Monitoring Drought and Land Degradation in Senegal's Ecoregions

Introduction

This report was originally submitted to USAID's Mission to Senegal in early 2000 as a discussion paper on the extent and severity of drought on the vegetation resources of Senegal. The paper was one of several thematic discussion papers that resulted from a program to monitor climate and human impacts on the natural resources of Senegal. We present it here as a background piece to more recent efforts to monitor and characterize land productivity, human impacts on land resources, and biodiversity both in Senegal and across the Sahel.

The environmental monitoring program of the mid to late 1990s was carried out by the U.S. Geological Survery/EROS Data Center, in partnership with the Centre de Suivi Ecologique (CSE). Funding for this program was provided mainly by USAID/Senegal, with supplementary funding from the USGS. The first objective was to test and apply practical techniques for monitoring natural and agricultural resources over time – approximately during the last half century. The second objective was to contribute to the understanding of biophysical changes in the natural resources and provide new information to Senegal's environmental policy-makers, and to the scientific community.

The monitoring effort took a three-tiered approach using the combined strengths of: (a) ground site investigations, (b) repetitive airborne videography, and (c) high-resolution satellite remote sensing spanning over 35 years. The major resources we monitored were: vegetation, agriculture, biodiversity, soils, and to a lesser extent, surface water. This report is limited to the impact of the drought of the 1970s, 1980s and relatively dry 1990s on the perennial vegetation, with some references to changes in vegetation cover (land cover) owing to rapidly expanding agriculture.

Vegetation is the biological resource that sustains many forms of life, including humans. It is a priceless resource, providing food, fiber, medicine, and habitat for wildlife, fuel and construction material, and stability for the soils. Yet, more than any other natural resource, the vegetation of Senegal is being modified by human pressures at unprecedented rates.

We used vegetation as the main indicator of the state of the natural resources because it can be more easily observed and measured than changes in the soil resource. While the loss of woody vegetation cover and diversity reveals only part of the degradation story, it is a reasonable indicator of the overall ecosystem health and productivity. Vegetation loss often represents the beginning of a chain of events ultimately leading to desert-like conditions, since it may lead to feedbacks such as declining soil fertility (Breman and de Wit, 1983), and the reduced generation of convective rainfall during the wet season (Charney et al., 1975; Charney, 1975). Vegetation cover and diversity are barometers of change – long-term natural evolution, and shorter-term climate and human-induced change. The vegetation structure and cover lend themselves to mapping and monitoring from remote sensors in airplanes and satellites, as well as direct field-based studies. The biological composition and diversity of vegetation is usually monitored on the ground. Interviews with local people provide valuable complementary information on vegetation conditions over time.

In this report, we examine changes in the vegetation resource over the past 35 years using actual photographic records. In some cases, we use historical documents to discuss even longer-term changes. We focus primarily on the perennial, woody vegetation as the primary indicator. Thus, we do not deal with monitoring the yearly fluctuations of herbaceous annual vegetation that is so intimately tied to seasonal rainfall conditions. Furthermore, we do not present a detailed map or inventory of the many types of vegetation formations and plant communities that occur in Senegal because good references already exist on this. For detailed descriptions and maps of the vegetation cover (and soils, hydrology and geology), we suggest the reader consult the earlier works by White (1983); Lawesson, 1995; and Stancioff, Staljanssens, and Tappan (1986). The latter reference is particularly complementary to the present report because much of our work builds upon the original field work and satellite image analyses undertaken for that study.

In our monitoring efforts, we stressed the use of photographic evidence of changing conditions, using both ground based, aerial, and satellite photographic and imaging systems. The use of before-and-after photography and satellite imagery is a new and unique contribution to the body of knowledge on Senegal's natural resources. Although we present quantitative information where possible, much of the material is qualitative because the historical baseline was largely descriptive or photographic. We believe that in providing qualitative trends and before-and-after photographic evidence of change, other researchers can investigate in greater depth the trends we have found, using additional tools. We also attempted to leave with CSE an image baseline, in the form of aerial videography flown in 1994 that would allow CSE and its partners to carry out quantitative monitoring of Senegal's surface resources in the future. Finally, we have tried to present our monitoring results in a spatial format where possible, through the thematic maps.

Drought Impact

Senegal has experienced periods of drought as well as a general decline in rainfall for the past 80 or more years. The major droughts of this century have been: the 1910-1914 drought (Aubréville, 1949), the 1942-1949 drought, the 1968-1973 drought, and the 1982-1984 drought. Many authors have written about drought and its negative impact on vegetation cover, vegetation production, agricultural yields, and land productivity. There is no doubt that drought and declining rainfall has had an impact, but it has often been difficult to decouple the effects of drought from human and animal pressures on vegetation resources.
In the 1980's, a number of studies used vegetation indexes computed from time-series satellite images to attempt to characterize the southern expansion of the Sahara into the Sahelian Region (Helldén, 1988; Nicholson, Tucker, and Ba, 1998; Tucker, Dregne, and Newcomb, 1991). The vegetation index, based on the NOAA-AVHRR Normalized Difference Vegetation Index (NDVI), was based primarily on the response of annual vegetation to the summer rains in the Sahelian Region. As drought buffeted the region, the vegetation index values dropped, with a shift southward of the seasonal green-up areas during the drought years. However, wetter years like 1988, 1994, and 1999 have shown that the annual seasonal vegetation patterns are resilient following a major drought.

Annual Sahelian grasslands do show considerable resilience following drought, and satellite based vegetation indexes work well to monitor the rebound. Figure 1a and 1b shows this resilience. Indeed, in an article recently published by Tucker and Nicholson (1999), the authors used NDVI data derived from NOAA-AVHRR satellite imagery to study variations in the size of the Sahara Desert from 1980 to 1997. Through a combination of the satellite and ground data, the 200 mm annual precipitation boundary was mapped for the Saharan-Sahelian region by year. Although highly significant year-to-year variation in the size of the Sahara Desert has occurred, no systematically increasing or decreasing trend was evident. This is contrary to reports in the popular press touting an expanding Sahara Desert.

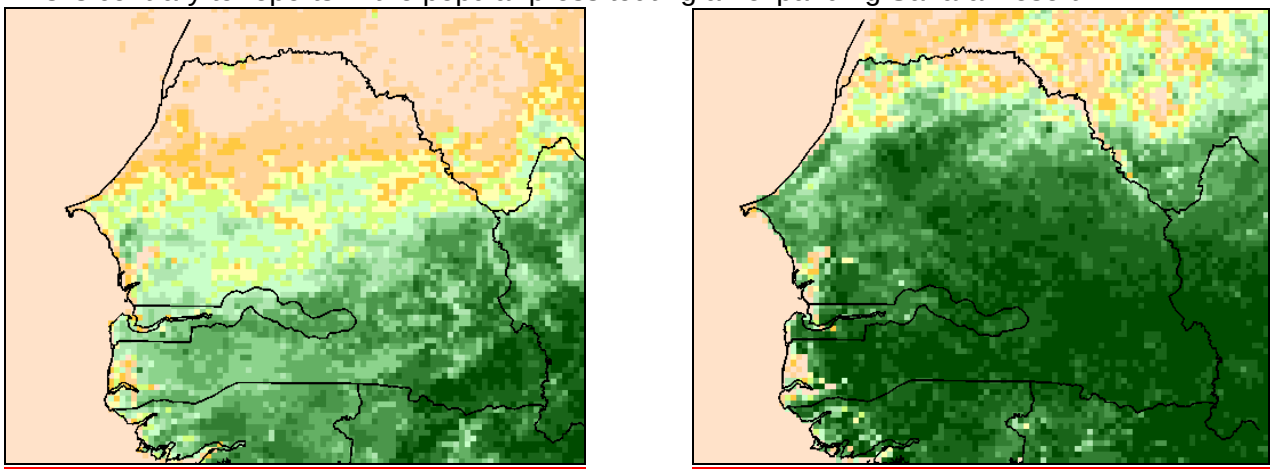


Figure 1a and 1b. *A comparison of vegetation index images derived from NOAA-AVHRR satellite data over Senegal showing a drought year (left, 1984) and a relatively wet year (right, 1999), each during the period of peak green-up of mid September. With adequate rainfall, the seasonal, annual vegetation patterns show considerable resilience*.

