Woody vegetation changes in the Sahel of Burkina Faso assessed by means of local knowledge, aerial photos, and botanical investigations

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Abstract

Three different methods (local knowledge, aerial photos, and botanical investigations) were used to document changes in woody vegetation cover in the Sahelian part of Burkina Faso. Local people had observed a general decline of woody plants that was most pronounced in valleys, and aerial photos supported this view. Local people also reported a lack of rejuvenation of many woody species, and this was confirmed by botanical data and size class distribution analysis. Together the three methods documented a diminution in density and diversity of the woody vegetation cover which, estimated from size class distributions, will continue in the nearest future. Some of the trees and shrubs that are most appreciated by local people are also sharply declining, and local societies are therefore faced with reductions in some of their most essential natural resources.

Keywords

Aerial photos, Burkina Faso, degradation, local knowledge, Sahel, size class distributions, vegetation changes, woody vegetation.

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Sahelian woody vegetation has received little attention in management strategies (Maydell, 1995), although it is well documented that woody plants of the Sahel are both essential for sustaining the livelihood of local people (Maydell, 1990) and severely affected by degradation processes (GEMS, 1988; Claude et al., 1991). Also the newest theories for range management (e.g. Scoones, 1996) largely ignore problems concerning management of woody resources (Lykke, this volume). Our aim is therefore to make a case study for assessment of woody vegetation changes in a typical Sahelian area to gain management relevant information about the woody resource. This is done on the basis of three relatively easily available means: local knowledge, aerial photos, and botanical investigations. Both structural and floristic levels of vegetation change are assessed to describe all possible aspects of changes in the woody resource as well as the impact of such changes on the livelihood of local people.

In both social and biological sciences, a consensus has emerged about the value and credibility of local knowledge concerning environmental issues, which suggests an increased use of local information as a basis for management strategies (Sandford, 1983; Gadgil et al., 1993; Meffe & Carroll, 1994; Stiles, 1995). We follow this suggestion by focusing on local perceptions of modifications in vegetation structure and increase/decline in local populations of woody species. It has been found in earlier studies from Africa that local people hold detailed and reliable information about vegetation changes (Amanor, 1994; Kinlund, 1996; Lykke, 1998a).

Aerial photos have for years been an overlooked data source when it comes to remote sensing of vegetation change. The focus has been on digital data from satellite borne multi-spectral sensors, because the visible and near-infrared part of the data are well suited for vegetation classification and mapping, at least on a regional scale. For more detailed vegetation studies, however, aerial photos have potential as sources for remote sensing, because of a high spatial resolution (1-5 meters) and a long time-span from the most ancient photos to the most recent (about 50 years).

Botanical investigation is a means to estimate the abundance of woody species and thereby quantify the resources available to local people. The status of tree populations can be revealed by way of size class distribution analyses. For natural populations with good and continuous rejuvenation, size class distributions are generally exponentially decaying with many more trees in smaller size classes than in larger ones (Hall & Bawa, 1993). With certain reservations, a lack of juveniles can therefore be an indication of declining populations. In contrast to interviews and aerial photo interpretation, which describe former changes, size class distribution analysis can indicate trends in species composition change in the nearest future.

Study area

The study took place near Gorom Gorom in the Sahelian zone of Burkina Faso (Fig. 1). The landscape is characterised by flat plateaus interrupted by valleys ('basfonds'), longitudinal dune systems, and seasonal lakes. The word 'valley' is used in a broad sense to include floodplains and banks of seasonal streams. Following the tradition in the Sahel, lands are communal. Older dunes and parts of plateaus are cultivated, but valleys are rarely so due to periodic flooding. During the last 30 years many nomadic pastoralists have settled down in order to supplement their income by agriculture, and today most people in the area live as agro-pastoralists (Reenberg & Fog, 1995). Many families also supplement their income by migratory work.

The rainy season lasts about three months (June-September) with irregular and unpredictable precipitation, as is typical for the Sahel. From 1958 to 1996, the average precipitation in Gorom Gorom was 403 mm per year. From 1958 to 1969 the annual precipitation was above average, but from 1970 to 1996 only 7 out of 27 years were above average. Two major droughts occurred in this period, one during the early 1970s and one during the 1980s.

Methods

Eleven Fulani/Rimaibe villages were selected for interviews: Débérélink, Ménégou, Bidi, Bélèl, Tassamakat, Fourkoussou, Guidoy, Diagarèntou, Kolèl, Assinga, and Allakoum (Fig. 1). All villages were located close to a valley. In each village a group of elderly men and a group of elderly women were questioned through semi-structured interviews (in one village it was not possible to meet the women). The twenty-one groups were asked about observed structural vegetation changes and observed increasing or decreasing woody species. Free-listing techniques were used and only species mentioned by two groups or more were included in the results. People were also asked about uses of woody plants, this issue is only briefly mentioned here but further discussed in Lykke (1998b).

