# 7

# Biosphere

7.1 Vegetation cover and land use change in Benin
    7.1.1 Introduction
    7.1.2 Characterizing vegetation cover in Benin using NDVI calculations from remote sensing data
    7.1.3 Fire: Some quantifications of this important ecological factor of savannas
    7.1.4 Assessing natural vegetation and land use distribution in Central Benin
    7.1.5 Changing land use: Hot spots of current land use and land cover changes
    7.1.6 Conclusions
7.2 Vegetation dynamics under climate stress and land use pressure in the Drâa catchment
    7.2.1 Introduction
    7.2.2 Vegetation units
    7.2.3 Plant diversity along gradients
    7.2.4 Resilience of arid and semi-arid ecosystems
    7.2.5 Rehabilitation pace
    7.2.6 Conclusions

# I-7 Biosphere

**J. Röhrig and H. Goldbach**

Vegetation and vegetation dynamics strongly impact global and regional water cycles affecting both, climate (see chap. I-5) and water availability (see chap. I-6). Furthermore, land cover and land use have a significant impact on the sustainability of resource management and socio-economic factors such as food and income production and human migration. The actual vegetation cover in Benin and Morocco is very diverse (described in detail in sect. I-3.6). Vegetation dynamics are caused by seasonal climate changes, altered soil properties, human land management which is driven *inter aliae* by economic factors. In addition to seasonal vegetation dynamics, in both study areas the expansion of land use has modified or even eliminated natural vegetation causing land degradation in several regions. Particularly in the Drâa catchment in Morocco, extensive grazing, irrigation with subsequent salinization as well as firewood collection have degraded vegetation cover and plant diversity. In Benin, human activities have altered the current species composition of savannas and have negatively impacted forest regions. In Central Benin, increased agricultural activities and bush fire frequency have significantly changed the vegetation cover within recent years.

This chapter discusses the primary factors influencing vegetation dynamics and land use change in the two research areas in Benin and Morocco. In section I-7.1 vegetation cover and dynamics in Benin are analyzed by remote sensing. We first present the spatial distribution of vegetation cover in Benin as shown through low resolution data (NOAA NDVI; Normalized Difference Vegetation Index). We then consider the spatial and temporal distribution of bush fire using MODIS data at a moderate resolution. Finally, land cover and land use dynamics in Central Benin are presented in greater detail with LANDSAT images. In section I-7.2, the impact of topographic gradients on plant diversity and life forms is analyzed for the Drâa catchment in Morocco based on own field surveys. We further discuss the reaction of different vegetation units to climatic fluctuations and land use pressure, integrating concepts of resilience and rehabilitation.

P. Speth et al. (eds.), *Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa*, DOI 10.1007/978-3-642-12957-5_7,

# I-7.1 Vegetation cover and land use change in Benin

**M. Judex, J. Röhrig, C. Linsoussi, H.-P. Thamm, and G. Menz**

## Abstract

Land surface parameters are important factors of the socio-ecological system. In central Benin the land cover is subject to strong changes, either due to seasonal dynamics or due to rapid land use changes.

To assess land cover performance and calculate the land cover types as well as their transformation, different satellite remote sensing data sets are used covering all of Benin with low spatial resolution and the Upper Ouémé catchment with high resolution. Time series of the low resolution data show the high intra-annual changes of the vegetation cover due to seasonal bush fires. Up to 23% of the total area of Benin is affected by one or more fire events between 2000 and 2009.

The high population growth rates are one of the reasons of the rapid land cover and land use changes especially in Central Benin. The majority of the people is working in the agricultural sector or depends on it. Analyses based on high resolution LANDSAT data reveal that the agricultural area increased by up to 55% in the period from 1991 to 2000. Those land use changes are unevenly distributed in space and hot spots are identified. The loss of savannas and forests is detected by NDVI time series analyses of low resolution satellite data. The results of these satellite-based analyses form the basis for hydrological and land-use modeling as well as soil erosion assessment in the study area.

*Keywords: Vegetation trends, NDVI, bush fire, burned area, remote sensing, land cover, land use, classification, change detection*

## I-7.1.1 Introduction

Vegetation cover and land use are key parameters in the hydrological cycle and are important for the socio-economic conditions including food security, agricultural colonization, and human migration. In Benin, particularly in the central part, recent years have witnessed changes in land use and land cover due to population expansion and economic development (see sect. I-3.8; Adjanohoun et al. 1989; CENATEL 2002; Igué et al. 2004). Primary vegetation has remained only within forests protected by the state or religious convictions and in marginal areas such as inselbergs and sites with ironstone (Bohlinger 1998; Reiff 1998; Neumann et al. 2004). Additionally, species composition of the savannas all over the country has been altered primarily by human activities (Bohlinger 1998; Neumann et al. 2004; Orthmann 2005). To define projections of future land use and land cover (see sect. II-4.3), it is essential to produce concrete information regarding recent changes and trends in land use. This information can be used to construct sustainable resource management policies. We used remote sensing techniques and satellite data from different sources to determine the current vegetation cover and to assess ongoing changes. The spatial patterns of vegetation cover and trends were derived using low resolution data (NOAA AVHRR) for the whole of Benin (see subsect. I-7.1.2). Bush fire is a common event in the savanna ecosystem and is widely initiated during different land use purposes. A first assessment of the spatio-temporal dynamics in Benin was made using MODIS remote sensing data and was complemented by field surveys (see subsect. I-7.1.3). In addition, land cover and land use dynamics were investigated in more detail for the IMPETUS study area, the Upper Ouémé catchment in Central Benin (see subsect. I-7.1.4).

### I-7.1.2 Characterizing vegetation cover in Benin using NDVI calculations from remote sensing data

Remote sensing is commonly used to gain information about the actual vegetation cover and its characteristics and trends of both. Monitoring approaches are frequently based on land cover performance through vegetation indices including the NDVI (Normalized Difference Vegetation Index; e.g., Tucker 1979; Budde et al. 2004; Pettorelli et al. 2005), SAVI (Soil-Adjusted Vegetation Index; Huete 1988), or EVI (Enhanced Vegetation Index; Huete et al. 2002). These indices are based on characteristics of green vegetation: High near infra-red (NIR) and low visible red reflectance (RED) values. The NDVI measures the degree of greenness and quantitatively reflects the capacity of the land to support photosynthesis and primary production.

$$\mathbf{NDVI = (NIR-RED)/(NIR+RED)} \qquad \textbf{(eq. I-7.1.1)}$$

The annual integral of NDVI (integrated NDVI; iNDVI) is an indicator of general land performance over time periods. The value of iNDVI is also strongly correlated with net primary production (NPP e.g., Prince et al. 1998; Li et al. 2004). In Benin we determined the maximum iNDVI between 1982 and 2003 to derive information about the recent spatial distribution of biomass. Therefore, the NDVI 10-day composites from the NOAA Global Inventory Monitoring and Modelling Studies (GIMMS) were taken (Pinzon et al. 2004; Tucker et al. 2005). These data are available online at a resolution of 8 km x 8 km. For western Africa, the more recent and spatially more detailed 1 km SPOT VEGETATION NDVI data is less appropriate than the AVHRR data due to insufficient cloud screening of SPOT

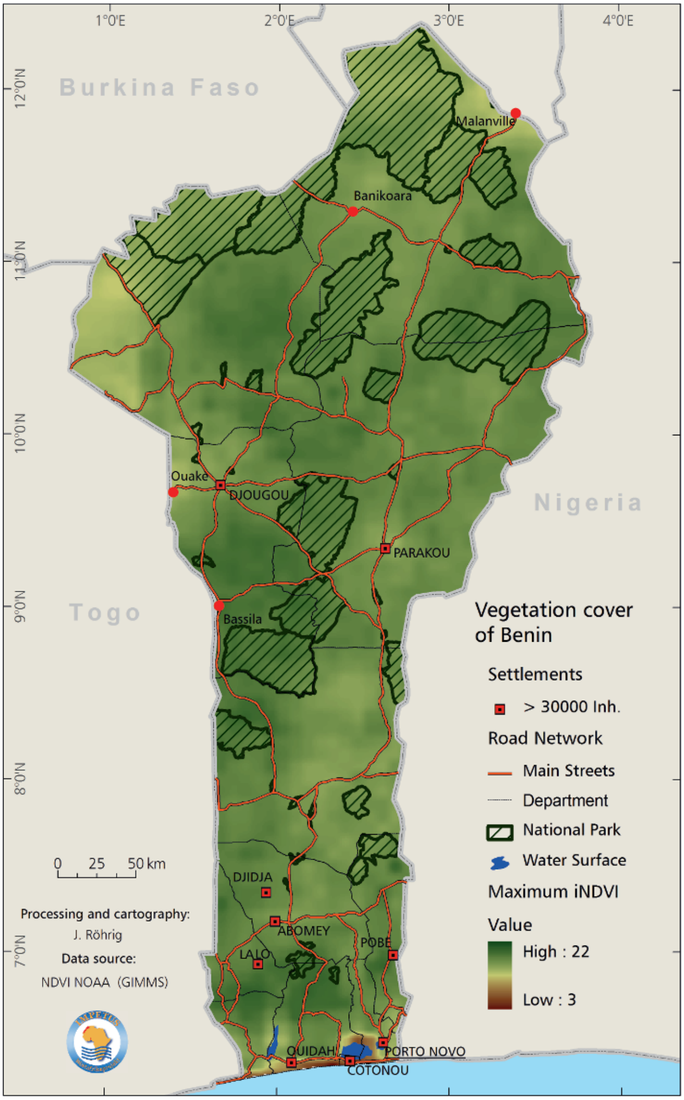

**Fig. I-7.1.1: Vegetation cover of Benin assessed with NOAA NDVI data.**

suppressing the rainy seasons (see Röhrig et al. 2005; Klein and Röhrig 2006; Fenshold et al. 2007). Figure I-7.1.1 illustrates the iNDVI pattern in Benin. This distribution reflects well the actual patterns of land cover. Higher values indicate a denser and more healthy vegetation cover. Large-area cultivation such as the area nearby Parakou, Djougou, or Banikoara (see subsect. I-7.1.4) are clearly detectable and show lower iNDVI values than the surrounding areas. In contrast, regions with high natural vegetation cover, including the region of Bassila are characterized by higher values. Additionally, degraded sites, like Ouakè in the northwest or Malanville in the north are characterized by low values.

