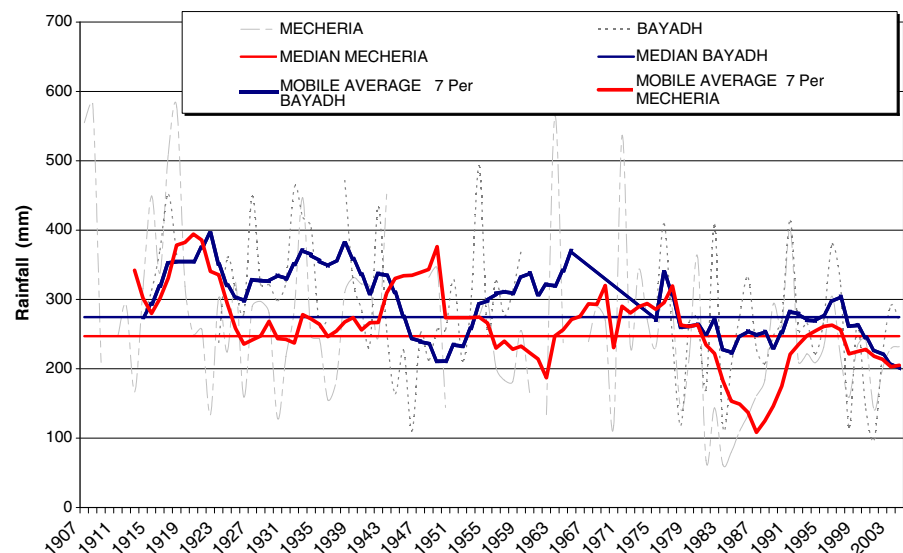
Fig. 1 General locating of survey zone

To illustrate the climatic context, the evolution of rainfall since the beginning of the century is graphed (Fig. 2).

The rainfall evolution shows an alternation of dry and humid periods with no clear trends during approximately the first half of the century. At the end of the second half, dry periods become notably more frequent and intense, especially during the 1981–1988 years (Hirche et al. 2007) considered to be the driest period of the last century. It is remarkable to note that this drought period is partially the same as for the Sahel which has been affected by a notable large-scale drought during the 1983–1985 period after the first drought period that began in 1968.

Since the end of the 1970s, the mobile averages are almost always below the average rainfall. Temperatures show average minimum values for the coldest month (January) of 1.5°C and −1.8°C for Mecheria and El Bayadh, respectively, and average maximum values of the hottest month (July) of 35.1°C and 33.5°C. For all stations, the dry period (Bagnouls and Gaussen 1953) extends over 6 months and the bioclimate belongs to the medium-arid class with cold winters variant.

Fig. 2 Evolution of annual rainfall since the beginning of the century

Sand storms are rare in El Bayadh (3.1 days year^{-1}) but are more frequent in Mecheria (7.8 days year^{-1}). Dust storms are much more frequent with an increase in the number of dust days since 1990 (Nouaceur 2001). Between 1990 and 1997, an average of 30 days per year was recorded in El Bayadh reaching 119 days per year between 2001 and 2004. The same was observed in Mecheria, where 58 days were recorded between 1990 and 1997 and 136 days between 2001 and 2004. This increase seems to be important, even if the period considered (2001–2004) is too short for statistical support. Nevertheless, whatever the station any year between 2001 and 2004 has more than 100 days of dust storms. In any event, if these results are proven over a longer series, they would be very alarming because they relate to the magnitude of soil denudation. The weak recovery of vegetation would then give free way to winds over vast areas of the Algerian steppe.
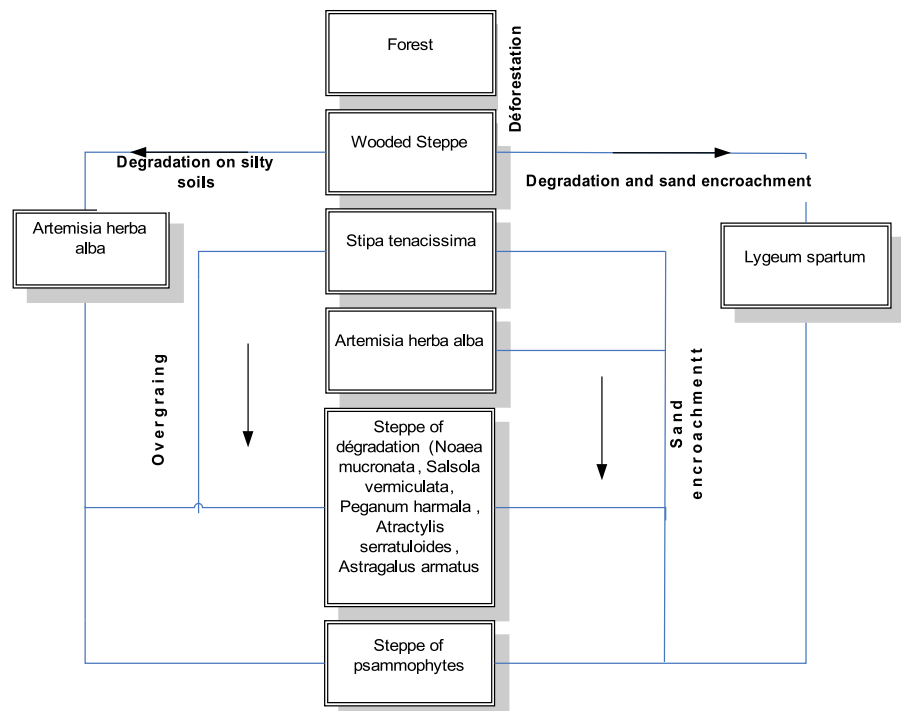
Vegetation

With regard to the vegetation, several phytoecological and phytosociological studies undertaken by the CRBT (1978), Djebaili (1978), Aidoud-Lounis (1997), and Kadi Hanifi-Achour (2003) describe the vegetation dynamics at work in steppic regions. A synthesis based upon these different studies is given in the following flowchart (Fig. 3).