Aerial photos from 1955, 1974, 1981 and 1995 in the scale of 1:50.000 cover the study area. All were scanned in 600 dpi resolution, corresponding to a ground resolution of around 2 meters. Aerial photos have been geometrically corrected in two steps. The first step is an image correction, where all images are corrected with the 95 image as reference. Geometrical errors in an image to image correction are relatively small (less than 5 meters) as all images are affected by the same distortion. The accuracy of image correction is very important for a comparison of woody vegetation along a time series gradient. The image co-ordinate system is relative and unusable with absolute GPS

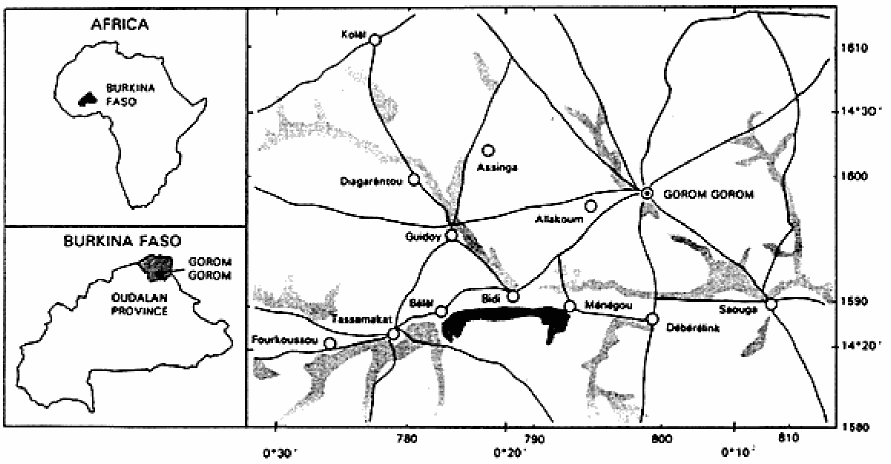

Figure 1: Location of study area in the vicinity of Gorom Gorom, Oudalan Province. The investigated valley system is indicated in light grey and a seasonal mare in dark grey.

coordinates. The second step is therefore a transfer of image coordinates to the UTM coordinate system. A satellite image map, geometrically corrected to UTM, serves as the reference system in a new ground control point correction (two SPOT satellite images from 1991 and 1996 are available). The RMS (root mean square) errors are 10-15 meters, but the absolute precision is not important in this step.

Quantifying woody vegetation in absolute terms from aerial photos is a difficult task, but two methods were investigated. The first method is based on application of normalised images, or parts of images, for a classification of trees versus the surroundings. Normalised images are aerial photos on which, under equal conditions, the same type of object appears within the same range of pixel values. This classification method uses the grey tone of each pixel to decide whether it covers a tree or not. Pixel-based classification gives several calibration difficulties, not only inter-annually, but also within the same row of photos (taken within the same minute), and even within the same aerial photo as pixel values for the same type of surface/object varies substantially across the image. It is always questionable to "correct" these differences, because one could blur or erase information in the original photo. Also the normalisation is difficult when there are no reliable reference objects in the image. Finally, the thresholds for classification are determined by the operator and therefore influenced by visual interpretation. The second method is based on simple counts of trees within well-defined grids. This method was even more dominated by the operator's visual interpretation, and had to be conducted by the same person all the way through. The main problem with this method is that trees may be miscalculated because of shadow effects, and trees in groups are difficult to distinguish. For trees in groups one tree was counted for each six pixels which corresponds to 12 m^2. Despite these shortcomings, the two methods were considered useful for revealing relative changes over time.

Botanical investigations were based on stratified random sampling of 38 sites, each with 10 sample units. Twenty sites were placed randomly in relatively dense areas along the valley system, and eighteen were placed randomly on the plateau. Geographical positions were measured with GPS. Each sample unit consisted of one 20 x 20 m plot sampled for woody plants < 5 cm dbh (diameter at breast height, 1.3 m above ground) and plotless sampling of woody plants ≥ 5 cm dbh and ≥ 10 cm dbh. Plotless sampling was carried out by the point quarter method (Cottam & Curtis, 1956): four random quadrants are defined around a point followed by measurements of distance from the point to the nearest tree or shrub ≥ 5 cm and ≥ 10 cm dbh in each quadrant. Nine of the plots on plateaus were so sparsely covered by woody vegetation that plotless sampling was omitted (less than 4 individuals ≥ 5 cm dbh per ha).

Site densities from plotless sampling were calculated according to Pollard (1971), and species densities according to Causton (1988). Spearman correlations were used to test for a possible connection between declining species and species important for construction, fruits, medicine, browse, and most appreciated in general. This was done on the basis of the number of groups of people who mentioned them. ANOVA analyses were used to test for significant differences in density, species number, and basal area between plateau and valley sites. Finally, size class distributions were analysed for valleys and plateaus including all species, as well as separately for each of the most common species (species with at least six sampled individuals).

Results

Local knowledge

The 21 groups of people from 11 villages gave almost identical answers to questions concerning structural vegetation changes. Villagers described a decline of woody plants and a lack of tree and shrub sprouts. These phenomena were most severe in valleys where many characteristic species had become rare or extinct. People perceived practically all woody species as declining, except *Acacia tortilis* that was frequently said to increase in abundance. People were asked to name particularly declining species: 25 were mentioned (App. 1).