In addition to the vegetation cover over the period 1982-2003, the overall iNDVI trend was assessed for the 22-year period. Long-term decline of vegetation function and productivity serve often as a proxy assessment of land degradation. Figure I-7.1.2 illustrates that several known changes in land use and land cover are detectable with this method, including the widespread transformation of forests into settlements and fields along a new road in the Ouémé catchment built in 1997 (see subsect. I-7.1.4). Certain areas with periodic bush fires, including the protected forests in Central Benin (see fig. I-7.1.3) show clear negative trends. The positive trends seen particularly in the northwestern region may be caused by increased rainfall in this time period and rather small land use changes.

### I-7.1.3 Fire: Some quantifications of this important ecological factor of savannas

Large areas of Benin are affected by annual bush fires, raising several concerns. Many factors determine the prevalence of fire, but the current climatic and vegetation conditions make the occurrence of fire very likely. The tropical savanna is characterized by two distinct seasons (see sect. I-3.4). The rainy season determines vegetation growth, which provides fuel. During the dry season, vegetation becomes dry and susceptible to burning. In addition to this pattern of climate, there are other driving factors of bush fire in these areas. Anthropogenic factors are frequently cited, resulting from either intentional or negligent human actions. Recent developments in remote sensing bush fires enable us to systematically study fire distribution and fire regimes on different spatial scales. This subsection investigates bush fire dynamics from 2000 to 2009 using MODIS “Burned Area Products” (MCD45A1) and the results of field surveys performed by local fire management institutions. MODIS burned area level 3 product is derived from processing of combined MODIS-TERRA and MODIS-AQUA 500 m daily land surface reflectance data using a directional reflectance (BRDF) model-based change detection approach (Roy et al. 2005). This algorithm reveals the dates of burning by identifying rapid changes in daily MODIS reflectance time series.

#### Fire regime in Benin

Bush fires generally occur during the dry season between November and May. In Benin, every year 13% to 23% of the country’s territory is burned (see table I-7.1.1). Nearly the entire area of Pendjari National Park burns annually. Generally, an area burns once a year during the dry season, although some regions burn multiple times. Areas that burn several times are usually found inside national parks

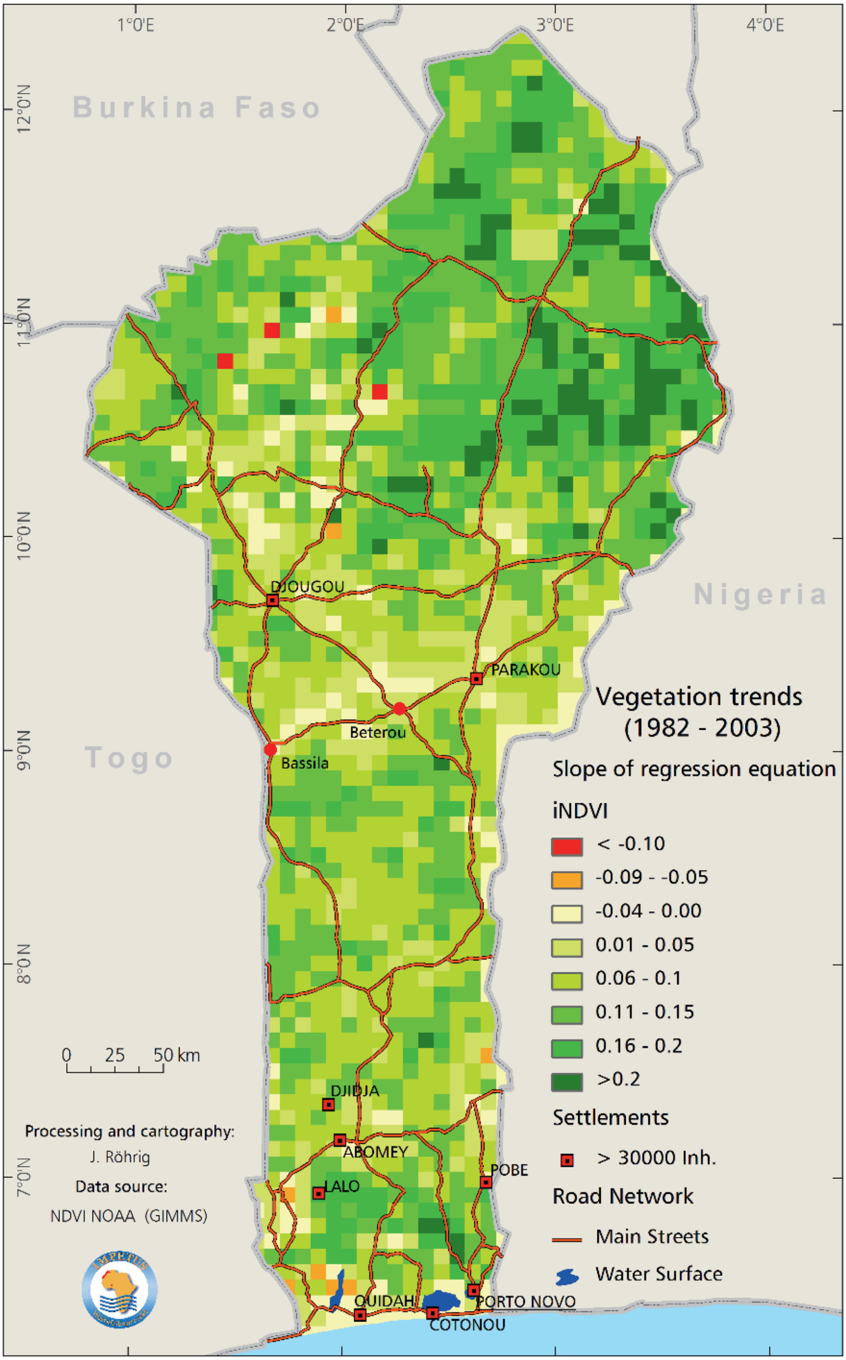

Fig. I-7.1.2: Vegetation trends between 1982 and 2003.

and occur often at the periphery of the late burning sites. These areas are extensions of the late burning areas to the early burned areas (see figs. I-7.1.3 and I-7.1.4). Since 2007, the total area burned and the frequency of fire events decreased each year (see table I-7.1.1).

## Bush fire drivers

Clearing natural vegetation with fire to prepare land for agricultural use is a common practice in Benin (FAO 2007). This procedure is a component of the slash-and-burn system used by many farmers. It is not perceived as a disturbance by farmers and is regarded as necessary in clearing new agricultural areas. According to farmers, ashes from the burned plant biomass improve soil fertility, which is required for yam cultivation in the central and northern parts of the country. This method is also a way to fight plant pests. Agricultural land clearing fires occur between February and April late in the dry season and continue until the first rains occur (for the southern zone with bimodal rainfall) (see figs. I-7.1.3 and I-7.1.4) or until May (for the Sudanian and Sudano-Sahelian region). Hunting occurs during the dry season and frequently results in bush fires which burn out of control and cause extensive property damage and mortalities each year. Fires for hunting are used in Central and northern Benin. Small hunting fires are lit early in the dry

**Table I-7.1.1: Evolution in pixel count of fire frequency from 2000 to 2009 based on MODIS Fire Product (one pixel: 500m x 500m).**

| Frequency | 2000-2001 | 2001-2002 | 2002-2003 | 2003-2004 | 2004-2005 | 2005-2006 | 2006-2007 | 2007-2008 | 2008-2009 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 433,382 | 434,645 | 420,468 | 452,593 | 458,937 | 437,786 | 437,355 | 468,705 | 475,433 |
| 1 | 109,865 | 108,381 | 122,312 | 90,709 | 84,935 | 104,915 | 105,666 | 74,711 | 68,024 |
| 2 | 1,525 | 1,745 | 1,938 | 1,452 | 901 | 2,044 | 1,738 | 1,346 | 1,313 |
| 3 | 3 | 4 | 56 | 21 | 2 | 29 | 16 | 13 | 5 |
| 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| burned pixel (total) | 111,393 | 110,130 | 124,307 | 92,182 | 85,838 | 106,989 | 107,420 | 76,070 | 69,342 |
| proportion of burned area [%] | 20 | 20 | 23 | 17 | 16 | 20 | 20 | 14 | 13 |