The use of vegetation indexes derived from meteorological satellite image data (such as from NOAA-AVHRR) for assessing longer-term drought (and human) impact on the ecological trends of the Sahelian Region has been more problematic, given the challenge of decoupling annual vegetation growth patterns and erratic rainfall from long-term changes in vegetation productivity. Nevertheless, recent research on Senegal has begun to examine long-term productivity using the 17-year archive (1982 to 1999) of NDVI data over West Africa (Tappan et al. 1992; Li et al., 1999).

During the present monitoring study, we have taken a new look at drought impact, focusing on perennial vegetation as the primary indicator of long-term change. The rationale was that perennial vegetation is less sensitive to the vagaries of yearly rainfall patterns, and more indicative of longer-term changes that may occur over periods of decades. Our evidence comes both from revisiting ground monitoring sites over a 10 to 15 year period, high-resolution satellite images from the 1960's compared to the 1990's, and Rapid Rural Appraisal studies Rapid Rural Appraisal (RRA) studies and semi-structured interviews (SSI's) conducted in the western two-thirds of Senegal.

Drought Overview from Ground Sites

In order to gain a national perspective of the impact of drought on the perennial vegetation, the joint EROS/CSE field team examined direct evidence of drought at approximately 300 permanent field sites visited between 1994 and 1997. The main indicator used was direct observation of tree and shrub mortality. Care was taken to distinguish between mortality caused by human actions on woody vegetation such as axe scars, bark stripping, lopping and pruning, and mortality caused by drought stress. Our assessment was based on the latter. We used a second indicator, rephotography, which allowed us to compare site photos from the 1982-84 period to the site conditions at the photo point (the exact location of the rephotographed landscape) during the site revisits of 1994-97. We developed a subjective, 5-class scale of severity of drought impact on woody vegetation: levels 1 and 2 represent little or no observable evidence (no dead or stressed shrubs and trees), level 3 indicates that dead woody species are present (but not common) within the population of woody species, and levels 4 and 5 indicate very significant to severe levels of woody mortality.

In discussing the drought impacts by ecoregion, a useful reference on the diversity of landscapes of Senegal is the land-use and land-cover map of Senegal (Figure 2). The map is the product of multi-date Landsat image interpretations and extensive fieldwork carried out in the 1982-84 period (Stancioff *et al*. 1986). This reproduction is a generalization of the original detailed map published at a scale of 1:500,000. It portrays the land-use and land-cover situation of approximately 1982-84.

Let us now proceed to examine specific findings within the agro-ecological regions, focusing on those most impacted by the recent droughts. Figure 3 is a reference map that presents the ecoregions we used for grouping Senegal's land resources into areas of similar agro-ecological areas.

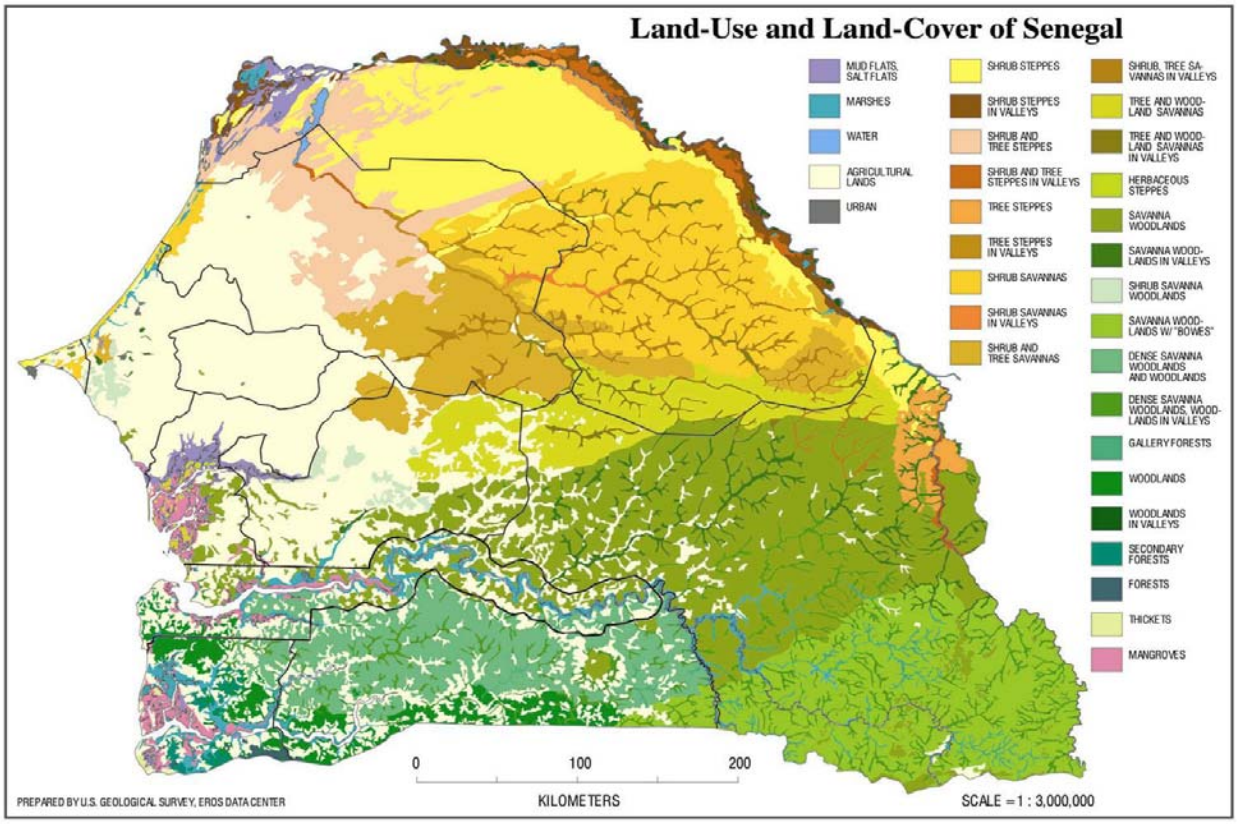


Figure 2. Land-Use and Land-Cover of Senegal, modified from the "Carte du Couvert Végétal du Sénégal" in Stancioff *et al*., (1986). The map was produced from Landsat images and extensive field work carried out in 1982-84.

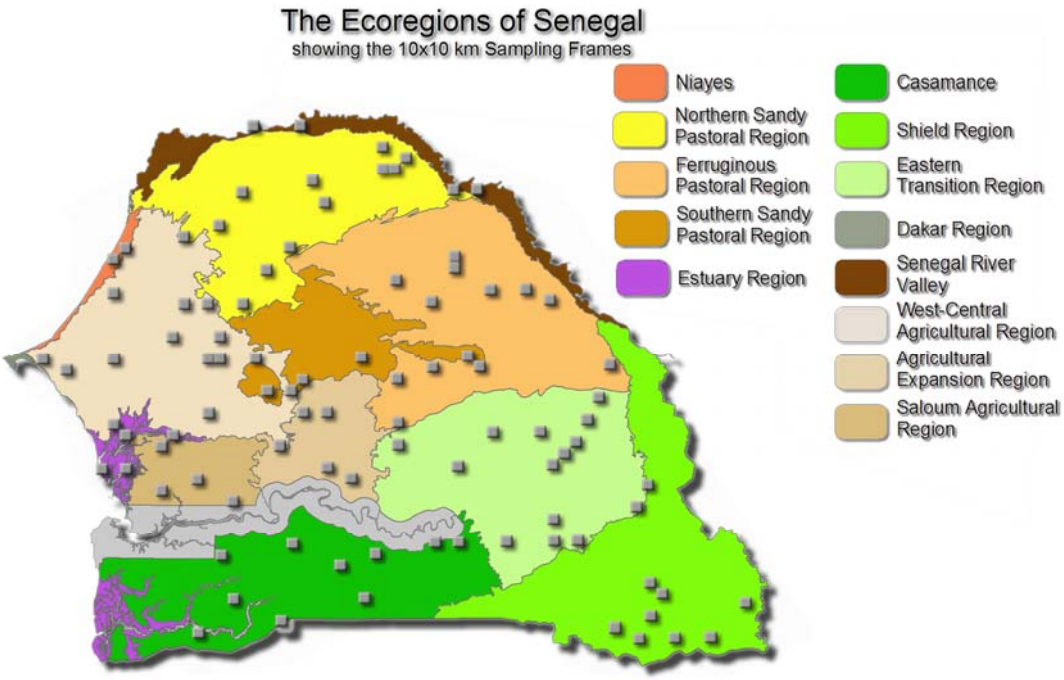


Figure 3. The Ecoregions of Senegal. The small squares represent random sample sites where we analyzed land cover change using time-series imagery.