It appears that the Algerian steppe was initially colonized by forests. Their gradual deterioration led to the colonization of xerophytic vegetation consisting of a mixture of herbaceous and perennial plants. The most emblematic is the herbaceous *Stipa tenacissima*, which colonized the majority of flat zones, corresponding to the geomorphologic units called "glacis". The plant is also observed on craggy landscapes. *Lygeum spartum*, another herbaceous graminoid, appears where sand accumulates, often in depressions. When degradation occurs on rich silt soils the chamaephytic *Seriphidium herba-alba* appears. These three species constituted the framework of the Algerian, and even the North African steppe. The studies also showed that pressure on the environment, mainly by overgrazing, led these formations to disappear. They have been replaced by plant units resulting from a dynamic degradation with less functional performances, such as *Atractylis serratuloides*, *Salsola vermiculata*,

Fig. 3 Flowchart establishing the dynamic of vegetation

Peganum harmala, and *Astragalus armatus*. The conversion of arid grassland to shrublands due to overgrazing and/or drought is a well-known phenomenon. Allington and Valone (2010) review the main concerned models and conclude that "current conceptual models of desertification predict that arid grasslands exists in one of two alternate stable states over timescales relevant to management: perennial grasslands or desertified shrubland". When sand accumulation becomes prominent, psammophytes such as *Thymelea microphylla* take hold.

Data collection and processing

The methodology proposed in this work is similar to that followed by Hanafi and Jauffret (2007) in Tunisia and by Hirche et al. (2008) in Algeria. It requires the comparison of vegetation maps established from two widely separated time periods in order to assess the intensity of desertification. The definition of desertification considered in this work is taken from the Convention to Combat Desertification: "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNEP 1994). Hence, desertification results in a reduction in the biological potential (Dregne 1995). The aim of the present work is precisely to assess the loss of vegetation cover. The first map was produced in 1978 and the second one in 2006. The specifications of mapping and sampling are in accordance with the environmental monitoring requirements established by Godron et al. (1968), repeated and confirmed by ROSELT's methodological guide (Le Floc'h et al. 2007).

The land cover maps of 1978 correspond to two topographic sheets (El Kreider and Mecheria, 1:200,000 scale, North Sahara Datum). The firsts vegetation maps were established in monochromatic version in 1978 and edited by our colleagues in final colored version in 1979 and 1981 (Achoubi et al. 1979; Aidoud et al. 1981). They were based on the interpretation of panchromatic (black and white) aerial photographs, (scale 1:40,000) captured in 1975. The photographic correction and restitution was carried out at the NCI (National cartography Institute). We used this edited sheets in paper support and then we scanned, georeferenced, and digitized them using GIS software (Map Info). Following digital joining of the maps (El Kreider and Mecheria), we extracted a window file corresponding to the study area.

Corrections were also undertaken on Landsat Thematic Mapper image (2006), with 30 m resolution. The pre-processing work consists of geometric corrections (neighborhood re-sampling) with 33 points and an acceptable error; the RMS is less than one pixel (0.92). All the maps were finally re-projected in UTM WGS 84. The final layouts for output were prepared with Arc View software and the final scale was the same as the 1978 maps (1:200,000).

The classification process is an image-interpretation of the corrected TM images. We followed the sampling strategy of Gounot (1969), and established 140 ground geo-referenced samples distributed throughout the study area. It is related to "mixture sampling" developed by Gounot (1969) that uses all the information sources. It resulted in a delimitation of vegetation units and sub-units (facies). Every unit is assessed by taking a phyto-ecological releve, quadrats points for measuring vegetation and sand cover (Daget and Poissonet 1971). Fieldwork for this task required 2 years of intensive sampling.

For each sample we recorded dominant species, the vegetation cover, and the sand cover (Fig. 4).

Is our approach feasible, considering that the nature and scale of supports are different for both the two periods: aerial photography and satellite images?
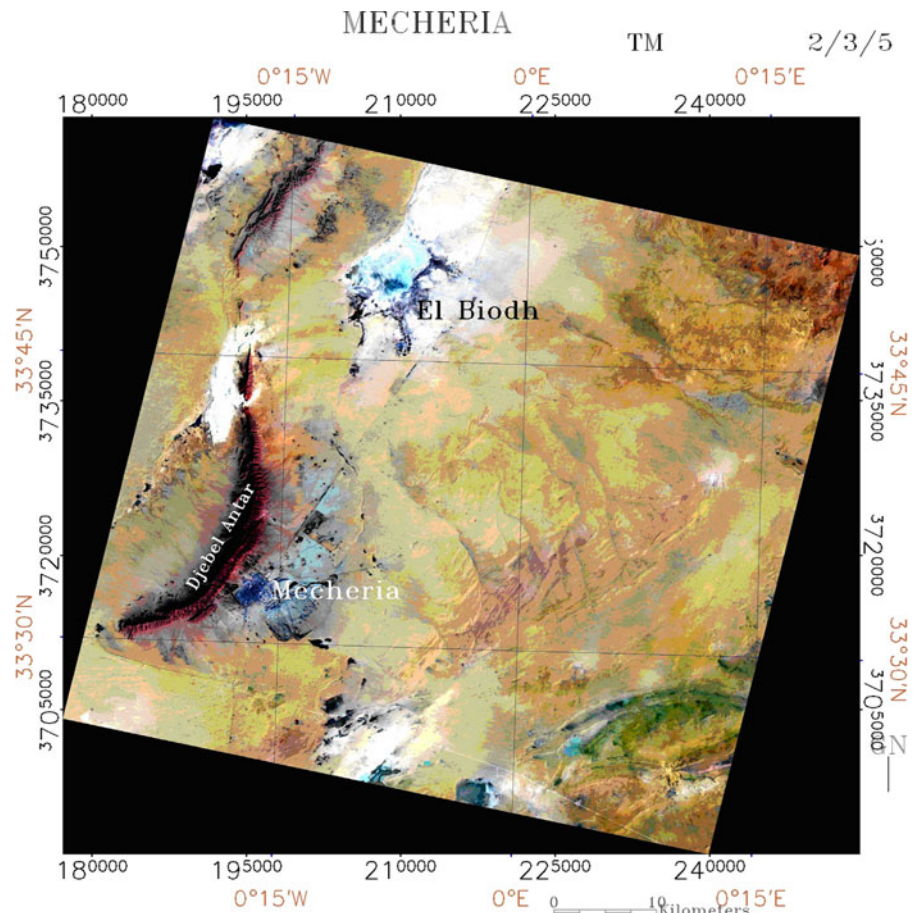
In order to answer this question, it is of utmost importance to discuss first the perception levels and be aware that spatial heterogeneity is scale dependent (Wu et al. 2002).