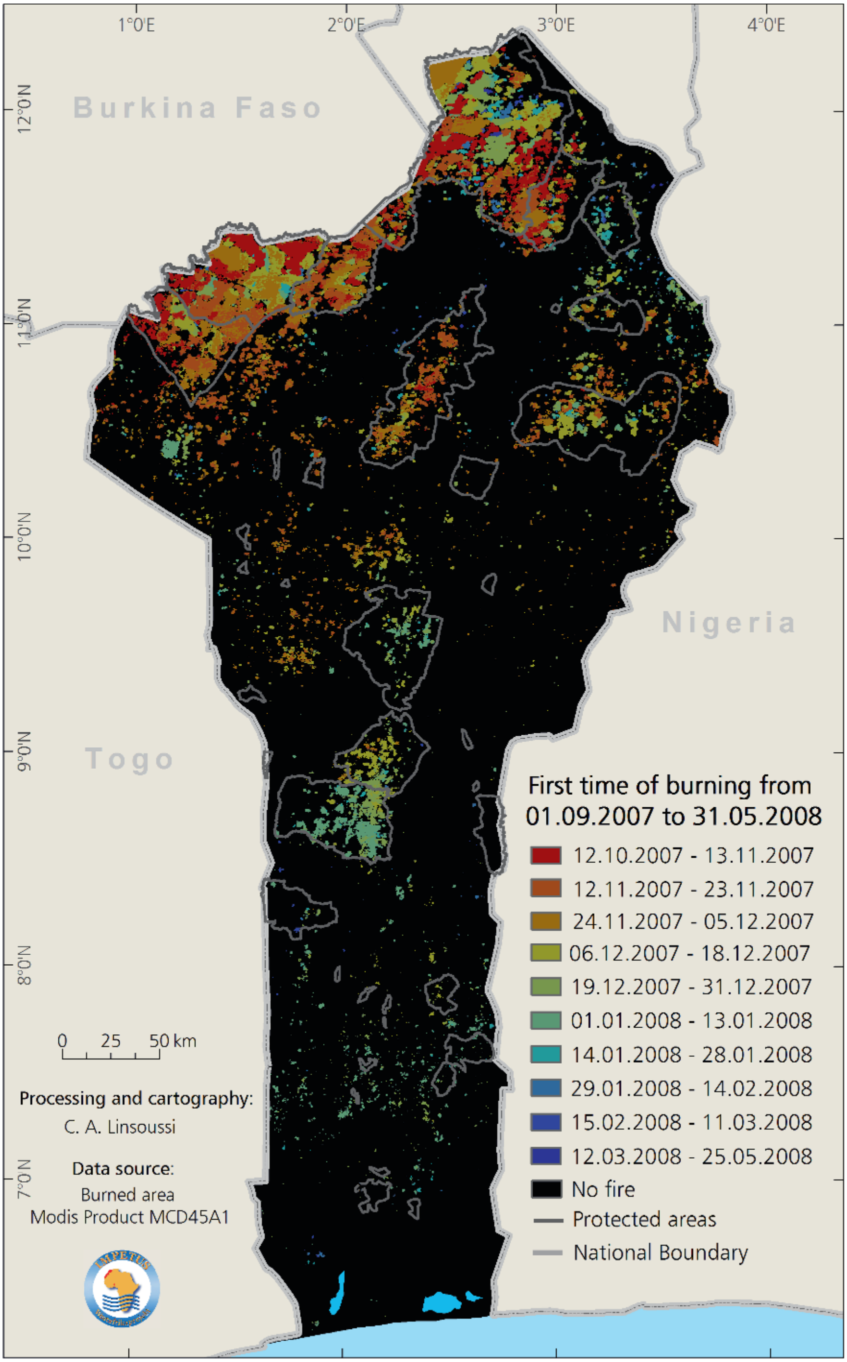

Fig. I-7.1.3: First time of burning from 01.09.2007 to 31.05.2008.

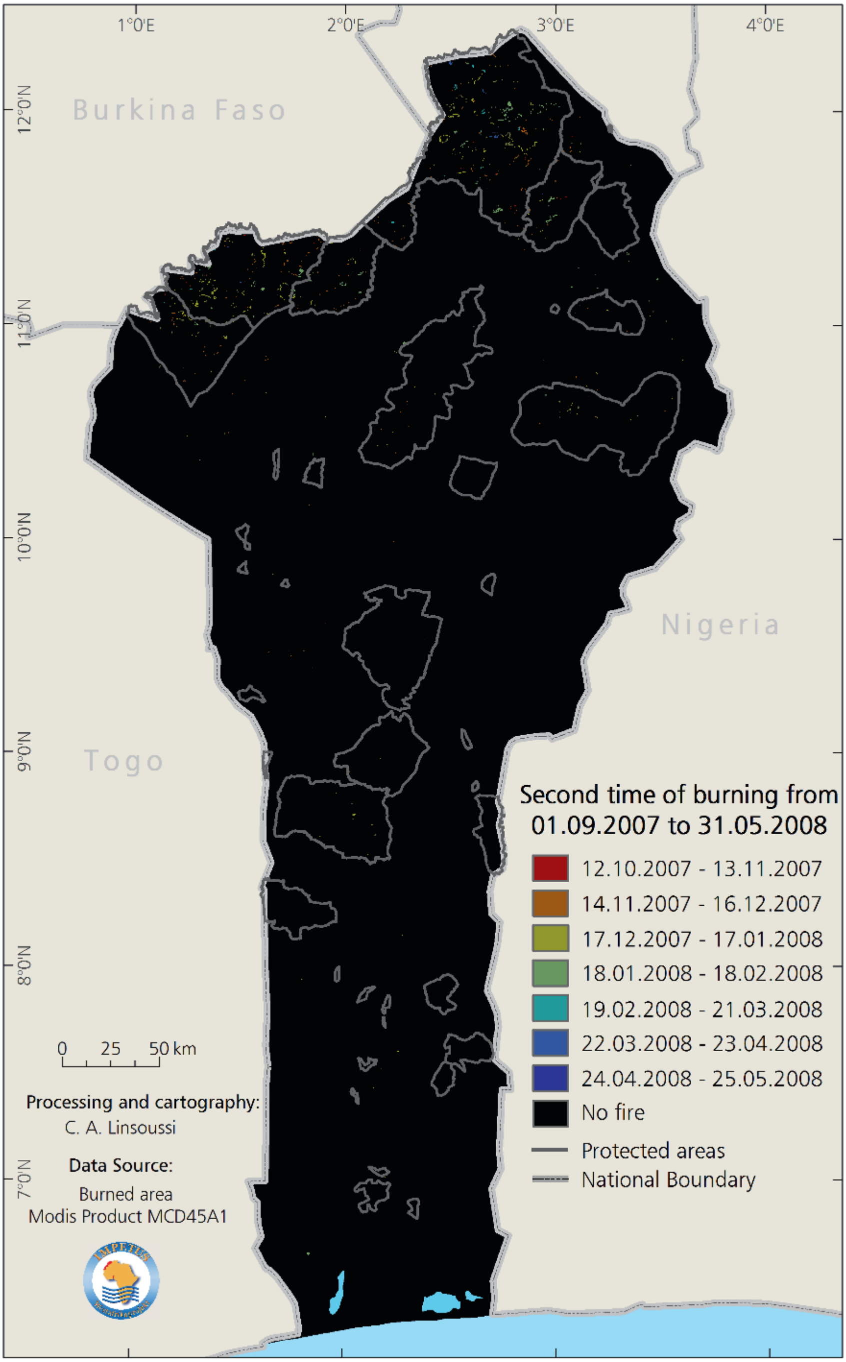

Fig. I-7.1.4: Second time of burning from 01.09.2007 to 31.05.2008.

season in December by small groups of young men hunting small animals such as rodents. The larger fires occur later in the season and are often organized in each village or group of villages during the dry season from January to May (DGFRN 2008). This type of fire is most widespread because it is organised by large groups of people using great transportation means. Gathering wild honey in the forests and savannas is another important activity during the dry season. Fire torches are used at night to destroy bee hives, and are often abandoned in the vegetation and generate uncontrolled bush fires (DGFRN 2008). Fires for pastoral use occur mainly in the dry season, affecting the entire country. These fires are started by shepherds on transhumance to stimulate the natural regeneration of fresh forage. These pastoral fires are uncontrolled and are sometimes the source of conflict with local farmers. They are the likely primary cause of burning of protected areas (*forêt classée*). Large areas of savannahs, forests, and fallows are affected every dry season by these fires. In addition, protective fires are lit ubiquitously very early in the dry season. These are used to clear flammable vegetation that could become fuel for accidental fire. Many infrastructures including houses and lofts are protected in this manner. This method is also used to burn areas around private plantations of palm, teak, and fruit orchards. Fire is used by rural individuals to stimulate the renewal of *Vitex doniana* leaves, which are sold in local markets as vegetable. During the dry season, women set fire to fallow land and later harvest young leaves from the burned areas. This type of fire is primarily used in the regions of Atlantique and Zou and can affect large areas. Burnings are controlled by forest officers in charge of managing protected areas and state-owned plantations. At national parks Pendjari and W in the North, fire is used as a planning tool for protection, forage production (pasture regeneration) and facilitating sightseeing for tourists.