Northern Sandy Pastoral Region

In the northernmost agro-ecological region of Senegal, the Northern Sandy Pastoral Region or Sandy Ferlo, one would expect the effects of decades of drought and below normal rainfall to be the most severe. This is not the case: drought impact levels were moderate overall. The soils of the region are derived from ancient Ogolian dunes which have a large natural water storage capacity, providing moisture between intermittent wet season rains, and sustaining deep rooted plants well into the dry season, particularly in the interdunal depressions. Nevertheless, the effects of drought have taken their toll on the woody cover, with a loss of some of the mesophytic species over the past 3 decades.

This region was once covered by a floristically rich shrub savanna (Michel, Naegelé, Toupet, 1969). Lawesson (1995) believes that the original vegetation in historical time was dense woody vegetation in the form of a thicket or bush land. Today, the region is dominated by grassland with varying amounts of woody cover of 1 to 40 %, with the woody strata generally not exceeding 4 meters in height. Woody species are scattered throughout and vary in density as a function of climate, soils, geomorphology, and livestock and human pressures.

As with other parts of the Sahel, there is much discussion in the literature about natural resource and degradation and desertification, yet few if any studies present quantitative or at least photographic evidence of changes in these phenomena over time. Lawesson (1995) hypothesizes that relatively little has changed in the vegetation since the early 1900's, basing his conclusions on the close resemblance of photographs published by early French naturalists such as Engler, Trochain, and Adam, and his own photographs taken in the early 1990's. Others disagree, writing at length about degradation and desertification in the latter half of the 20th century in the Sahelian Region. Many point to a general decline in vegetation cover, biodiversity, and productivity of the region, citing a combination of factors: low rainfall, human pressures, the high concentration of animals around water sources, and the breakdown of traditional pastoral system among the Peul. Poupon (1976) conducted an inventory of herbaceous and woody vegetation in during the severe drought of 1972. He found the herbaceous stratum totally absent and the tree stratum severely affected, with 53% mortality among the *Acacia Senegal*.

As discussed above, we found significant (moderate) evidence of drought related impacts on the woody vegetation, mostly on sandy slopes and uplands. A pair of photos from permanent site 304 exemplifies our findings (Figures 4a and 4b for sites at least 10 kilometers from major towns or permanent settlements). As with most sites, dead shrubs or trees were present, but not in great numbers. Interestingly, we noticed significantly less standing or fallen deadwood in the 1990's compared to the 1980's. Furthermore, for most sites, the woody vegetation cover had actually increased as trees recovered and matured following the severe drought of 1982-84. The greatest mortality, with little evidence of regeneration, was observed among woody species of both Sahelian and Sudanian zone affinities. Table 1 presents the woody species that exhibited the highest degrees of mortality among all sites.

Figure 4a and 4b. *A 10-year comparison of ground site 304 along the edge of the Réserve Sylvo-Pastorale des Six Forages, in the Northern Sandy Pastoral Region. The photos indicate stable conditions in the woody vegetation stratum. Drought has taken a moderate tool on some woody species. Dates: left: October 1983; right – January 1994.*

Table 1. Common woody species with the highest observed mortality rates, Northern Sandy Pastoral Region

Species	Family	Ecological Zone	Wolof name
Acacia senegal	Mimosaceae	The Sahel	Verek
Balanites aegyptiaca	Balanitaceae	The Sahel	Sump
Boscia senegalensis	Capparidaceae	The Sahel	Njandam
Calotropis procera	Asclepiadaceae	The Sahel	Paftan
Dalbergia melanoxylon	Fabaceae	The Sudan	Jalamban
Grewia bicolor	Tiliaceae	The Sahel	Kel
Pterocarpus erinaceus	Fabaceae	The Sudan	Ven
Sclerocarya birrea	Anacardiaceae	The Sudan	Ber
Sterculia setigera	Sterculiaceae	The Sudan	Mbep

Drought related mortality was locally severe in the north-western part of this region, with mortality present among all species, including the very hardy *Balanites aegyptiaca* (*sump*), and *Calotropis procera* (*paftan*). It is interesting to note that tree and shrub mortality can be monitored using aerial videography from a low flying airplane. Figure 5 shows the carcasses of *C. procera* as seen in a single aerial video frame. Woody mortality could only be detected and identified in the telephoto (zoomed) mode of video acquisition, which provided an image resolution of approximately 2 centimeters. During normal video acquisition, image resolution was about 30 cm.

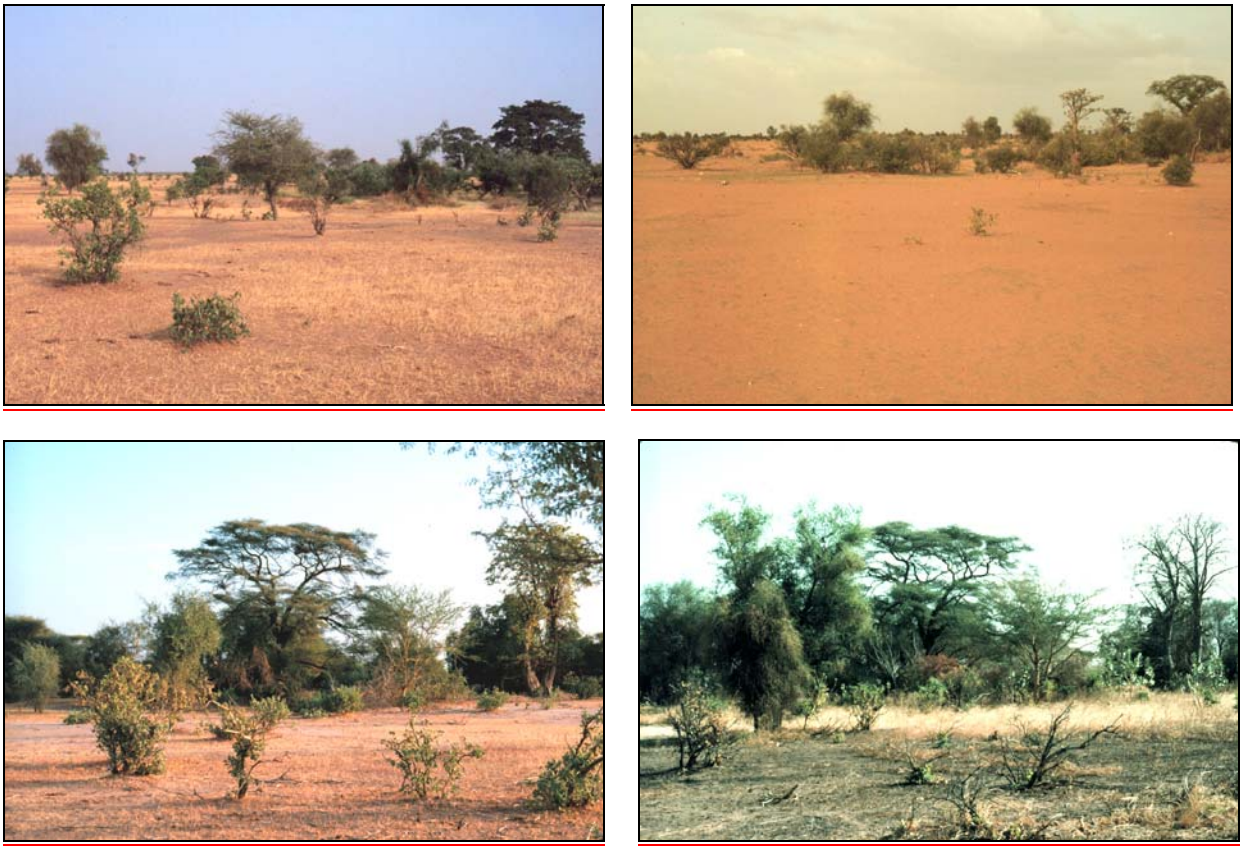
Figure 5. *This image shows the carcasses of C. procera as seen in a single aerial video frame. Image resolution is about 2 centimeters. Shrub and tree mortality could be readily detected on video images in the telephoto (zoomed) mode.*