According to the pyramid of perceptions (Long 1974; Godron et al. 1968), a homogeneous ecological region contains ecological sectors made up of ecological systems.

In the survey's zone, we distinguish the following perception levels:

The ecological sector is related to physiognomic types (example: *S. tenacissima* steppe), to plant associations, or to vegetation sequences (Godron and Poissonet 1972).

Fig. 4 Spatiomap
representing the
survey area

The ecological systems are delimited within every ecological sector. They integrate the different land use models (grazing, agriculture), the state of vegetation degradation (vegetation cover) and the soil variables. At this level, anthropozoïc impacts are discerned (Melzi 1993).

The station level is the one that allows a precise diagnosis of land occupation.

The privileged perception level is traditionally the ecological systems (or ecological stations) corresponding to a large scale, such as 1:25,000 or 1:50,000 in temperate climatic zones. Long (1974) considers that in arid zones, a medium scale (1:100,000 or even 1:200,000) is adequate to express the same level of perception (plant groupings) and proposes a "sliding scale" to map and characterize arid regions. While aerial pho-

tographs are commonly more accurate than satellite imagery and have the advantage of large scale (1:40,000), we were obliged to do regroupings in order to produce a 1:200,000 scale map. Furthermore, this scale was chosen because land cover mapping of Algeria is not available at large scales. Despite the comparatively coarse spatial resolution of the TM images, their restitution (regrouping) using the "sliding scale" mentioned above allowed for bringing both aerial photographs and satellite imagery together. Some authors suggest a "natural" scale of the LANDSAT TM or SPOT images close to 1:250,000 (Woodcock and Strahler 1987; Light 1990). In order to be rigorous, it would have been ideal to have more recent aerial coverage. These are unfortunately unavailable.

Another problem with mapping in arid zones is that the steppe vegetation, which lies low to the ground, is not perceptible in aerial photographs.

For this reason, their better spatial resolution does not always constitute a major advantage. The poor quality of photographs is another unfavorable element.

It is necessary to homogenize the work of the earlier survey with our present work. For this purpose, we pursued an analogical classification (image-interpretation), developed from the imagery. The photo analysis allowed the delimitation of vegetations units. However, very sparse vegetation cover does not allow direct observation of the vegetation. To limit this constraint, we relied instead upon detailed thematic knowledge about links between soil and vegetation (Pouget 1980; Kadi Hanifi-Achour 2003) but it remains insufficient. Fieldwork was essential to get more information to complete the interpolation.

The comparison of the two maps is based upon physiognomic types, vegetation cover, and soil surface properties. The resulting database used the following parameters, which were then integrated into the GIS:

- Urban sites
- Physiognomic type
- Species
- Soil surface properties (sand, stone, gravel, rock, barren soil, litter, and covers)

We observed vegetation physiognomy of primary and secondary dominant species as a summary expression of ecological features (Ionesco and Sauvage 1962).

- The primary dominant species indicates the major biologic characteristic. It defines the vegetation units often called formation.
- The second dominant species expresses the present state of vegetation relating to its ecology. The combination of the first and second dominant species defines a sub-unit known as the facies.
- Global vegetation cover (GVC), valued from the vivacious species, is divided into three classes:

  Class A: GVC ≤ 25%
  Class B: 25 < GVC ≤ 50%
  Class C: GVC > 50%

The classification key integrates the dynamic filiations and on the major components of the landscape.

Finally, similar to the Tunisian study (Hanafi and Jauffret 2007), the problem of different data sources (satellite image and aerial photographs) was widely solved by systematically visiting the whole area and using the same methodology which was used to produce the first maps (1978).

Land cover maps and landscape ecology

Landscape ecology is a concept widely accepted and used presently especially with the development of GIS software and computing capacities (Heggem et al. 2000; Wang et al. 2001; Yang and Lo 2003; Kilic et al. 2006). Landscape ecology is based largely on the notion that environmental patterns strongly influence ecological processes (Turner 1989). We used the concept expressed by Forman and Gordon (1986) who define landscape as "a heterogeneous land area comprising a cluster of interacting and repeating ecosystems". In this sense, heterogeneity describes the diversity of landscape elements within the studied areas according to fragmentation and neighborhood (Baudry and Burel 1999). It explains the flux of matter and energy described above, between different landscape elements, which can then be evaluated using two complementary approaches: the first, the oldest, and most intuitive is structural and aims to describe the composition of habitats by relating habitat to its constituent species. Its inherent inconvenience results from the elaborate nature of the indicators it produces (Turner and Gardner 1991). The second approach aims to give a functional sense of heterogeneity according to the fragmentation and connectivity of its component landscapes (Gaucherel et al. 2003).