The legislation in Benin allows only controlled fires in the vegetation and bans uncontrolled fires. Every year the government officially defines the periods of the fire season within each region. Unfortunately, there are no appropriate means to monitor and assess compliance with these official periods.

### I-7.1.4 Assessing natural vegetation and land use distribution in Central Benin

Remote sensing data collected by satellites are routinely employed in land use and land cover analyses, particularly in remote areas where no or limited information is available. Because little land cover information is available in most parts of Benin, satellite image analysis represents an excellent method to characterize spatio-temporal characterization of land cover and land use (Jensen 1996; Richards and Jia 2006). This method allows obtaining very high spatial homogeneity and high resolution results.

## Data and methods

Multi-temporal, high resolution optical LANDSAT TM and ETM+ data were used to map land use and detect changes in land use. Gaps in the LANDSAT data set due to clouds or bush fire smoke were filled using ASTER images. In total, two LANDSAT TM scenes were used; seven LANDSAT ETM+ scenes and two ASTER scenes. One LANDSAT scene covers 180 km x 180 km at a nominal pixel resolution at nadir of 30 m × 30 m (Irish 2000). The multi-spectral ASTER sensor covers with the first five channels the same spectral range as LANDSAT channels 2, 5, and 7. A single ASTER image nominally covers a 60 km × 60 km scene at a spatial resolution of 15 m × 15 m (ERSDAC 2005). To analyze the land use and land cover changes in the Upper Ouémé catchment a complete set of data of the years 1991 and 2000 were used.

All scenes were geometrically corrected and standardized to a set of scenes with very high precision by image-to-image co-registration. Atmospheric correction was not applied as each dataset was classified separately due to seasonal changes (Song et al. 2001). Only LANDSAT scenes from the same recording time and of the same path were tiled and analyzed simultaneously.

To gain information about land cover and land use, the multi-spectral satellite images were transformed into land cover and land use classes through a classification algorithm. The maximum-likelihood classifier (MLC) (see Richards and Jia 2006) was selected for the generation of the land use and land cover maps for 1991 and 2000. For the classification of 1991 LANDSAT imagery, the training data were collected directly from the satellite data through image interpretation because no ground truth data were available. For the 2000 LANDSAT data, 170 training data points from ground truth was used for classification as well as over 300 validation points (Judex 2008c).

**Table I-7.1.2: Used datasets for land cover and land use analysis.**

| Sensor | Recording time | Path / Row | Gap fill |
|---|---|---|---|
| LANDSAT TM | 13.12.1991 | 192 / 53+54 | |
| LANDSAT TM | 10.01.1991 | 193 / 53 | |
| LANDSAT ETM+ | 26.10.2000 | 192 / 53+54 | |
| LANDSAT ETM+ | 13.12.2000 | 192 / 54 | X |
| LANDSAT ETM+ | 04.12.2000 | 193 / 53 | |
| LANDSAT ETM+ | 07.12.2001 | 193 / 53 | X |
| LANDSAT ETM+ | 29.10.2001 | 192 / 54 | X |
| LANDSAT ETM+ | 16.12.2001 | 192 / 54 | X |
| LANDSAT ETM+ | 03.12.2002 | 192 / 54 | X |
| ASTER | 13.12.2000 | (192 / 54) | X |
| ASTER | 19.10.2003 | (192 / 54) | X |

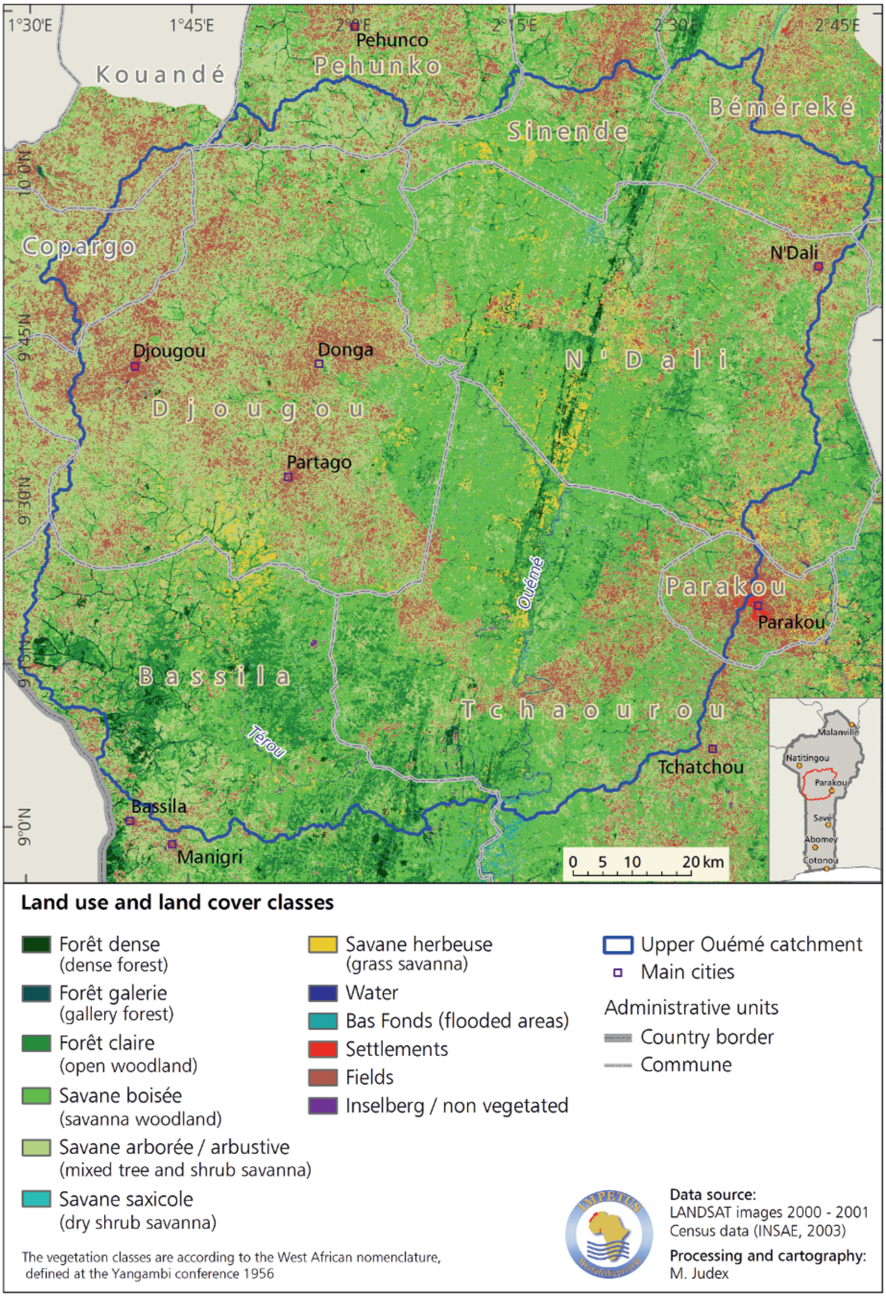

**Fig. I-7.1.5: Map of land use and land cover of Central Benin in 2000 (Source: Judex et al. 2008a).**

We employed a classification scheme adapted and extended from Reiff (1998), consisting of three principal categories: Type I - natural vegetation and fallow vegetation, type II - intensively used areas, and type III - water surfaces. Altogether 13 classes were defined (including a class "burned area" for the 1991 data; see fig. I-7.1.5. Previous work has shown that for very small field sizes (mean field size < 0.3 ha) accurate identification and classification of different crops is not possible (Judex 2003). In addition, a multi-spectral classification approach alone did not result in a land use and land cover map of sufficient accuracy for these purposes. Therefore, spectral classification techniques were extended by employing a ‘knowledge-based’ approach, which included information about the landscape (i.e. knowledge about the location of each pixel in the landscape; see Judex et al. 2006). Land use changes were then assessed using a post-classification comparison method.

## Satellite image classification

The high resolution land use and land cover map from the year 2000 is shown in figure I-7.1.5. Most of the areas in Central Benin are covered with semi-natural vegetation (87.8%). Only 12% are currently used as field areas. However, a large fraction of the savannah vegetation belongs to the short to long term rotational fallow cycle, the local mechanism to maintain soil fertility (see sect. I-3.10). Calculation of exact values is not possible because of the similarity in reflectance of fallow and natural vegetation. The distribution of all land use and land cover classes is shown in figure I-7.1.5 which indicates the high fraction of savannah vegetation types in the study area.

The distribution of land use is very unequal in space. Due to higher population densities, the regions around Djougou and Parakou are used intensively. Only very few small forest areas remain, mainly holy forests (*forêts sacrées*). The highest proportion of undisturbed areas is located inside protected zones, the so called *forêts classées*, e.g. the *forêts classées de l'Ouémé superieure* visible in the middle part in figure I-7.1.5. Unprotected areas with large undisturbed forests and savannahs exist in Central Benin, serving as an incentive to many land searching farmers from the northern part of the country (see next subsection). Table I-7.1.3 lists the shares of aggregated land cover and land use categories for the main municipalities (*communes*) in Central Benin. Djougou features the highest population density, with 46.1 inhab./km², and has the highest proportion of agricultural land use with nearly 22% of the total surface in use. More than 50% of the area is occupied by savanna which can be assumed to be fallow vegetation. The situation in the commune Bassila is very different, with a large proportion of forest area and very little agricultural land use. N'Dali and Tchaourou have also high proportions of forest areas but slightly more agricultural areas than Bassila.