Throughout much of the Sandy Ferlo, countless small interdunal depressions dot the landscape, as seen in the aerial photograph in Figure 6. The depressions generally support relatively dense stands of woody vegetation. They play a key and increasingly important ecological role. First, they collect runoff from the rains, forming temporary ponds during most rainy seasons, providing wildlife and cattle with drinking water for one to several months into the dry season. Second, they form unique wildlife and flora habitats – islands of life in a harsh, semi-arid environment, forming their own microclimates of lower temperatures and higher humidity. Third, whereas the sandy uplands have lost some or much of the vegetation cover over the past 30 years, the wooded depressions have become important refuges that preserve some of the flora and fauna through years of drought. This phenomenon was strikingly noticeable in our ground site revisits, and in aerial and satellite photos taken over time.

Figure 6. *This aerial view shows the countless small interdunal depressions that dot the landscape. The depressions generally support relatively dense stands of woody vegetation, form seasonal ponds providing wildlife and cattle sources of water, and harbor diverse flora and fauna. All aerial views in this report were taken from an altitude of about 350 meters above sea level. Date: September 1994.*

We found many wooded depressions contained Sudanian zone tree species that have long since disappeared from the sandy uplands, including, *Anogeissus leiocarpus (ngejan), Bauhinia rufescens (rand)*, *Dalbergia melanoxylon (jalamban)*, *Diospyros mespiliformis (alom)*, *Feretia*

apodanthera (sanceer), *Mitragyna inermis (xos)*, *Securidaca longipedunculata (fuuf)*, *Stereospermum kunthianum (feex)*, *Sterculia setigera (mbep),* and *Tamarindus indica (dakkar)*. The depressions play the role of a natural buffer against the impact of drought, helping to preserve some of the biological diversity, possibly helping to reseed and reconstitute the upland vegetation during wetter periods. Figures 7a, 7b, 7c, and 7d present photos taken over 10 and 12-year periods at two monitoring sites (sites 310 and 321). They show the relative diversity and vigor of the woody vegetation in depressions, and (in site 321) the loss of woody species outside the depression area. Sites 310 and 321 contained 10 and 19 woody species, roughly twice the number of their surrounding uplands. The contrasts between the increasingly barren upland areas and the wooded depressions are further illustrated by the pair of satellite images in Figures 8a and 8b. While this example is from the Mbégué Classified Forest in the Southern Pastoral Region, the phenomenon is widespread in the pastoral and agricultural regions of northern Senegal.



Figures 7a, 7b, 7c, and 7d. *The paired photographs were taken over 10 and 12 year periods at two monitoring sites (sites 310, top, and 321, bottom). They show the relative diversity and vigor of the woody vegetation in depressions, and (in site 321) the decline of woody species outside the depression area. Dates: upper left – October 1983; upper right – August 1993; lower left – November 1983; lower right – November 1995.*

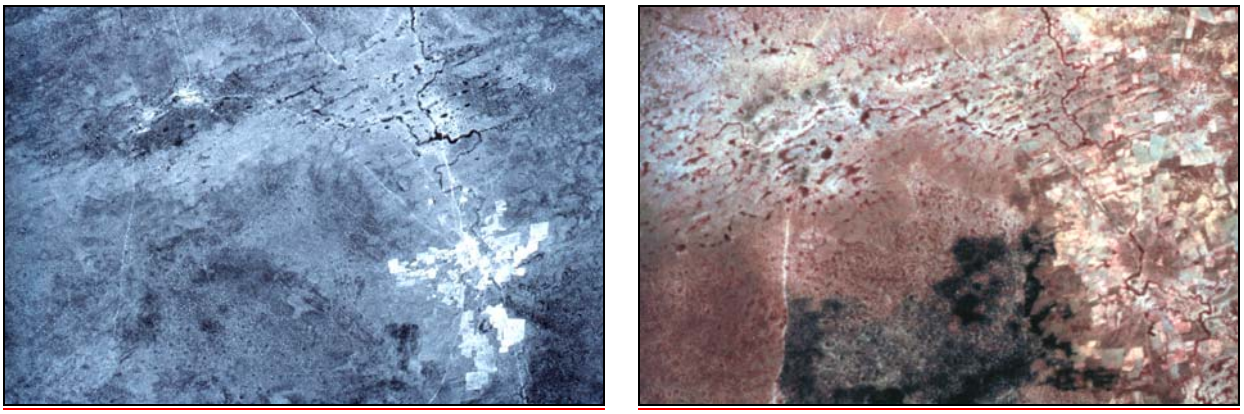


Figure 8a and 8b. *This pair contrasts satellite views of an area in the Forêt Classée de Mbégué. The left photograph was taken in 1965, and the right one in 1992. The comparison shows the increasing contrast in vegetation cover between the increasingly barren upland areas and the wooded depressions, probably the result of die-off from drought.*

We conducted numerous semi-structured interviews (SSI) with Fulbe herders to obtain their views on drought impact. The open-ended questions centered around how the landscapes appeared when they were young, what has caused the changes in the landscapes and vegetation, what woody species were common before the droughts of the 1970's and 1980's, what species are common today, and what species have become rare or absent. In nearly every SSI, the Fulbe spoke of major changes in the vegetation cover since the pre-drought period. The vegetation has become less dense -- lighter. Many woody species have disappeared or become rare (the lists vary somewhat from one interview to another), while a few appear to have become more common, invading the sandy upland areas. One group interviewed at the Belogne Kojoli Camp west of Vendou Tiengoli stated that *sump (Balanites aegyptiaca), njandam (Boscia senegalensis) and nger (Guiera senegalensis) are now more common on the dunes, but we have completely lost 3 kinds of trees and 2 have become rare. Vegetation in the depressions and around the seasonal ponds is denser now than before.* Many other informants spoke of the loss or rarity of dozens of species. Representative responses from several SSI's indicated that the decrease in rainfall constitutes the single most important natural factor influencing the loss of vegetation cover. The multiple droughts since the 1940's were commonly cited as the primary causes, with the greatest impact from the droughts of the 1970's and 1980's.

Villager's Perspectives on Drought in the Brar *Terroir*

Brar is a very old Wolof village (dating back over 1000 years) on the western edge of Lac de Guiers, in the Keur Momar Sarr *Communauté Rurale.* It lies in an area of ancient dunes, with sandy tropical ferruginous soils. The present landscape is typical of the Sahelian landscapes of the Sandy Ferlo, dominated by scattered thorny acacia (mainly *A. raddiana (seng), A. senegal (verek), A. seyal (surur), A. albida (kad)*, and *A. nilotica (gonake)* near the lakeshore), *Balanites aegyptiaca (sump)*, and a variety other shrubs and small trees. The people of Brar have always engaged in agriculture, animal husbandry, and fishing. Traditionally, the main rain fed crops were peanuts, millet, and sorghum, but the decline in rainfall and the lack of government support for agriculture have undermined the agricultural production system. The people are now eking out livelihoods in more marginal activities, including flood recessional agriculture, small-scale irrigation, livestock fattening (sheep), commerce, and migration to Dakar and other cities.