For these and other reasons, much emphasis has been placed on developing methods to quantify landscape patterns as a prerequisite to understanding pattern–process relationships (Baker 1989; Turner 1989; Turner and Gardner 1991; Johnson et al. 1992; McGarigal and Marks 1995). Several indices describe landscape patterns (Worms et al. 2004; Groom et al. 2005). Among the indices retained for our study are the Shannon landscape

diversity index and the number of classes of the largest patch index.

Landscape ecology considers the landscape as a mosaic of land units. The elements that compose the mosaic comprise two orders: (1) class, in our case classes of land cover, and (2) patch, which are the elementary units. Finally, the landscape comprises three hierarchical levels: the landscape (largest), the class, and the patch (smallest element). The spatial indicators are measured by indices that describe spatial organization.

The selected indices, as well as their denominations, are borrowed from McGarigal and Marks (1995), these are given below.

Percentage of landscape (PLAND)

It represents the part occupied by the class$_i$ in relation to all the classes.

$$\text{PLAND} = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \, (100)$$

P_i proportion of the landscape occupied by patch type (class) i.
a_{ij} area (m^2) of patch ij.
A total landscape area (m^2)

It measures the percentage of the landscape comprised in a particular land cover class. It is one of the most used (Forman and Gordon 1986; Leitao et al. 2006; Esbah et al. 2009).

Number of patches

NP equals the number of patches of the corresponding patch type (class). It represents the number of patches of a particular land cover class and translates the importance of fragmentation, considered as one of the principal threats to ecosystem integrity (Forman 1997; Forman and Gordon 1986; Groom et al. 2005).

NP   ni
ni   number of patches in the landscape of patch type (class) i.

Largest patch index

LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage). In other words, LPI equals the percentage of the landscape comprised by the largest patch.

$$\text{LPI} = \frac{\max\limits_{j=1}^{a} (a_{ij})}{A} \, (100)$$

a_{ij} area (m^2) of patch ij.
A total landscape area (m^2)

Shannon's diversity index

Shannon's diversity index is a measure of ecological diversity, particularly those expressing rare patch types.

$$\text{SHDI} = -\sum_{i=1}^{m} (p_i * \ln \, p_i)$$

P_i proportion of the landscape occupied by patch type (class) i.

These analyses are often carried out with the Fragstat software established by McGarigal and Marks (1995). However, this software works rather on raster images and could not be used. We used the GIS software ArcGIS 9.2 that includes several embedded functions supporting the measurements of landscape metrics. Moreover, in accordance with Leitao and Ahern (2002) and Leitao et al. (2006), these indices are appropriate to describe the fragmentation and shrinkage processes (Esbah et al. 2008; Leitao et al. 2006).

Results

Evolution of indices

The following paragraphs describe the landscape evolution applying to the above described indices.

Table 1 Synthetic table of different landscape indices used in land cover map of 1978

	Formation	Area (ha)	PLAND	SHDI	NP	LPI
1	Wooded steppe	5,515	0.01	0.09	4	1.23
2	*Stipa tenacissima* Steppe	178,428	0.46	0.51	48	7.79
3	*Lygeum spartum* Steppe	168,095	0.44	0.52	61	11.09
4	*Seriphidium herba alba* Steppe	19,437	0.05	0.22	15	0.90
5	Salsola sieberi var.zygophylla Steppe	2,251	0.01	0.04	1	0.59
6	Dune	4,345	0.01	0.07	1	1.13
7	Crops	2,380	0.01	0.05	3	0.43
8	Sebkha (Salty wetland)	4,179	0.01	0.07	5	0.57
	Total	384,630	1.00	1.57	138	

Percentage of landscape

Table 1 lists the results extracted from the 1978 land cover map (Fig. 5). It only shows five formations, (nine if we retain non-vegetation units) and contrasts with the 2006 map, which considers 20 formations. Among these, 14 are vegetation units, with the remainder represented by the dunes and urban sites (Fig. 6).