**Table I-7.1.3: Surface percentages of important land cover categories for four communes in Central Benin (in 2000).**

| Commune | Forest[1] | Savannah[2] | Agriculture |
|---|---|---|---|
| Djougou | 20.1% | 50.9% | 21.8% |
| Bassila | 72.0% | 23.0% | 4.8% |
| N'Dali | 56.2% | 34.3% | 9.3% |
| Tchaourou | 62.2% | 26.0% | 10.4% |

[1] Forest = *forêt dense, forêt claire, savane boisée*;

[2] Savannah = *savane arborée / arbustive, savane saxicole*

## I-7.1.5 Changing land use: Hot spots of current land use and land cover changes

Analyzing detailed spatial land use and land cover changes is possible with multi-temporal remote sensing data. We compared data from 1991 and 2000 by a pixel-by-pixel based change detection method. The result is a) a contingency matrix in which changes for every land use / land cover combination are quantified and b) maps identifying locations of changes at the pixel level.

High intra-annual vegetation dynamics pose a problem in detecting and analyzing changes in this area. Data from 1991 were taken during the dry season when a considerable amount of area was affected by bush fire; burned area was less prevalent during 2000. Therefore, the interpretation of some class combinations seems to be not plausible at first glance in table I-7.1.4.

Most of the changes are attributable to seasonal changes: 35% of the total area is affected by bush fires causing changes in several vegetation classes. However, land cover changes due to anthropogenic deforestation and agricultural expansion are also clear. During the observation period, the agricultural areas increased by 45% in the Upper Ouémé catchment. Our analyses further revealed the spatial distribution of ‘hot spots’ of that change (see fig. I-7.1.6). These areas correspond to regions of high population growth and considerable land resource availability. Many change hot spots are located in the neighborhood of large protected forest areas or are near large cities (e.g., Parakou). The deforestation hot spots are shown in figure I-7.1.6. These changes in land use pose a major threat to remaining forest resources.

The observed land use and land cover changes are likely to continue because there is no regional land use planning or regulating activities, and agricultural production capacities are projected to remain low. Therefore, livelihood security may be threatened due to decreasing land availability and declining soil fertility (see sect. II-4.1).

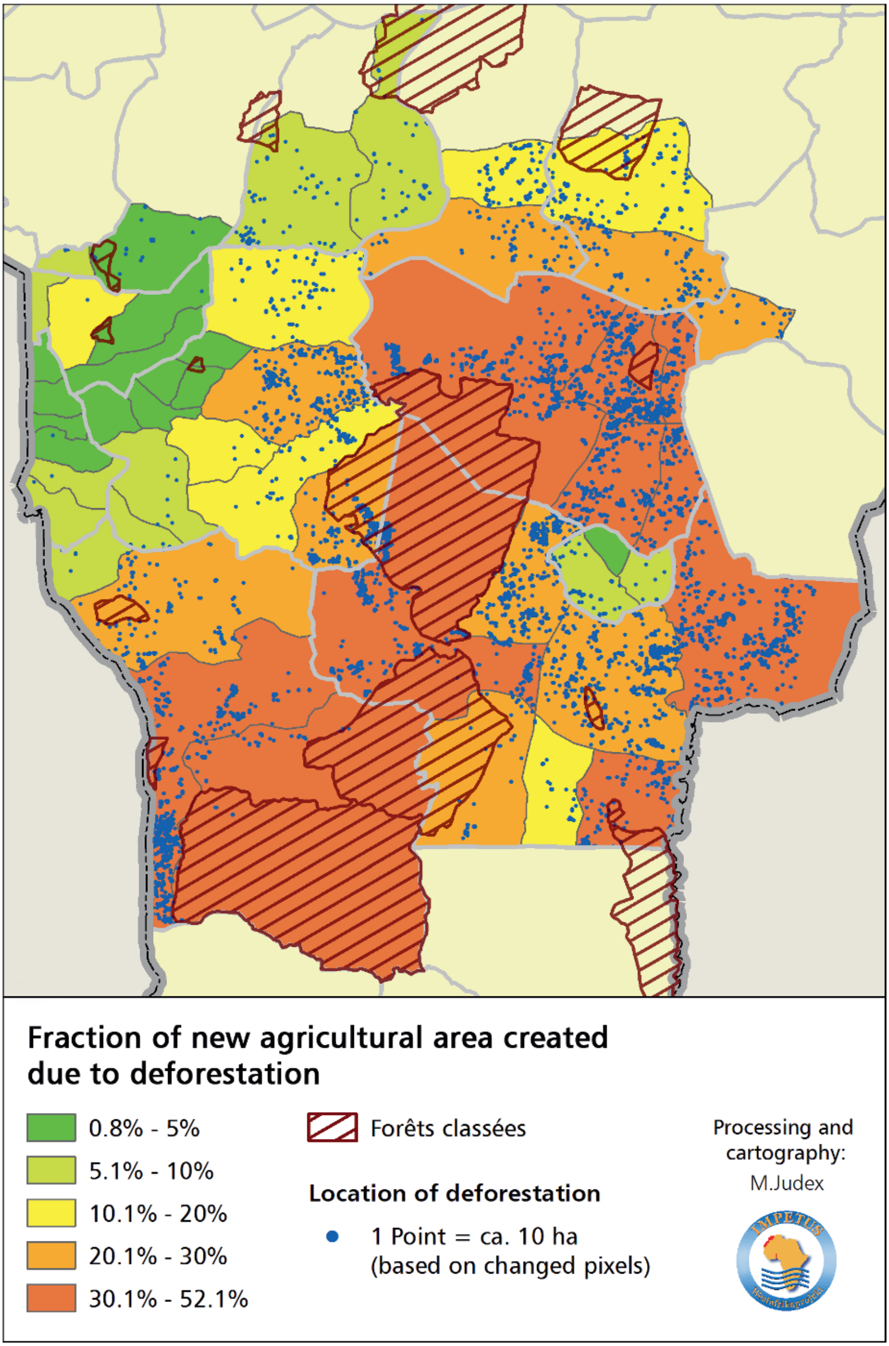

**Fig. I-7.1.6: Land cover and land use changes due to deforestation in Central Benin. Data derived from LANDSAT images (13.12.1991 and 26.10.2000) (Source: Judex et al. 2008b).**

**Table I-7.1.4: Results of land use classifications of 1991 and 2000 [in hectares] and changes [in percent] for four communes in Central Benin.**

| | | Forest & dense savannah | Savannah | Settlement | Agricultural area | Burned area |
|---|---|---|---|---|---|---|
| Tchaourou | 1991 | 351,219 | 54,965 | 139 | 38,838 | 208,603 |
| | 2000 | 431,782 | 159,293 | 424 | 60,452 | 0 |
| | change | 22.9% | 189.8% | 205.0% | 55.7% | -100.0% |
| N'Dali | 1991 | 221,881 | 37,391 | 106 | 24,046 | 92,595 |
| | 2000 | 225,521 | 119,470 | 289 | 30,363 | 0 |
| | change | 1.6% | 219.5% | 172.6% | 26.3% | -100.0% |
| Bassila | 1991 | 377,605 | 23,213 | 68 | 16,843 | 154,793 |
| | 2000 | 431,917 | 116,089 | 135 | 23,918 | 0 |
| | change | 14.4% | 400.1% | 98.5% | 42.0% | -100.0% |
| Djougou | 1991 | 100,955 | 71,270 | 237 | 47,706 | 173,403 |
| | 2000 | 99,625 | 213,653 | 672 | 79,483 | 0 |
| | change | -1.3% | 199.8% | 183.5% | 66.6% | -100.0% |

## I-7.1.6 Conclusions

Analysis of remote sensing data clearly shows the spatio-temporal dynamics of vegetation cover and land use in Benin. Two primary factors determine the vegetation cover in Benin: the strong seasonal dynamics which are the prerequisite for the bush fires and the extremely high rate of land cover change. Although laws regulate bush fire, traditional burning procedures are still practiced. The high rate of population growth is one of the main drivers of land use and land cover changes. Considerable changes are apparent even at coarse resolution across Benin whereas with high resolution data detailed change directions were calculated. Although large forest areas are still present, particularly in the central part of Benin, population pressure is already noticeable as people migrate into these regions. If population density rises, resource planning becomes increasingly necessary to prevent conflicts and to maintain ecosystem services.