According to the elders, in the 1920's Brar was in the midst of a 'very dense and diverse forest'. Wild animals were numerous. Except for elephants and giraffes, large mammals were present,

including lions and hyenas. The rains were abundant, and the crops were 'vast and rich', providing ample harvest, filling the granaries. The phenomenon of rural exodus was virtually non-existent.

The villagers cite 1937, the beginning of a major drought, as the year in which the environmental situation began to change, impacting all natural resources and by extension, the socioeconomic fabric of the local community. Rainfall began to decline progressively, with severe droughts in the 1940's, 1970's and 1980's. The water level of Lac de Guiers has fallen considerably over this period, its shoreline receding from the edge of the village to a distance of several kilometers. The lake level remained low until 1986-88 when the Diama and Manantali dams on the Senegal River became operational, significantly raising the lake level. Several large seasonal ponds dried up, the water table dropped, and the village wells became slightly brackish.

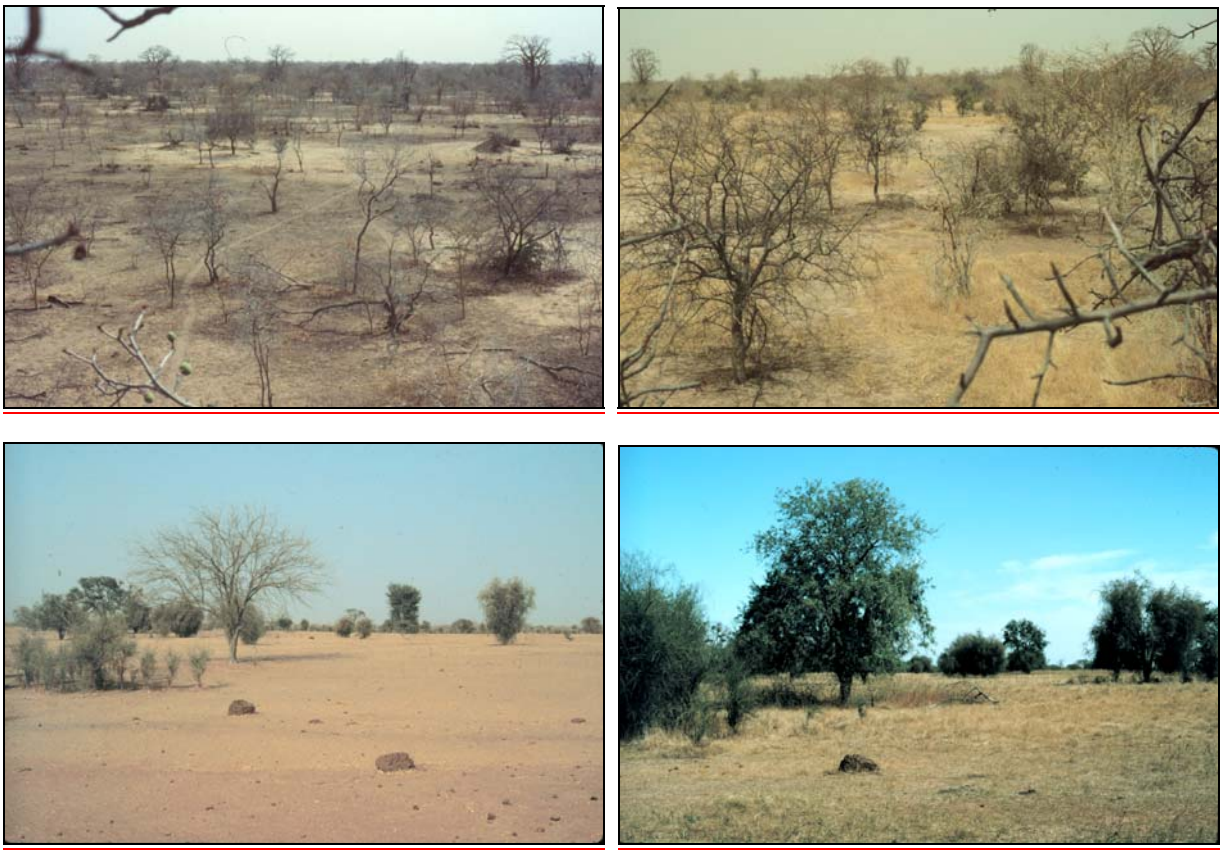
Since 1937, the villager elders talk about a general degradation of the vegetation quality and cover. They list the following woody species as having completely disappeared: *Lannea acida (son), Diospyros mespiliformis (alom), Mitragyna inermis (hoss), Dalbergia melanoxylon (jalamban), Grewia bicolor (kel), Feretia apodanthera (sanceer), Pterocarpus lucens (beey beey), and Stereospermum kunthianum (feex). Other species of economic importance have declined drastically, including: Tamarindus indica (dakkar), Sclerocarya birrea (ber), Commiphora africana (ngutoot), Salvadora persica (ngaw), Zizyphus mauritiana (sideem), Balanites aegyptiaca (sump), Acacia nilotica (neb neb), Acacia raddiana (seng), and Acacia albida (kadd).* The oldest women remember a time when they would gather sacs of fruit that they would sell in the markets of Louga and Saint Louis, earning them 15,000 F.CFA a week. Today this activity has ceased owing to the scarcity of fruit trees like the sump and the sidem.

The villagers speak of a progressive decline in vegetation density and biodiversity from 1937 to the present, which they attribute mainly to rainfall decline and periodic drought. The vegetation degradation does not appear to be related to agricultural pressures since the amount of land allocated to cropland has declined since the 1930's. Charcoal production, however, has exerted some pressure on the woody resources since the early 1970's.

Southern Sandy Pastoral Region

Higher rainfall is the fundamental natural characteristic that distinguishes the Southern from the Northern Sandy Pastoral Region, and along with it, somewhat denser and biologically more diverse vegetation communities. Annual rainfall in the 1980's and 1990's ranges from 400 to 500 mm, in contrast to the 150 to 300 mm levels of the northern region.

The drought impact on this region was minor to moderate according to our observations at 24 sites we revisited in 1994-96. In the 1982-84 site visits, our field notes indicate much more evidence of tree mortality than did our revisits. It is likely that the dead wood from the die-off of the 1970's and early 1980's is less evident a decade later owing to decomposition and harvesting for firewood. On the opposite end of the spectrum, we observed a number of sites in which the woody cover was denser than in the 1980's, exhibiting remarkable resilience following the severe 1982-84 drought. Two examples of this are seen in Figures 9a, 9b, 9c, and 9d (site 582, and a photographic site 44 km east of Linguère.



Figures 9a, 9b, 9c, and 9d. *These paired photographs show the stable and resilient vegetation cover at two sites in the Northern Sandy Pastoral Region (site 582 (upper pair), and a photographic site 44 km east of Linguère (lower pair). Dates: upper left - May 1982; upper right - February 1997; lower left – March 1984; lower right – December 1994.*

One exception to the relatively low level of observed drought impact is the significant mortality in the four sites revisited in the Mbégué Classified Forest that lies 40 km north of Kaffrine.

The perennial vegetation of this preserve is quite degraded from its original state, owing to overgrazing, cutting of trees and shrubs by surrounding agricultural communities, bush fires, and the recent drought. The contrast between the increasingly barren upland zones and the woody depressions is becoming more marked with time, as shown in the paired figures above.

Representative comments from informants in the region attributed drought as the primary cause of decreased vegetation cover and the loss of many species of shrubs and trees. Some cited the drought of the early 1970's as having had the greatest negative impact, and some associate 1970 with the beginning of the period of landscape changes and loss of vegetation. Others indicate that the change began decades earlier. The chief of the Fulbe camp of Tambedou, 25 km south of Linguère, recounted that *when I was young we had to keep an eye on our small children because they would get lost in the dense bush just beyond our camp. Lions used to roam this area. Now you see the difference -- nothing but grass and a few trees.* Figure 10 presents an aerial view of the Tambedou camp, showing the open nature of the landscape, and with dense stands now limited to the woody depressions.