Extensive formations of *S. tenacissima* (alfa) and *L. spartum* (sennagh) occupy the landscape in 1978 map.
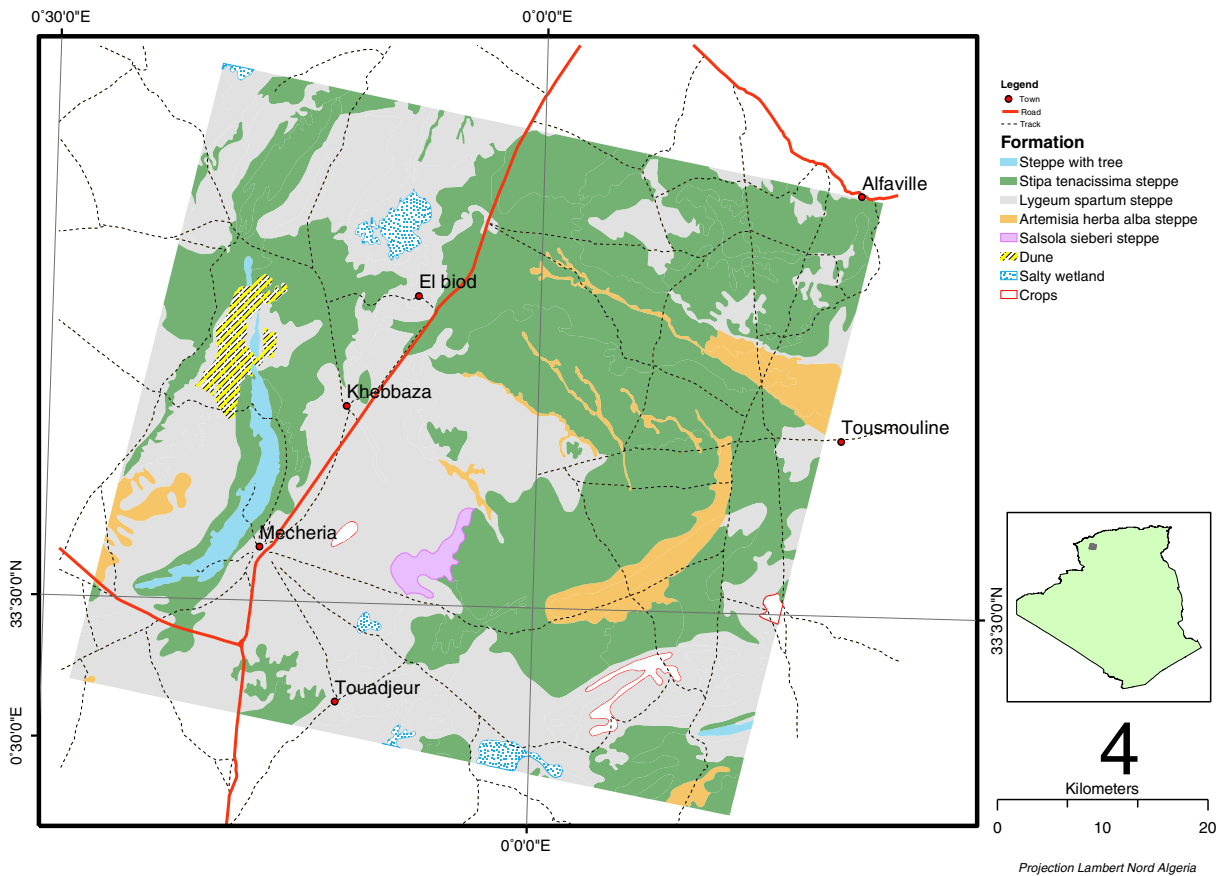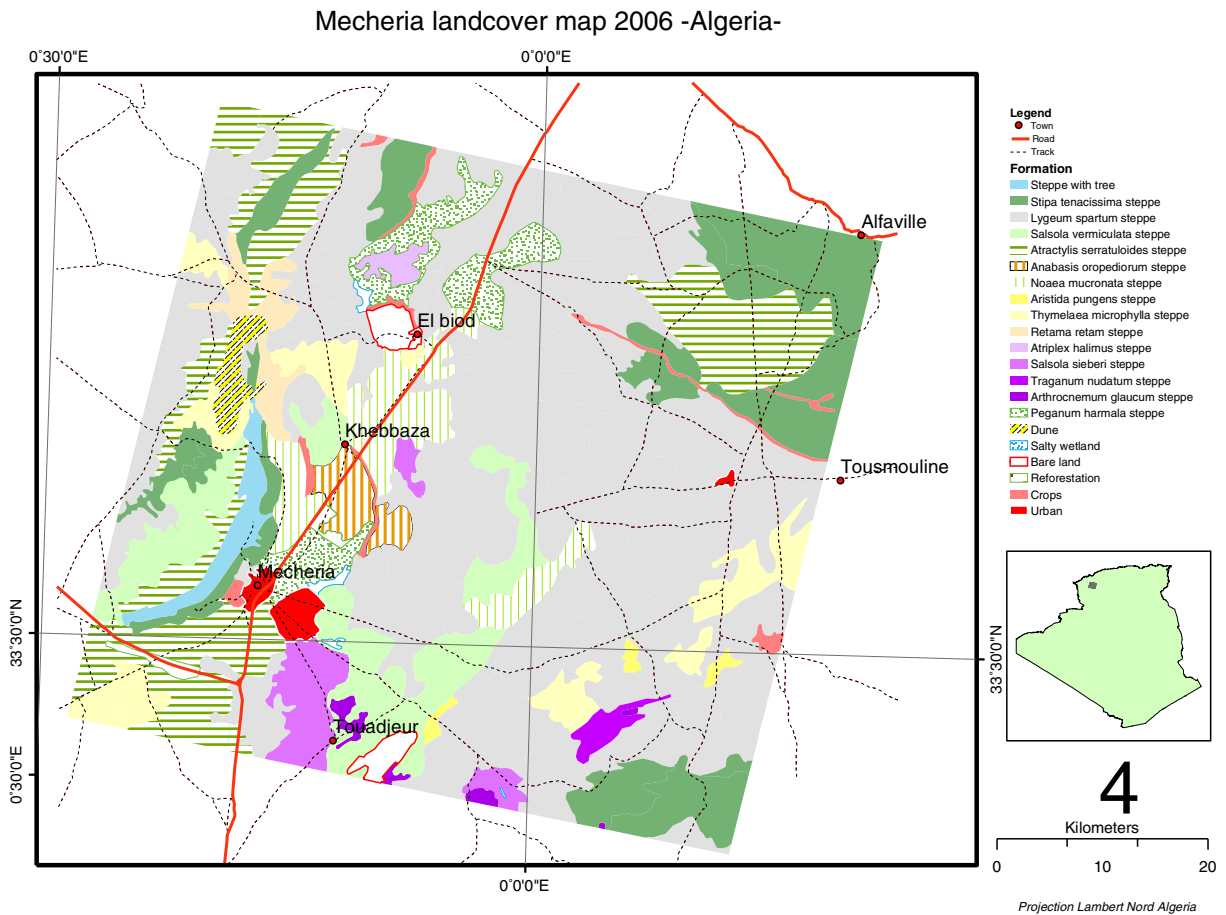

Fig. 5 Land cover map of 1978

Fig. 6 Land cover map of 2006

Indeed, the 1978 land cover map shows the dominance of the *S. tenacissima* and *L. spartum*, which occupied more than 90% of the study area. Two colors are dominant on the map, green (charcoal-gray for *S. tenacissima*) and grey (clear gray for *L. spartum*; Fig. 5).

Formations of *S. herba-alba*, once covering 19,437 ha, are present with lower surfaces and come in third position with only 5% of the surface.

The land cover map of 2006 (Fig. 6) differs significantly from that of 1978.

The main characteristics of the recent maps (2006) are summarized below in Table 2.