## References

Adjanohoun EJ, Adjakidje V, Ahyi MRA, Aké assi L, Akoegninou A, d'Almeida J, Apovo F, Boukef K, Chadare M, Cusset G, Dramane K, Eyme J, Gassita J-N, Gbaguidi N, Goudote E, Guinko P, Houngnon, P, Lo I, Keita A, Kiniffo HV, Kone-Bamba D, Musampa Nseyya A, Saadou M, Sodogandji Th, de Souza S, Tchabi A, Zinsou Dossa C, Zohoun Th (1989) Contribution aux études ethnobotaniques et floristiques en République Populaire du Bénin. Médecine traditionnelle et pharmacopée. Agence de Coopération Culturelle et Technique, Paris

Bohlinger B (1998) Die Spontane Vegetation in traditionellen Anbausystemen Benins: Ihre Bedeutung und Möglichkeiten des Managements. PLITS 16 (1). University of Hohenheim, Stuttgart

Budde ME, Tappan G, Rowland J, Lewis J, Tieszen LL (2004) Assessing land cover performance in Senegal, West Africa using 1-km integrated NDVI and local variance analysis. J Arid Environ 59(3):481-498

CENATEL (2002) Rapport final: Base de données georeferencées sur l'utilisation agricole des terres au Bénin. Contrat N° 23428. Cotonou

DGFRN (2008) Diagnostic participatif des feux de brousse au Benin & stratégie nationale de gestion des feux de végétation. Internal report. Cotonou

ERSDAC (2005) ASTER User's Guide. Part I. General (V 4.0). Earth Remote Sensing Data Analysis Center – technical report

FAO (2007) Fire management global assessment 2006. Rome

Fenshold R, Nielsen TT, Stisen S (2007) Evaluation of AVHRR PAL and GIMMS 10-day composite NDVI time series product using SPOT-4 vegetation data for the African continent. Int J Remote Sens 27(13):2719-2733

Huete AR (1988) A soil-adjusted vegetation index (SAVI). Remote Sens Environ 25:295-309

Huete A, Didan K, Miura T, Rodriguez E (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sens Environ 83:195-213

Igué AM, Gaiser T, Stahr K (2004) A soil and terrain digital database for improved land use planning in Central Benin. Eur J Agron 21:41-52

Irish R (2000) Landsat 7 Science Data User Handbook.
http://landsathandbook.gsfc.nasa.gov/handbook.html. Accessed 28 November 2009

Jensen J (1996) Introductory digital image processing. A remote sensing perspective. 2nd edn. Prentice Hall, New Jersey

Judex M (2003) Analyse und Erklärung der Landbedeckungs- und Landnutzungsänderungen im Upper Oueme Catchment (Benin, Westafrika) durch die Verknüpfung von LANDSAT Daten mit sozioökonomischen Daten. Diploma thesis, University of Bonn, Bonn

Judex M, Thamm H-P, Menz G (2006) Improving land-cover classification with a knowledebased approach and ancillay data. In: Braun M (ed) Proceedings of Second Workshop of the EARSeL SIG on Remote Sensing of Land Use & Land Cover: Application & Development, Bonn, 28-30 September 2006

Judex M, Thamm H-P, Menz G (2008a) Land Use and Land Cover in Central Benin. In: Judex M, Thamm, H-P (eds) (2008) IMPETUS Atlas Benin: Research Results 2000-2007. 3rd edn., pp. 85-86. Department of Geography, University of Bonn, Bonn

Judex M, Thamm H-P, Menz G (2008b) Land Use Dynamics in Central Benin. In: Judex M, Thamm H-P (eds) (2008) IMPETUS Atlas Benin: Research Results 2000-2007. 3rd edn., pp. 87-88. Department of Geography, University of Bonn, Bonn

Judex M (2008c) Modellierung der Landnutzungsdynamik in Zentralbenin mit dem XULU-Framework. Doctoral thesis, University of Bonn, Bonn.
http://hss.ulb.uni-bonn.de/diss_online/math_nat_fak/2008/judex_michael.
Accessed 12 September 2008

Klein D, Röhrig J (2006) How does vegetation respond to rainfall variability in a semi-humid West African in comparison to a semi-arid East African environment? In: Braun M (ed) Proceedings of Second Workshop of the EARSeL SIG on Remote Sensing of Land Use & Land Cover: Application & Development, pp. 149-156. Bonn, 28-30 September 2006

Li J, Lewis J, Rowland J, Tappan G, Tieszen LL (2004) Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series. J Arid Environ 59(3):463-480

Neumann K, Hahn-Hadjali K, Salzmann U (2004) Die Savanne der Sudanzone in Westafrika: Natürlich oder menschengemacht. In: Albert K-D, Löhr D, Neumann K (eds) Mensch und Natur in Westafrika: Kapitel. 2.1. Ergebnisse aus dem Sonderforschungsbereich 268, Kulturentwicklung und Sprachgeschichte im Naturraum Westafrikanische Savanne, pp. 39-68. DFG. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

Orthmann B (2005) Vegetation ecology of a woodland-savanna mosaic in central Benin (West Africa): Ecosystem analysis with a focus on the impact of selective logging. Doctoral thesis, University of Rostock, Rostock

Pettorelli N, Vik JO, Mysterud A, Gaillard JM, Tucker CJ, Stenseth NC (2005) Using the satellite-derived Normalized Difference Vegetation Index (NDVI) to assess ecological effects of environmental change. Trends Ecol Evol 20(9):503-510

Pinzon J, Brown ME, Tucker CJ (2004) Satellite time series correction of orbital drift artifacts using empirical mode decomposition. In: Huang N (ed) Hilbert-Huang Transform: Introduction and Applications. Chapter 10 (II). Applications, pp. 167-186. World Scientific Publishing, London

Prince SD, Goetz S, Czajkowski K, Dubayah R, Goward, SN (1998) Inference of surface and air temperature, atmospheric precipitable water and vapour pressure deficit using AVHRR satellite observations: validation of algorithms. J Hydrol 212+213: 231-250

Reiff K (1998) Geo- und weideökologische Untersuchungen in der subhumiden Savannenzone NW-Benins. In: Meurer M (ed) Das Weidewirtschaftliche Nutzungspotential der Savannen Nordwest-Benins aus floristischer-vegetationskundlicher Sicht. Karlsruher Schriften zur Geographie und Geoökologie 1, pp. 51-86. University of Karlsruhe, Karlsruhe

Richards J, Jia X (2006) Remote sensing digital image analysis: An Introduction, 4th edn. Springer Berlin, Heidelberg, New York

Roy DP, Jin Y, Lewis PE, Justice CO (2005) Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data. Remote Sens Environ 97:137-162

Röhrig J, Thamm H-P, Menz G, Porembski S, Orthmann B (2005) A phenological classification approach for the upper Ouémé in Benin, West Africa using SPOT VEGETATION. In: Veroustraete F, Bartholomé E, Verstraeten WW (eds) Proceedings of the Second International SPOT VEGETATION Users Conference. 1998-2004: 6 years of operational activities, pp. 301-306. Ispra

Song C, Woodcock CE, Seto KC, Lenney MP, Macomber SA (2001) Classification and change detection using Landsat TM data: When and how to correct atmospheric effects? Remote Sens Environ 75:230-244

Tucker, CJ (1979) Red and photographic infrared linear combinations for monitoring vegetation. Remote Sens Environ 8:127-150

Tucker CJ, Pinzon JE, Brown ME, Slayback D, Pak EW, Mahoney R, Vermote E, El Saleous N (2005) An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT Vegetation NDVI Data. Int J Remote Sens 26(20):4485-4498

# I-7.2 Vegetation dynamics under climate stress and land use pressure in the Drâa catchment

**M. Finckh and H. Goldbach**

## Abstract

The Drâa catchment comprises parts of the Mediterranean, Ibero-Mauretanian and Saharan floristic regions. Rangeland vegetation is dominated by shrublands, steppes, and deserts. Plant species diversity peaks between 1,500 m and 2,500 m altitude, at the boundary between arid and semi-arid bioclimates, and annual plants strongly contribute to this mid-altitudinal peak in species diversity.

The vegetation of arid disequilibrium systems in the Middle Drâa basin is driven primarily by rainfall and generally shows no signs of degradation. Biomass of non-equilibrium steppes is influenced by rainfall, but the resilience against overgrazing is limited and species composition degrades under strong grazing pressure over long time scales. The standing biomass of semi-arid equilibrium systems with reliable annual precipitation do not show strong interannual fluctuations, but these pastoral ecosystems are frequently overstocked and therefore are subject to severe degradation.

Rehabilitation pace in non-equilibrium systems is relatively quick in terms of biomass rehabilitation, although community restoration takes many years. Regeneration processes in oromediterranean equilibrium ecosystems are extremely slow and require many decades. The actual land use pressure overstresses the resilience of these fragile mountain ecosystems.

*Keywords: Southern Morocco, High Atlas, diversity gradient, vegetation, life forms, pastoral ecosystems, arid rangelands, vegetation dynamics, resilience, degradation, rehabilitation*

## I-7.2.1 Introduction

The Drâa basin comprises the transition zone from sub-humid oromediterranean scrublands to arid Saharan deserts. From the catchment divide in the High Atlas southward, vegetation zones are located along a gradient of increasing temperature and decreasing precipitation. This gradient includes an increasing interannual coefficient of variance for precipitation (Knippertz et al. 2003) and a southward shift in seasonality from Mediterranean-type winter rainfall to bimodal rainfall in spring and autumn (Schulz 2008). The IMPETUS project implemented a gradient oriented monitoring transect for vegetation and climate observations in the Drâa basin (for details on locations, plot design, weather stations, and test site environments see section I-4.3). About 93% of the catchments area is used as rangeland by mobile and sedentary pastoralists. Stocks (and thus grazing pressure) have markedly increased in the High Atlas over the last decades (Chiche 2007). Just about 7% of the area is used for irrigation agriculture in the oases along the streams (Schmidt 2003).