Figure 10. This aerial view shows the Tambedou Fulbe camp, surrounded by an open, grassy landscape, with dense stands now limited to the woody depressions. Fifty years ago, a much denser stratum of woody vegetation covered the land, according to the Tambedou elders. Date: September 1994.

The Ferruginous Pastoral Region

Drought appears to have had the greatest impact on the Ferruginous Pastoral Region than any other. Observations at the permanent sites, supported by photographic evidence, show consistently significant to severe levels. Even sites remote from human settlements and watering points show signs of a major ecological transformation, marked by the widespread mortality of the less drought-resistant Sahelian and Sudanian species, and the overall impoverishment of the region's biodiversity. Mortality among woody species is highest on the gravelly, lateritic plateaux. The soils are shallow, and exposed to compaction by livestock. The poor water storage capacity of the soils, exacerbated by drought, has stressed the vegetation beyond tolerance levels. Woody species mortality is widespread, occurring over vast stretches of plateaux, creating veritable graveyards of shrubs and trees. The highest mortality rates were among *Pterocarpus lucens (mbey mbey), Boscia senegalensis (njandam),* and *Grewia bicolor (kel).* What is remarkable is that these are the most common species in the region, so there has been a major decline in the vegetation cover. Many other species were affected, and Table 2 lists the most common ones.

Ground site 355 north of Loumbol is representative of the evidence we found of severe mortality among woody species since 1983. Figure 11a and 11b shows the use of rephotography over a 13-year period to record the drought related degradation. The landscape is dominated by the diminutive *Pterocarpus lucens (mbey mbey)* tree that dominates the lateritic plateaux of the region. Furthermore, mortality among many tree species was severe along the gentle slopes between the plateaux and the wide fossil valleys of the region. A landscape photo from site 384 northwest of Namari exemplifies the severe tree mortality on such slopes (Figure 12. One species that does not appear affected by the drought is the hardy *Adenium obesum (liisugaar),* which occurs commonly, resembling a miniature baobab.

Table 2. Common woody species with the highest observed mortality rates, Ferruginous Pastoral Region

Species	Family	Ecological Zone	Wolof name
Acacia macrostachya	Mimosaceae	The Sudan	Sam
Bombax costatum	Bombacaceae	Sudan/Guinea	Garabu lawbe
Boscia senegalensis	Capparidaceae	The Sahel	Njandam
Dalbergia melanoxylon	Fabaceae	The Sudan	Jalamban
Grewia bicolor	Tiliaceae	The Sahel	Kel
Guiera senegalensis	Combretaceae	The Sudan	Nger
Pterocarpus lucens	Fabaceae	The Sudan	Saagari; mbey mbey
Sclerocarya birrea	Anacardiaceae	The Sudan	Ber

Sterculia setigera	Sterculiaceae	The Sudan	Mbep

Figure 11a and 11b. This photo pair shows the use of rephotography over a 13-year period to record the drought related degradation. The landscape is dominated by the diminutive Pterocarpus lucens (mbey mbey) tree that dominates the lateritic plateaux of the region. Severe levels of mortality occur throughout the Ferruginous Pastoral Region. Dates: left – November 1983; right – February 1996.

Figure 12. *A ground photo from site 384 northwest of Namari, in the Ferruginous Pastoral Region, or lateritic Ferlo. The site exemplifies the severe tree mortality caused by drought on the gentle slopes of fossil valleys that cut through the region. Date: February 1996.*

On a positive note, during a wet season visit to sites in the region in 1996, we noticed considerable regeneration of *Pterocarpus lucens (mbey mbey)*. With adequate rainfall and light grazing conditions, this species and others should be able to make a comeback. This is another example of the resilience of the vegetation. The rainy season of 1999 was particularly wet. A follow-up study on regeneration after a wet year would be very useful.

In the same zone, seasonal ponds occupy depressions on the plateaux and in the valleys. The deeper soils are able to support a relatively dense vegetation cover. Owing to its significant role as a source of browse fodder for livestock, the vegetation around these depressions is protected by the pastoralists in order to slow evaporation of the seasonal surface water, and to prevent their being filled in by mobile topsoil. The more favorable conditions of these depressions make them refuges for a number of vegetation species that are vulnerable to drought at this latitude.

The Senegal River Valley

It is not possible to make generalizations about the impact of drought on the vegetation of the Senegal River Valley because of the complexity of the geomorphology, land use and land cover, and vegetation types. It is further complicated by both reduced rainfall and the disruption of the natural hydrological cycle following the completion of the Manantali and Diama dams in Mali and Senegal. Furthermore, the distribution of our ground monitoring sites is limited (total of 9 revisited sites) relative to the other regions. We will therefore restrict our discussion to the condition of the riverine forests of *Acacia nilotica (gonake)*, which occur primarily on the natural levees, in some of the wide clayey depressions, and along old river channels.

Before the drought of the 1970's and 1980's, major portions of the alluvial plain were flooded annually. The *Acacia nilotica (gonake)* forests depend on annual flooding for survival, as shown in the aerial view in Figure 13. Since 1968, the annual floods have been minimal or absent. Low rainfall, the introduction of irrigation canals and drainage ways for agriculture, and the disruption of the annual floods from the Manatali Dam in Mali have all contributed to reducing the annual floods, jeopardizing the survival of the riverine forests. Since 1987, the annual flood has been reduced substantially, because the flow from the Bafing River has been impounded by the Manantali Dam. Although water has been released from the Manantali Dam to provide a managed flood every year since 1987, the volume of water released has been far less than would have been available under natural conditions. A noteworthy exception to this was in 1999, when higher than average rains occurred in the Senegal River basin. Flooding of the Senegal River valley was extensive, as seen in the Landsat image acquired on September 26, 1999 (Figure 14).

Figure 13. *This aerial view from September 1994 shows a portion of the once-extensive Acacia nilotica (gonake) forests that depend on annual flooding for survival. Since 1968, the annual floods have been minimal, with the exception of a few years like 1999.*

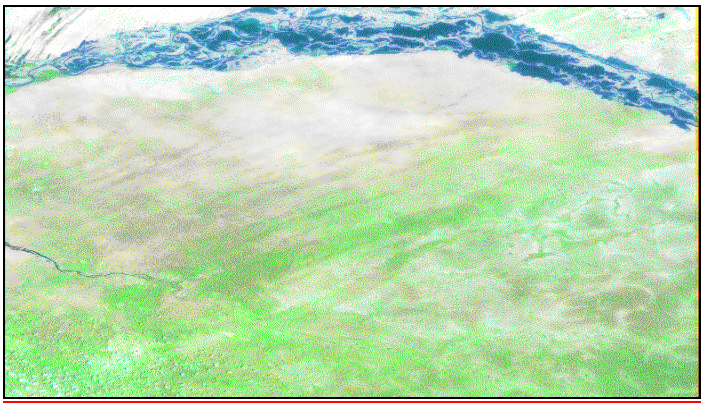


Figure 14. *1999 was an exceptional year owing to high rainfall. Flooding of the Senegal River valley was extensive as seen in the Landsat image acquired on September 26, 1999 over the middle Senegal River valley.*

A decade before the river waters were harnessed by the Manantali, in the late 1970's, severe mortality had already taken its toll in many of the riverine stands. In 1983, we noted and photographed dead but still standing *A. nilotica* forests between Podor and Matam, testimony of the once verdant forests that occupied much of the alluvial valley (see Figure 15). By the mid-1990's, much of the dead wood from these former trees had been harvested as fuel wood, leaving behind a dusty plain. We examine the demise of the riverine forests in more detail in another report on the woodland resources.