There is a higher heterogeneity of vegetation units (formations): 14 formations are now present, with 11 new units since 1978. However, only eight of them have an area exceeding 2% of the study area. In 1978, *S. tenacissima* was

dominant and has now been replaced by the *L. spartum* and other species indicating land deterioration, a trend observed by many authors (Aidoud et al. 1983; Aidoud and Touffet 1996; Aidoud et al. 2006).The rhizomatous root system of *L. spartum*facilitates this extension and seems to be an"opportunist" species, the development of which isfavored by drought and land degradation.

Results show that the *S. tenacissima*steppe has experienced a formidable decline. It hasdramatically regressed from 178,429 ha in1978 to 44,366 ha in 2006, which corresponds toa phenomenal 75% reduction. The term "Alfa sea"so characteristic of the region in the 1960s, holdsno significance at present. The same decrease has been observed in Tunisia, but was less pronounced(Hanafi and Jauffret 2007).

Table 2 Synthetic table of different landscape indices used in the land cover map of 2006		Formation 2006	Area (ha)	PLAND	SHDI	NP	LPI
	1	Wooded	4,483	0.01	0.07	1	1.17
	2	*Stipa tenacissima*	44,366	0.12	0.36	14	2.63
	3	*Lygeum spartum*	184,996	0.48	0.51	46	5.78
	4	*Anabasis oropediorum*	4,726	0.01	0.08	2	0.88
	5	*Noaea mucronata*	15,637	0.04	0.19	4	2.33
	6	*Peganum harmala*	12,346	0.03	0.16	3	1.20
	7	*Atractylis serratuloides*	41,699	0.11	0.35	6	3.58
	8	*Salsola vermiculata*	26,251	0.07	0.26	5	2.28
	9	*Aristida pungens*	1,347	0.00	0.03	3	0.12
	10	*Retama retam*	5,050	0.01	0.08	2	0.80
	11	*Thymelaea microphylla*	17,286	0.04	0.20	9	1.17
	12	*Salsola sieberi*	6,160	0.02	0.10	1	1.60
	13	*Traganum nudatum*	1,794	0.00	0.04	1	0.47
	14	*Arthrocnemum glaucum*	1,541	0.00	0.03	5	0.21
	15	Dune	2,819	0.01	0.05	1	0.73
	16	Crops	3,674	0.01	0.06	9	0.24
	17	Reforestation	1,342	0.00	0.03	2	0.22
	18	Sebkha	4,515	0.01	0.08	7	0.41
	19	Bare soil	1,633	0.00	0.03	2	0.37
	20	Urban	2,965	0.01	0.05	3	0.48
	Total		384,630	0.98	2.76	126	

Number of patches

The increase of heterogeneity corresponds generally to an increase in the number of patches for each class. Results indicate that the global number of patches, contrary to all expectations decreased from 138 in 1978 to 126 in 2006. This result could be explained by the homogeneity of new formations that became widespread in the landscape. The number of patches of *S. tenacissima* decreased from 48 in 1978 (Table 2) to 14 in 2006 (Table 3). Similarly, *L. spartum*, occupied 61 patches before and 46 at present. Some former patches changed to formations indicative of deterioration, such as *A. serratuloides* (six patches) or *S. vermiculata* (five). Furthermore, cultivated surfaces showed an increase in their number of patches from three to seven. This is a general trend in all North Africa. The extension of crops was underlined by

Hanafi and Jauffret (2007) in Tunisia, reaching 48% of the area. In Morocco, Benbrahim et al. (2004) considers that every year 20,000 ha are cleared and cultivated.

Largest patch index

The analysis of the large patch index shows that a decrease for both *S. tenacissima* (7.79 to 2.63) and *L. spartum* (11.09 to 5.78) is observed. The larger units are now shrinking to lower levels. This translates to a degradation of the vegetation and the corollary is the division of large initial units into smaller ones.

Shannon's diversity index

Results show that this index was equal to 1.57 in 1978 (Table 1) and increases to 2.76 (Table 2) in 2006, expressing an increase in landscape heterogeneity.

Evolution of the vegetation cover

By maintaining identical coding for the 1978 classes and the 2006 ones, results become comparable (Table 3).

Table 3 Comparison of vegetation covers in 1978 and 2006

Class of global vegetation cover (GVC)	1978 (%)	2006 (%)
GVC > 50%	/	0.12
25 < GVC < 50%	61.49	8.95
GVC < 25%	35.67	87.25
Other	2.83	3.65

As the table shows rangeland degradation become very important. In 1978, nearly 2/3 of rangelands had vegetal covers above 25%; currently, less than 1/10 is present in the same class cover. In Tunisia, the "Good state" vegetation sub-units (superior to 25% or 30% of vegetation cover) cannot be observed anymore among the main vegetation units (Hanafi and Jauffret 2007).

These results highlight that the entire zone is threatened by desertification. The threshold of 25–30% has an important biologic significance. Several authors consider that the transportation of mineral elements, such as sand, increases when vegetation cover is below 25% (Le Houérou 1992; Coudée Gaussen 1994; Geerken et al. 1998). Low vegetation cover helps to explain the importance and increase of wind speed and frequency (Nouaceur 2008). The consequence is the appearance of small dunes across the entire area.

Sand encroachment evolution

Unfortunately, records of sands cover of the year 1978 were lost and to quantify the trend is impossible. However, we consider that it is important to present existent data because they help to understand the evolution of vegetation in this area. In 2006, the landscape was covered by some vegetation units linked to sand like *T. microphylla*, while in 1978 the sandy units with psammophytic dominant specie were nonexistent (Table 4). It is

Table 4 Sand cover rate in 2006

Formation	Sand cover weighted by surface (ha)
Wooded Steppe	5
Stipa tenacissima	35
Lygeum spartum	39
Anabasis oropediorum	18
Atractylis serratuloides	28
Noaea mucronata	27
Peganum harmala	24
Salsola sieberi	41
Salsola vermiculata	36
Arthrocnemum glaucum	6
Traganum nudatum	47
Thymelea microphylla	52
Aristida pungens	85
Retama retama	91
Atriplex halimus	54

interesting to note that in some similar contiguous units of vegetation, outside the study area, we have found some releves (samples), with an average amount of sand inferior to 16%.