In the following subsection, we will discuss the consequences of the biophysical and socio-economic framework for ecosystem resilience against climate stress and land use pressure.

### I-7.2.2 Vegetation units

The Upper and Middle Drâa catchment includes parts of three major floristic regions, the Mediterranean, Ibero-Mauretanian, and Saharan region respectively. Beginning with the High Atlas, the vegetation shows a southward sequence of oromediterranean scree and dwarf-shrub vegetation, Ibero-Mauretanian sagebrush-steppes dominated by *Artemisia herba-alba*, Pre-Saharan *Hammada scoparia* -steppes and *Convolvulus trabutianus* -rock-steppes, down to Saharan semi-deserts and deserts with *Acacia raddiana* dominated wadi-vegetation (Quézel and Barbero 1981; Quézel et al. 1994, 1995; Finckh and Poete 2008). Riparian vegetation along watercourses and agricultural systems show the corresponding transition from (Sub-) Mediterranean to Saharan flora and vegetation.

### I-7.2.3 Plant diversity along gradients

Vegetation units generally show specific ranges of vascular plant diversity. In the Drâa region, mean species density on rangelands per 100 m² fluctuates widely between less than five species in extreme Saharan or oromediterranean environments and more than 45 in semi-arid steppes. Species density [100 m²] along the gradient of altitude throughout the Drâa basin shows a unimodal hump shaped distribution (see fig. I-7.2.1), rising steadily from 475 m (or less than 50 mm annual precipitation) to a peak at 2,225 m (or 275 mm Pann, respectively) and decreasing again at higher altitudes. Accumulated species richness along the test site transect attains maxima at total annual precipitation of 225 mm, about 50 mm / 250 m below the peak in species density.

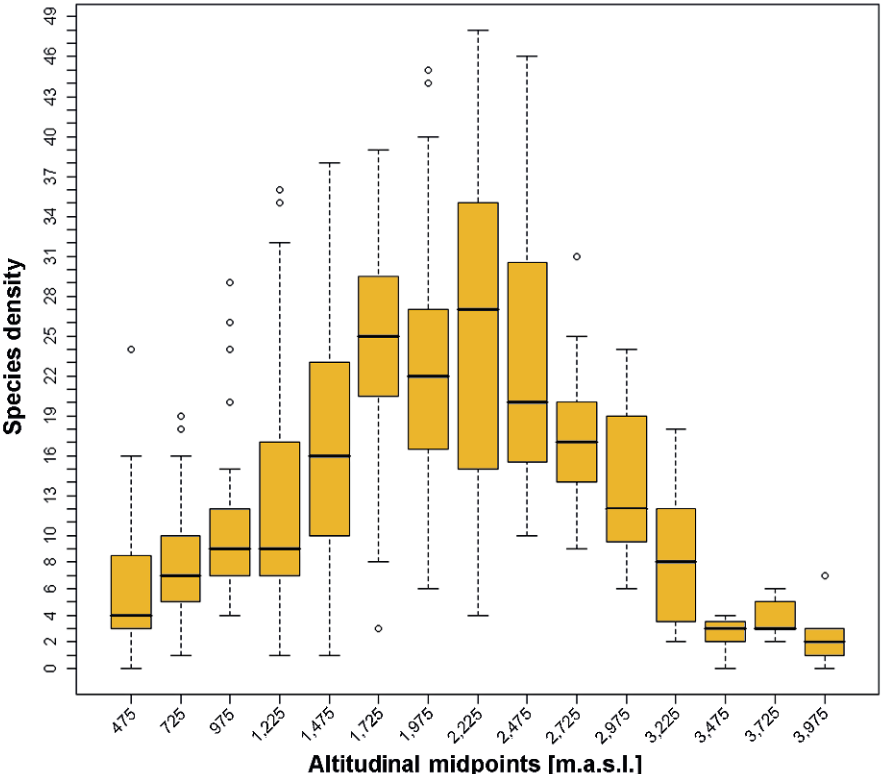

**Fig. I-7.2.1: Species densities at 100 m² plots along the altitudinal gradient in the Drâa basin.**

There is still no scientific consensus regarding the underlying causes of the hump-shaped functions of alpha diversity along large scale altitudinal gradients (Colwell et al. 2005; Field et al. 2009), although the so-called mid-domain effect (Colwell and Lees 2000) or climate-productivity relationships (Field et al. 2009) are frequently cited to explain such patterns. Limiting environmental factors such as decreasing temperatures at the upper end and decreasing precipitations at the lower end of the altitudinal gradient play a major role for this pattern. The difference between species density and accumulated species richness is due to changes in the life form spectra of the plant communities. Annual species (*thérophytes*) gain prevalence beneath the 200 mm isoline. These species contribute about 60% of the life form spectrum and maintain this threshold at the arid test sites further south (Finckh 2006). As therophyte guilds depend on specific climatic triggers, they can be partly absent in *relevés*. The permanent life forms (*hemicryptophytes, chamaephytes*) that dominate the semi-arid and sub-humid wing of the transect are much more reliable in this respect. Species density is thus closer to total species richness. Apart from this theoretical debate, we observed that species density peaks in the altitudinal belt between 1,500 m and 2,500 m, that the percentage of small range endemic species increases strongly with altitude (Benabid 2000) and that the heterogeneity of plant communities increases with aridity.

### I-7.2.4 Resilience of arid and semi-arid ecosystems

The vegetation units along the transect respond differently to climatic fluctuations. Rank Abundance Distributions are a suitable tool for the analysis of this effect. All species found in one vegetation plot were ranked according to their abundances, i.e. number of individuals. Y-axis shows log-transformed abundances, while the x-axis shows the total number of species found, i.e. species richness. Interannual changes of the curves indicate differences in species and numbers of individuals between years.

Figure I-7.2.2 shows annual rank abundance distributions for a permanent monitoring plot within an exclosure in the arid Jebel Bani chain southwest of Tagounite. We observed few species and individuals present in the first two years after fencing, then a strong increase in both parameters in the relatively wet years 2004 and 2006, followed by a subsequent decrease. A neighboring plot within an exclosure fence showed the same temporal dynamics. We assume that this arid ecosystem

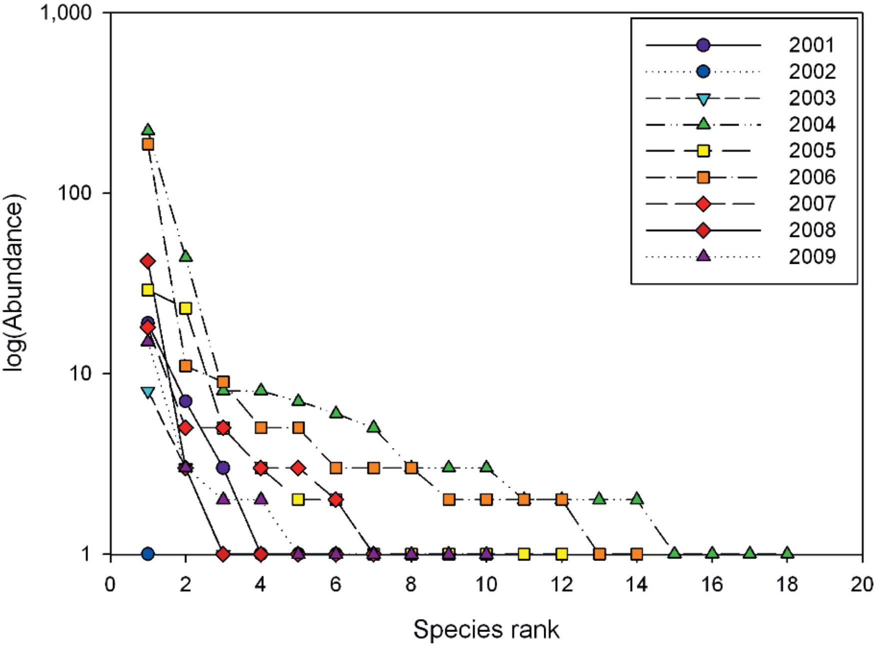

**Fig. I-7.2.2: Rank Abundance Distributions for arid ecosystems: the permanent plot JHBZS (sample size: 125 grid cells).**

constitutes a disequilibrium system in the strict sense (Gillson and Hoffmann 2007), in which vegetation dynamics are driven primarily by interannual rainfall variability rather than by grazing. If pastoral resources are available, they might be used for grazing, but the strong intra- and interannual fluctuations of biomass do not allow the maintenance of large stocks with permanent and selective grazing pressure.

The vegetation at the test sites receiving between 100 and 200 mm of annual precipitation correspond to nonequilibrium systems in the sense of Gillson and Hoffmann (2007). The standing biomass strongly fluctuates according to the rainfall of the respective season, but the life form spectra are dominated by perennial species. Many of these plants are adapted to strong interannual rainfall variability and able to build up reserves for dry years. If these steppes are subject to long term overgrazing, many species become overstressed and the species composition shifts towards unpalatable and annual species. These systems thus degrade over longer time periods, and productivity becomes less reliable, entering a state of opportunistic reactions to rainfall similar to disequilibrium systems. A few ungrazed vegetation areas remaining in rural cemeteries in the Basin of Ouarzazate and the Jebel Saghro provide evidence of the potential natural vegetation of this steppe belt, which is now almost completely degraded.