Figure 15. *A photograph taken in 1983 of ground site 331 showing the dead but still standing A. nilotica forests between Podor and Matam, testimony of the once verdant forests that occupied much of the alluvial valley.*

The West-Central Agricultural Region

Throughout the West-Central Agricultural Region, or 'Peanut Basin', there is considerable evidence of the negative effects of drought on the woody resources. It is, however, not as apparent as in the pastoral regions because there are few vestiges, if any, of the original vegetation cover. Beginning in the mid 1800's, the French colonialists introduced peanuts, encouraging Wolof and Serer farmers to methodically clear major areas of 'dior' soil areas for cultivation, resulting in a completely agricultural landscape. By 1900, pseudo-climax woodland characterized the area dominated by such Sudanian Zone tree species as *Combretum glutinosum (rat), Anogeissus leiocarpus (ngejan), Cordyla pinnata (dimb), Khaya senegalensis (xaay), Bombax costatum (garabu lawbe), Pterocarpus erinaceus (win),* and *Sterculia setigera (mbep)* (Giffard, 1974). While many of these species are uncommon or rare in the region today, a number of Sahelian and Sudanian zone species do survive in the fields of village *terroirs*. At least 69 woody species can still be found in the central Peanut Basin (Seyler, 1993). In addition to the relict species, several introduced species have become widespread, of which *Acacia albida (kad)* stands out, owing to its dominance in much of the central Peanut Basin. Our direct evidence of drought impact comes, as elsewhere, through reading the condition of field trees and shrubs, and from our time-series photographs. Semi-structured interviews and several important contributions from other investigators give us additional insights into the problem (see Figure 16).

Figure 16. *A photograph of a group interview with members of the Jambour Fall village. We used semi-structured interviews such as this one to gather indigenous knowledge about natural resource changes*

Informants at the village of Koumbel (in the Sadio *Communauté Rurale*) stated that our fruit trees have been decimated by the drought, leaving mainly the thorny trees like *sump (Balanites aegyptiaca), nger (Guiera senegalensis),* and *kad (A. albida)*

The discussion about drought impact we had with the village chief and other informants at Tchilla 2 (Rural Community of Niakhène) are representative of many similar discussions we had in the region: *Climate changes began about 30 years ago, about the same time our fields were extended because of the population increase in the village. These changes had bad consequences on the vegetation. In the past, the bush was covered by dense vegetation between the cultivated fields. There was a diversity of vegetation species, including: dakkar (Tamarindus indica), sideem (Ziziphus mauritiana), seng (Acacia raddiana), win (Pterocarpus erinaceus), ir (Prosopis africana), lëng (Vitex doniana), xasaaw (Hexalobus monopetalus), neo (Neocarya macrophyla), dugor (Annona senegalensis), guy (Adansonia digitata), hat (Andropogon gayanus). To this we add mango trees; regarding arboriculture, these species offered innumerable products including food: fruit of the guy, the neo, and the dakkar. Now, only the kad (A. albida) and the seng (A. raddiana) survive because they resist the drought. Our food has become poorer.*

Several important studies shed additional light on the problem of drought in this region. Seyler (1993) conducted an extensive study of the *Acacia albida (kad)* agro forestry system in the Peanut Basin. One of the parameters he examined was the perception among local farmers of the reasons for decrease in cover of *A. albida* and other tree species. The leading reason cited by 129 informants was drought (39% of informers relative to *A. albida*, 33% relative to other species). He goes on to point out that the survival of *A. albida* was highly correlated with water table depth, i.e. tree survival was poor when the water table dropped as an indirect result of drought. We noticed, as did Seyler, that dead *A. albida* trees tend to occur on higher ground, while trees of the lower elevations were usually not affected. Figure 17 shows this situation in a *terroir* near Fissel..

Figure 17. A photograph showing the mortality of Acacia albida (kad) trees that occasionally occurs on higher ground in the gently undulating plains of the central Peanut Basin. This example comes from a terroir near Fissel

Many informants related that the drought mainly took its toll on trees during the 1970 to 1984 period, and that since then, trees have for the most part survived, except where they have succumbed to human pressures. Our time-series photographs at numerous sites confirm the relative stability of the tree cover at many sites between the early 1980's and mid to late 1990's.

For many degraded agricultural *terroirs* (such as the one shown in Figure 18a and 18b in the eastern Peanut Basin east of Mbos), drought took its toll on trees between 1970 and 1984, but the drought impact since then has been minimal. The photo pair shows degraded but relatively stable conditions at site 69 over a 16-year period between 1983 and 1999. Other than *Guiera senegalensis (nger),* the shrub in the foreground, there has been very little regeneration among woody species.

Lericollais (1987) monitored tree densities and species in the fields surrounding the Sereer village of Sob in 1965 and 1985. He found an overall decrease of 23%. However, he attributed the decline to human population pressures, animal traction, shortage of land, and the clearing of *A. albida*, and not to the direct affects of drought. He did note a drop in the water table from 6m to 14m, negatively affecting tree survival.

A very noteworthy, recent dissertation by Patrick Gonzalez (1997) investigates tree densities, biodiversity, and human carrying capacity in northwestern Senegal over the past half century. The study area covers most of the northern extent of this agricultural region. He compared aerial photographs from 1954 and 1989, conducted extensive field surveys in 1993, interviewed numerous people in 135 villages, and performed a battery of statistical analyses to produce one of the most definitive studies on natural resource change in the Sahel. He shows quantitatively that tree density and biodiversity have declined in the study area since the 1950's, resulting in a retraction of the Guinean and the Sudanian vegetation zones to the South, tracking a concomitant shift of the Sahel from the North. Furthermore, the significance of latitude and longitude, combined with several other research results, provides evidence of the predominance of climatic factors over anthropogenic factors in the death of trees. He found that the average tree density in 1954 was 10.1 trees per hectare, and 7.8 trees per hectare in 1989. He also found that species richness declined by about 33% between 1945 and 1993, reducing people's wood, habitation, medicine, and nutrition options.

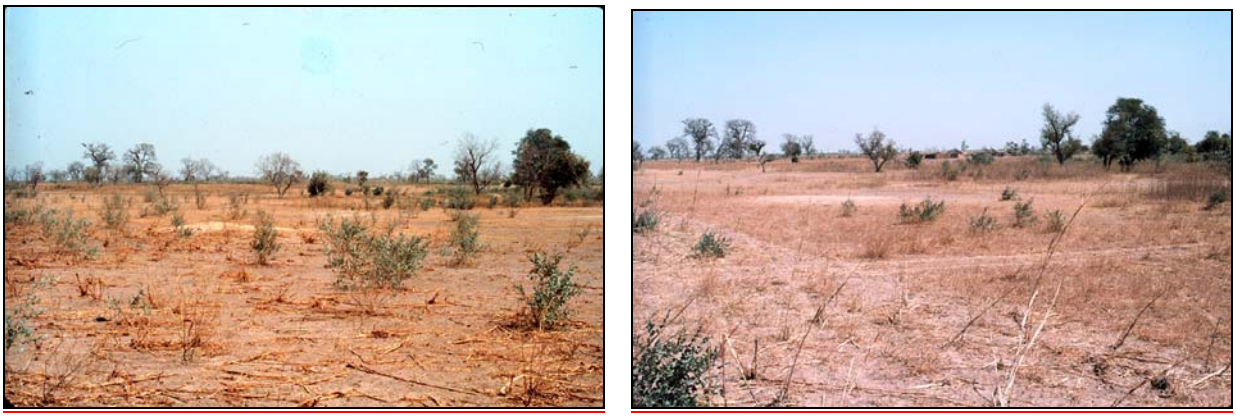


Figure 18a and 18b. Despite drought and sub-average rainfall since the early 1980's, relatively stable conditions prevail at many agricultural sites in the eastern Peanut Basin. This photo pair shows degraded but relatively stable conditions at site 69 over a 16-year period between 1983 and 1999. Other than Guiera senegalensis (nger), the shrub in the foreground, there has been very little regeneration among woody species. Dates: left – March 1983; right – February 1999.