Presently, the sand amount of *S. tenacissima* and *L. spartum* vegetation units is close to the average with 35% and 39%, respectively.

Formations classed as "degraded steppe", nonexistent in 1978, are associated with relatively reduced sand exposure (26%). As a result appearances of these steppes are unrelated to sand encroachment.
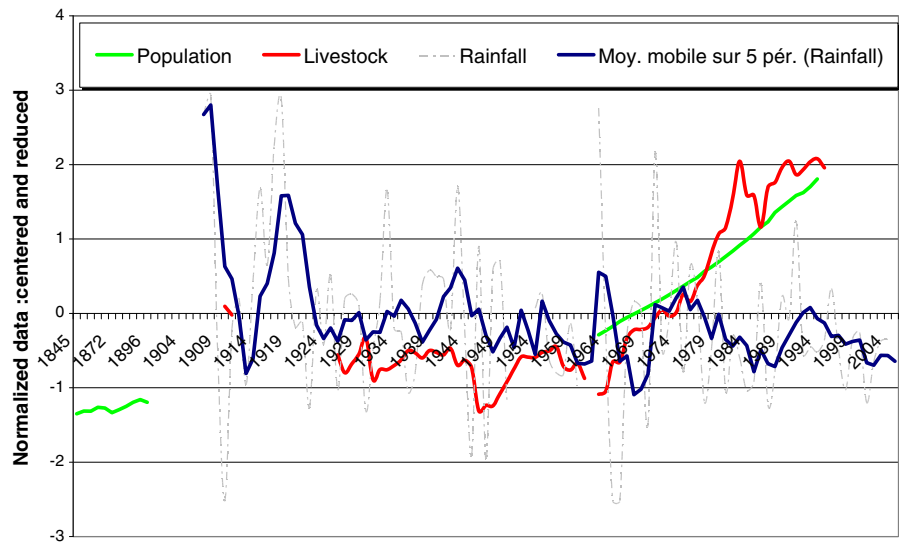
Socio-economic features

The relationship between pattern and process is necessary for a better understanding of vegetation dynamics (Li and Wu 2004). For this purpose, we compared the trends of livestock, population, and rainfall since the beginning of the century. A major drawback is that very old data are often inexistent. Algeria's administrative units changed during the course of the previous century, making it difficult to follow and compare different time sequences. For this reason, we used available information about Algeria's livestock population, even if this approach could be criticized, since it assumes that livestock evolution of the local steppe are identical to those of the country. The annual time series of livestock, population (national level), and local rainfall is shown in Fig. 7.

Two periods appear to be significant: first, the period before independence, while human population increased slowly, and both livestock and rainfall followed an irregular and non-periodic evolution. Additionally, droughts and animal diseases (epizooties) were frequent provoking a severe decline in livestock population that allowed the steppe vegetation to respond favorably with an increase in its density.

Second, we considered the post-independence period during which both human and livestock populations increased exponentially. By dint of fodder supply, livestock became a permanent pressure on rangelands. The prophylactic progress is another reason explaining the sharp increase of livestock. Besides, the exceptional drought towards the end of this period highlights the

Fig. 7 Evolution of
population, livestock, and
rainfall in Méchéria

dramatic pressure that resulted on rangelands.
Traditional balance is broken with the fodder
offer in decline and the needs increasing. We are
not anymore observing the case of sustainable
development.

The steppe is not a cropland but a rangeland
area. In these regions, fodder produced from
natural rangelands is insufficient for the current
stocking rate. An important resource to fill this
gap is represented by stubble from cereal pro-
duction and fallow. However, this is subject to
strong fluctuations and is not enough to cover all
the demand. So, fodder must be imported from
northern areas of the country or even from other
countries. However, arable land for the whole
country represents only 3.5% corresponding to
8.4 million hectares from the 250 million of the
country. This means to 0.23 ha per capita, much
less than the 0.6 ha usually deemed necessary to
meet basic food needs.

Average cereal yields since the beginning of
the century are generally less than 7 qtx ha^{-1},
one of the lowest in the Mediterranean Basin
(FAO 2009). The fodder production of the
steppe, which earlier exceeded an average of
150 Uf Ha^{-1} year^{-1}, can currently provide only
30–40 Uf Ha^{-1} year^{-1} (Nedjraoui 2006). The spi-
ral of growth in cereals demand only exacerbates
the degradation of rangelands, because it means
keeping a high-grazing pressure on the territory.

Interpretation and discussion

It appears that the overgrazing is the main compo-
nent in the rangeland degradation. The threshold
of 30% vegetation cover has an important biologic
significance. Several authors consider that the
transportation of mineral elements, such as sand,
increases when vegetation cover is below 25–
30% (Le Houérou 1992; Coudée Gaussen 1994;
Geerken et al. 1998). Low vegetation cover helps
to explain the importance and increase of wind
speed and frequency (Nouaceur 2008). The con-
sequence is the appearance of small mobile dunes
across the entire area.

This threshold seems to be important in terms
of the remaining grazed surface because when
it is surpassed the functional relationships are
disturbed (Cousins et al. 2003). For instance, *S.
tenacissima*, considered as coarse food, is eaten by
livestock who seek such food to ensure their in-
testinal transit. However, *S. tenacissima* is not par-
ticularly appreciated by livestock and presents low
bromatological interest (low energy content) with
its depletion appeared the need to provide supple-
mentary fodder. Livestock, despite drought, have
survived because they received additional ener-
getic nutritious rations, especially barley (Aidoud
et al. 1999). The degradation occurs mainly on
the glacis, flat area, whereas the abrupt lands, less
accessible, are clearly more preserved. *S. herba-alba*

(chih), one of the best appreciated fodder plants by livestock has now completely disappeared (Aidoud et al. 1998).