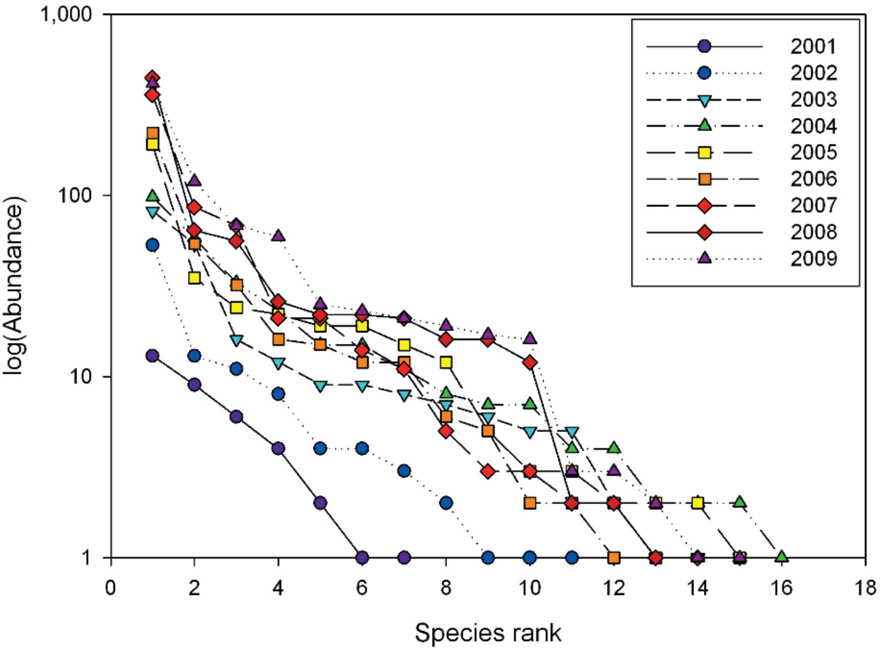

**Fig. I-7.2.3: Rank Abundance Distributions for semi-arid mountain ecosystems: the permanent plot TZTZ (sample size: 125 grid cells).**

Semi-arid and sub-humid steppes beyond the 200 mm isoline, dominated by perennial shrubs and hemicryptophytes, respond differently to grazing pressure. Rank abundance distributions from the oromediterranean permanent plot TZTZ (see fig. I-7.2.3) do not show strong interannual fluctuations but an increase in species number and abundances was observed during the first two years of fencing. In this equilibrium system with about 500 mm of annual precipitation, rainfall was more consistent, allowing perennial flora to dominate the scrublands (in biomass, not in species number). This permanently available resource facilitates the growth of larger herds present in the region over long periods, leading to a permanent grazing pressure. Rainfall reliability in arid and semi-arid rangelands is a double-edged driver, making the ecosystem subject to unlimited stocking and thus subject to severe degradation over long time periods.

## I-7.2.5 Rehabilitation pace

Little is known about the time span necessary for rehabilitation of degraded arid and semi-arid ecosystems. Sagebrush steppes, mainly dominated by short-living dwarf-shrubs and permanent grasses, attain a first regeneration phase within a few

**Fig. I-7.2.4: A relict of *Stipa*-dominated grass steppes on a rural cemetery close to Iknioun, Jebel Saghro. The dark brown colours in the background indicate the degraded *Artemisia*-steppes outside of the cemetery.**

years, in terms of standing biomass and population structure of the dominating species (unpublished data). However, comparisons to long-term exclosures, e.g., at rural cemeteries, still show key differences in species composition (see fig. I-7.2.4). Recolonization by grazing-sensitive species is a largely stochastic process, dependent on dispersal mechanisms and distances to refuge sites. We still lack data and model approaches required to estimate time spans for complete restoration.

In oromediterranean spiny dwarf-shrub communities' temporal dynamics are much slower. The vegetation period is shorter and growth conditions are more extreme in terms of solar radiation, wind exposure, evaporation, frost, and cryoturbation. At the oromediterranean test sites TIC and TZT in the High Atlas, few species are able to colonize open sites above 3,000 m.

By far the most important pioneer species at open sites is the spiny cushion shrub *Alyssum spinosum*. Once this species is established and has grown up to larger individuals, other species find safe sites for establishment under the tufts. The individuals younger than 30 years represent about 10% of the standing *Alyssum* biomass. The second relevant colonization strategy is clonal growth after establishment at safe sites. This is the case with several grasses, e.g. *Festuca* sp. The surface occupied by this species at test site TZT increased over a five year period only by 10%, so again, this process requires decades to revegetate a degraded site. To summarize, regeneration of vegetation cover in these ecosystems by the primary pioneer species takes decades, and late successionary species grow and establish much slower. The actual grazing pressure and firewood extraction by the local population exceed the growth in biomass and overstress the resilience of these fragile mountain ecosystems. In the long run, this overexploitation has severe consequences for biodiversity, pastoral productivity, slope stability and flash floods.

## I-7.2.6 Conclusions

Semiarid to arid steppe ecosystems in southern Morocco differ strongly with regard to vegetation dynamics and resilience. Vegetation dynamics of arid rangelands in the presaharan region are driven mainly by rainfall events and show strong interannual fluctuations. The lack of reliable forage availability hinders the build-up of large stocks of sheep and goats and thus prevents a permanent overstocking. No signs of rangeland degradatation were found in the arid part of the study area.

In contrast to the arid rangelands, biomass in semiarid ibero-mauretanian and oromediterranean rangelands in the southern High Atlas ranges shows minor interannual fluctuations. According to their altitudinal position, they offer reliable grazing resources in spring and autumn (mid altitudes) or in summer (high altitudes). However, the reliability of fodder allows for pastoral land users to build up large stocks with permanent (all year round) presence on the rangelands. In dry years, stocking numbers exceed by far the carrying capacity and resilience of the pastoral ecosystems and cause the degradation of rangeland vegetation. Important degradation processes comprise decreasing biomass productivity and decreasing vegetation cover which facilitates soil erosion. With regard to floristic changes, palatable and browsing sensitive perennial species disappear and vegetation shifts towards spiny, poisonous or annual species.

Regeneration of natural semiarid rangelands is slow for mid-altitudinal steppes and extremely slow for high altitudinal pastures. Actual land use trends enhance degradation processes and constitute, at least in the medium term, a much stronger driver of desertification than Climate Change.

## References

Benabid A (2000) Flore et écosystèmes du Maroc - évaluation et préservation de la biodiversité, 1st edn. Éditions Ibis Press, Paris

Chiche J (2007) History of Mobility and Livestock Production in Morocco. In: Gertel J, Breuer I (eds) Pastoral Morocco - Globalizing Scapes of Mobility and Insecurity, pp. 31-59. Ludwig Reichert Verlag, Wiesbaden

Colwell RK, Lees DC (2000) The mid-domain effect: Geometric constraints on the geography of species richness. Trends Ecol Evol 15:70-76

Colwell RK, Rahbek C, Gotelli NJ (2005) The Mid-Domain Effect: There's a Baby in the Bathwater. Am Nat 166(5), E-reply, E149-E154

Field R, Hawkins BA, Cornell HV, Currie DJ, Diniz-Filho JAF, Guegan J-F, Kaufman DM, Kerr JT, Mittelbach GG, Oberdorff T, O'Brien EM, Turner JRG (2009) Spatial species-richness gradients across scales: A meta-analysis. J Biogeogr 36:132-147

Finckh M (2006) Klima- und Landnutzungs-getriebene Dynamik von Vegetationsmustern in Südmarokko. Ber d Reinh Tüxen-Ges 18:83-99

Finckh M, Poete P (2008) Vegetation Map of the Drâa Basin. In: Schulz O, Judex M (eds) (2008) IMPETUS Atlas Morocco: Research Results 2000-2007. 3rd edn., pp. 31-32. Department of Geography, University of Bonn, Bonn

Gillson L, Hoffmann MT (2007) Rangeland Ecology in a Changing World. Science 315:53-54

Knippertz P, Christoph M, Speth P (2003) Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. Meteorol Atmos Phys 83:67-88

Quézel P, Barbero M (1981) Contribution à l'étude des formations présteppiques à genévriers au Maroc. Bol Soc Brot, Ser 2 53:1137-1160

Quézel P, Barbero M, Benabid A, Rivas-Martinez S (1994) Le passage de la végétation méditerranéenne à la végétation saharienne sur les revers méridional du Haut Atlas oriental (Maroc). Phytocoenologia 22:537-582

Quézel P, Barbero M, Benabid A, Rivas-Martinez S (1995) Les structures de végétation arborées à Acacia sur le revers meridional de l'Anti-Atlas et dans la vallée inférieure du Draa (Maroc). Phytocoenologia 25:279-304

Schmidt M (2003) Development of a fuzzy expert system for detailed land cover mapping in the Dra catchment (Morocco) using high resolution satellite images. Doctoral thesis, University of Bonn, Bonn

Schulz O (2008) Precipitation in the Upper and Middle Drâa Basin. In: Schulz O , Judex M (eds) (2008) IMPETUS Atlas Morocco: Research Results 2000-2007. 3rd edn., pp. 19-20. Department of Geography, University of Bonn, Bonn