The Estuaries Region

The low tidal flats of the Estuaries Region, flooded twice daily by the ocean tide, have historically been occupied by mangroves of the genus *Rhizophora* and *Avicennia.* Ancient mud flats called '*tannes'* occur on slightly higher ground between the channels.

Figure 19 shows an aerial overview of dense stands of mangrove in the islands of the Saloum Delta National Park.

Figure 19. *This aerial view from October 1994 shows overview of dense stands of mangrove in the islands of the Saloum Delta National Park.*

The Saloum and Casamance Rivers, which constitute the main arteries of the two estuary regions, receive only minimal water flow from upstream, and only in the rainy season (3 to 4 m3/sec at Kolda) (MEPN, 1998). Consequently, the waters remain brackish owing to the intrusion of saline marine waters.

Since the 1970's and continuing in the 1980's, some of the mangrove forest has perished, particularly in the northern third of the Saloum estuary complex, as well as along parts of the Casamance River. By some estimates, over half of the surface area of mangrove forest has

been reduced in recent decades, mainly from the effects of drought (MEPN, 1998). Mangrove stands occurred most of the way up the Saloum River to the east of Kaolack, whereas today, there is virtually no mangrove left.

The disappearance of the mangrove is related to a modification of physical-chemical conditions of the river water and ground water (increased salinity and acidity) owing to the decline in rainfall in recent decades. Marius (1985) found considerable increases in salinity levels in the ground water and in the soils in a channel near Bignona from 1974 to 1978. Salinity reached 3 to 5 times that of seawater. The hyper-saline conditions of the ground water and soils have lead to the stark disappearance of mangroves in many areas.

A Landsat image taken in late 1999 shows the magnitude of the decline of mangrove communities in the northern half of the Saloum estuary region (Figure 20). Comparative views using rephotography from an airplane over the flats of the Saloum River just east of Foundiougne, provide a closer view of the near total decline of mangrove in this area (Figure 21a and 21b.

Figure 20. *A portion of a Landsat 7 image taken December 6, 1999. It shows healthy mangrove cover in the south, but severe mortality and die-off in areas north of the line drawn over the image.*

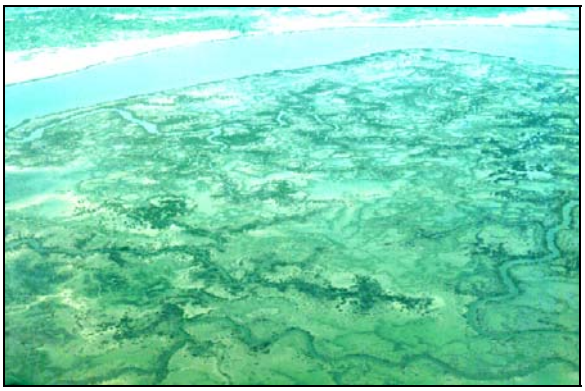


Figure 21a and 21b. *This pair of aerial views compare mangrove conditions in a tidal flat just east of Foundiougne, along the Saloum River. The photo at left was taken in September, 1984, while the photo at right was taken in October 1996. Note the complete die-off of the mangrove vegetation.*

On a positive note, the villagers of Faoye (south of Fatick) living adjacent to the degraded mangrove communities have noticed regeneration of mangrove plants in the mud flats since 1994. They attribute this to somewhat higher rainfall. Regeneration is also occurring in many areas along the lower Casamance River in the vicinity of Ziguinchor.

Other Agro-Ecological Regions

Drought of the 1970's and 1980's has had varying degrees of impact on the vegetation resources in the other Agro- Ecological Regions. Drought induced mortality among trees was quite significant in both the agricultural and natural areas of the Agricultural Expansion Region. The phenomenon was also prevalent in the northern half of the Eastern Transition Region. Site 435 (Figure 22a and 22b) is typical of the moderate level of drought-induced mortality in a Sudanian savanna woodland of the Eastern Transition Region. Despite significant mortality among many tree species, the tree density remained about the same because of natural regeneration.

Figure 22a and 22b. This pair of photos at ground site 435, in the Eastern Transition Region 105 km east of Tambacounda, is typical of the moderate level of drought-induced mortality in a Sudanian savanna. Despite significant mortality among many tree species, the tree density remained about the same because of natural regeneration. Dates: left – March 1984; right – February 1996.

In general, the drought impact in the south, i.e. in the Shield Region and in the Casamance Region – both subregions of the Sudanian and Guinean Climatic Regions, has been much less severe than in the north. In the south, it is the actions of humans, and to a lesser extent fire, that prevail, continuously modifying the land cover.

In order to evaluate the impact of drought in the Shield Region, a region with minimal influence from humans and livestock, we examined woody vegetation conditions in the Niokolo Koba National Park. The Park, covering some 913,000 hectares, contains some of the most pristine Sudanian zone flora and fauna remaining in Africa. It is among the last Sudanian areas with legislated protection on the continent. We revisited 15 permanent sites, representing a variety of habitats, including upland woodlands and savanna woodlands, shrub savannas, gallery forest, '*bowé'* or open herbaceous formations on laterite, and riparian vegetation along the Gambia River.

Sites in the upland woodlands and savanna woodlands were in excellent, stable condition, with little or no evidence of abnormal mortality levels. The 10-year photographic comparison of site 487 is typical of the stability seen in the Sudanian savanna woodlands of the Park (Figure 23a and 23b). An additional indicator was the stable level of biological diversity among woody species (27 species in a 4-hectare area at site 487).

Figure 23a and 23b. *The 10-year photographic comparison of site 487 is typical of the stability seen in the Sudanian savanna woodlands of the Park. Drought impact is moderate. Dates: left – April 1984; right – February 1994.*

In the savanna woodlands and woodlands, mortality from drought has hit several Sudanian Region species that appear particularly sensitive to moisture stress. They are: *Terminalia macroptera (wolo), Pterocarpus erinaceus (win), Pterocarpus lucens (mbey mbey), Cordyla pinnata (dimb), and Acacia macrostachya (sam).* This phenomenon was more apparent in the west where laterite outcrops are numerous and extensive.

The most notable drought impact was in some of the gallery forests, which support evergreen species from the southern Sudanian Region and from the Guinean Region. Several species, particularly the oil palm (*Elaeis guineensis*), showed signs of stress or mortality. Our hypothesis is that the ground water had dropped beyond the root zone during the dry years. We found evidence that the proportion of mesophytic species of Sudanian zone affinity was increasing, while the Guinean species proportion was declining.

Conclusion

The overall pattern suggests that drought impact on woody vegetation is significant (present) over the northern two-thirds of the country, with somewhat more severe levels in the Ferruginous Pastoral Region. The phenomenon is uniformly present in both agricultural lands and non-agricultural lands. Only the Casamance and Shield Regions exhibit little to moderate levels of impact. This pattern is consistent with the percent decline in rainfall isohyets since the late 1960's; the percent decline in isohyets is relatively large in the north (40% decline comparing the 1950-1969 period with the 1970-1989 period), less so in the south (15% decline in the Casamance).

The drought has had an impact on woody vegetation cover, thinning the density of cover, particularly in the northern ecoregions. We have also witnessed an emerging pattern of woody cover at the micro-landscape scale – particularly in areas of ancient sand dunes where a slightly undulating topography is present. Uplands become more open and degraded, while inter-dune depressions maintain a high degree of woody density, thus enhancing the tiger stripe pattern. This seems to be a natural coping mechanism during dry times, since the more hydrophytic environments of low lying areas provide an area of retreat for species unable to survive the dry upland conditions. When wetter periods return, many species can recolonize the uplands.

With the increase in rainfall in the late 1990s, we see evidence of resiliency and regeneration of woody cover. As long as human pressure (including livestock) can be limited to moderate levels, nature has shown its power of regeneration. We see much evidence of this in exclosures and other areas managed in a sustainable way. Future programs should further

investigate ways of working with nature to enhance natural regeneration, both in semi-natural landscapes, and by increasing on-farm tree cover.

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