Protected areas, generally enclosed were installed in 1975 by the CRBT to monitor the main vegetation units represented by *S. tenacissima*, *L. spartum*, and *S. herba-alba*. Field observations showed that protected sites had higher vegetation cover than non-protected ones. This was regardless of the drought that had a decreasing impact on vegetation for both protected and non-protected sites. In consequence, the effect of overgrazing seems to be more important than climate, a situation already underlined by other authors (Slimani 1998).

At present, instead of the original vegetation, there is an important expansion of species indicating rangeland deterioration: *A. serratuloides*, *Noaea mucronata*, and *P. harmala*. These species existed in 1978 but were never dominant and are not appreciated by ovine. In Tunisia, Le Floc'h (2001) and Hanafi and Jauffret (2007) described the same phenomenon with the same species. However, in Tunisia in addition to overgrazing, crop extension is a more important degrading factor than in Algerian steppes (Floret and Pontanier 1982; Le Floc'h 2001; Hanafi and Jauffret 2007). In Algeria, even if the extension of crops is recognized as a problem, overgrazing in the south-western steppe is still considered as the main one, because crops are limited there. Whatever the cause, a steppe resulting from deterioration is called a "steppe of degradation", which has to be distinguished from a degraded steppe. To be more accurate, a "steppe of degradation", is characterized by a regressive phytodynamic stage, with dominating species such as *A. serratuloides*, *S. vermiculata*, *P. harmala*, or *A. armatus*. Such steppe is different from a "degraded steppe" where, the floristic composition remains the same but with a reduced vegetation cover.

Sand accumulation is often observed as a final stage and characterized by the invasion of psammophytes such as, for example, *L. spartum* replaces *S. tenacissima*. The sandy formations, inexistent in 1978, now cover widespread areas. Their extension is clearly related to the degradation mentioned above and has been particularly pronounced during drought periods between 1981 and 1987. As a consequence of low vegetation cover, less than 30%, wind speed increases sufficiently to cause soil deflation (Coudée Gaussen 1994; Boudad et al. 2003).

It appears that the driving forces leading to this vegetation cover diminishing and land degradation are related mainly to socio-economic parameters. They are the principal keys to understand and foresee the ecosystem evolution. It is now widely accepted that the objective of desertification monitoring is to promote a dynamic approach to simulate socioeconomic effects on landscape changes (Bantayan and Bishop 1998). This is one of the main purposes of the DeSurvey project in which we are presently involved. The inclusion of socio-economic variables is explicitly addressed (Wang and Zhang 2001; Ramos and Mulligan 2004; Van Delden et al. 2007; Ibáñez et al. 2008). This knowledge enables the proposal of scenarios approaches, especially those normative (Nassauer and Corry 2004) as a means of integrating the science of landscape ecology with landscape planning (Ahern 2001).

Fieldwork confirmed and enabled the quantification that the south-west steppes are subject to degradation. It is highlighted by three dominant perennial species which define the physiognomic units. Annuals are linked to yearly fluctuations and cannot be considered as a structural component of rangelands to monitor desertification. Several important papers on the Sahelian region established that desertification is showing a reverse trend (Rasmussen et al. 2001; Herrmann et al. 2005; Prince et al. 2007; Helldén 2008). Likewise for the Mediterranean regions, Lacaze et al. (2003) found a trend towards "greener" conditions. On the contrary, most studies in Algeria in particular and in North Africa in general based on field observations and phytoecological studies (Kadi Hanifi-Achour 2003; Aidoud 1993; Aidoud et al. 2006; Nedjraoui 2006; Slimani et al. 2010; Hanafi and Jauffret 2007; Benbrahim et al. 2004) show a clear trend of degradation. As opposed to the Sahel, over the last three decades, the North African steppes are in a degradation process. Studies about the Sahelian region are often based upon remote sensing approaches that use NDVI as a proxy for biomass production and show a lack of data collected in situ. This relationship

is far from precise and its use in arid lands has been criticized (Hirche et al. 2009). Moreover, the majority of papers related to desertification monitoring in the Sahel do not distinguish between annual and perennial vegetation creating a questionable methodological approach. This issue has been described in a recent (Hirche et al. 2010) contribution concerning the conclusions about the Sahelian "greening".

Conclusions

The vegetation of Algeria's High Plateaus has undergone major degradation in ways that transformed the organization and composition of the steppe. Except for the number of patches, all the landscape ecology indices show that homogeneous widespread areas of the original vegetation units are now divided into several units, non-contiguous and with generally lower surfaces. The initial vegetation units have been transformed into a steppe of degradation with dominant species such as *A. serratuloides* and *S. vermiculata*. The main factors of degradation is overgrazing, whereas in Tunisia, the crop extension appears to be another important factor of degradation (Hanafi and Jauffret 2007). Previous studies, based on ground measures, established the same conclusion about the degradation of the steppe in Algeria (Aidoud and Touffet 1996; Hirche et al. 2001; Aidoud et al. 2006; Slimani et al. 2010) and Morocco (Benbrahim et al. 2004). Whatever the factors of degradation for North Africa, this phenomenon is quite perceptible. No studies based mainly on the field measurements describe a "greening-up" of the steppe in North Africa.

On the contrary, preliminary results show the expansion and spread of desertification which is characterized by very low vegetation cover (in our area generally less than 10–15%) and thus a very low potential for rangelands (30–40 Uf Ha^{-1} year^{-1}). With an area close to 27 million hectares, a territory being as large as Belgium and Great Britain together is threatened by a major ecological disaster. A modelization of the local desertification is being developed in collaboration with the EEZA team that could be a useful tool to be addressed to the stockholders for

a better understanding and finally a more efficient management solutions.

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