Many useful species were among the most declining. A significant correlation was found between species mentioned as declining and as important for construction (rho = 0.4, p = 0.009) and as most appreciated in general (rho = 0.4, p = 0.011). On average, male informants mentioned significantly more species as declining (9) than female informants (4) (F = 13.5, p = 0.002). This difference was mainly caused by the most used construction species (e. g. *Acacia nilotica*, *Acacia seyal*, *Balanites aegyptiaca*, and *Pterocarpus lucens*) that were frequently mentioned as declining by men who are responsible for the collection of construction material.

The villagers saw the decline of woody vegetation as a severe degradation of the local environment, especially in the case of valleys where the woody vegetation is particularly appreciated for medicine, edible fruits, construction wood, firewood, and fodder. Local people considered declining precipitation to be the main cause for the degradation, since the decline in woody vegetation accelerated at the time when lowered precipitation began to occur, which they consider to be around 1974. Increased human and livestock populations were noticed by the informants, but these were (with some exceptions) not regarded as main causes for the degradation. Although local people made detailed descriptions about vegetation changes that were perceived as a degradation of the local environment, they did not have concrete proposals for solving problems related to the depletion of the woody vegetation.

Aerial photos

The pixel-based classification method showed that a reduction of woody vegetation had taken place on plateaus and in valleys in the period from 1974 to 1995. From 1974 to 1981 the trend is a relative reduction in tree-cover, and the same in the period between 1981 and 1995, but on a smaller scale (Tab. 1).

The different development among the plots, which is very difficult to interpret, may be a result of cattle pressure, human activity or changes in valley systems etc. The reduction within the study area shows some variation. The valley systems seem to be particularly affected close to the villages or other habitations as well as in valley parts penetrated by cattle tracks (Fig. 2).

The general picture from the method based on counts of trees was also a substantial reduction of woody vegetation in valleys (Fig. 3), see next page. The largest reduction occurred between 1974 and 1981, and a somewhat lesser reduction in the period between 1981 and 1995. On the plateau, the picture seems to be the same, a reduction of trees with the largest reduction in the period between 1974 and 1981. It has not been possible to include aerial photos from 1955 in the analysis. Due to technical problems in the developing process, these photos do not have a quality that allows a proper comparison with photos from the more recent years.

Botanical investigations

Plotless sampling corresponded to a sample area of 52 ha for woody plants ≥ 5 cm dbh and 73 ha for woody plants ≥ 10 cm dbh. Sampling of woody plants < 5 cm dbh covered 15.2 ha. A total of 35 species of woody plants were sampled and further 17 species were observed, besides six species which were said by local people to have

Plot No.	*1974*	*1981*	*1995*
12	79	50	46
11	62	41	33
10	43	49	36
9	24	20	7
8	45	26	17
7	22	25	21
5	36	14	14
4	9	5	4
3	19	20	14
2	-	-	18

Table 1: *Changes in percentage tree-cover within 10 different plots from 1974 to 1995 based on classification. The size of the plots vary from 3 to 7 ha. (The empty cells in the table are cases, where the aerial photo is unusable or non-existing).*

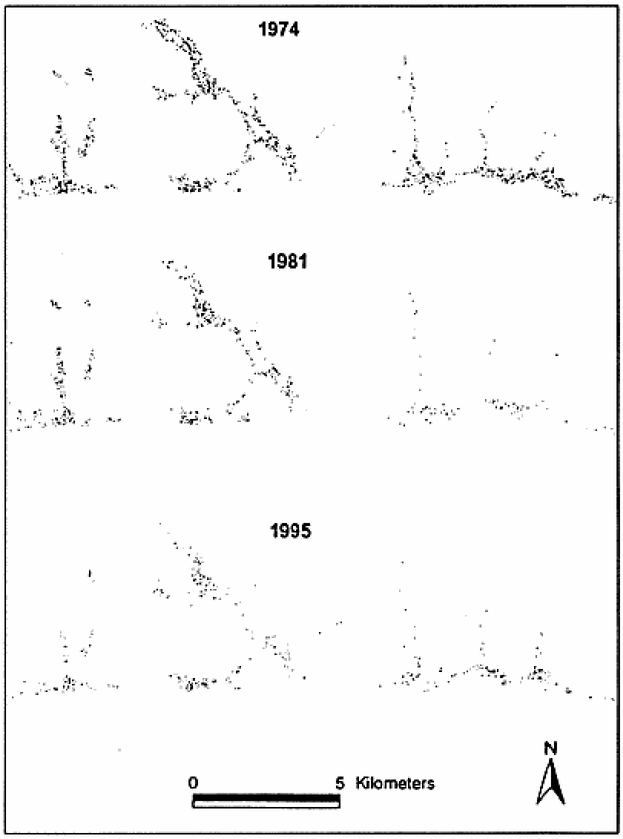

Figure 2: *Development of woody vegetation cover in valleys north of the longitudinal dune between the villages Fourkoussou and Ménégou. The results from 1974, 1981, and 1995 are extracted from normalised mosaics of classified aerial photos.*

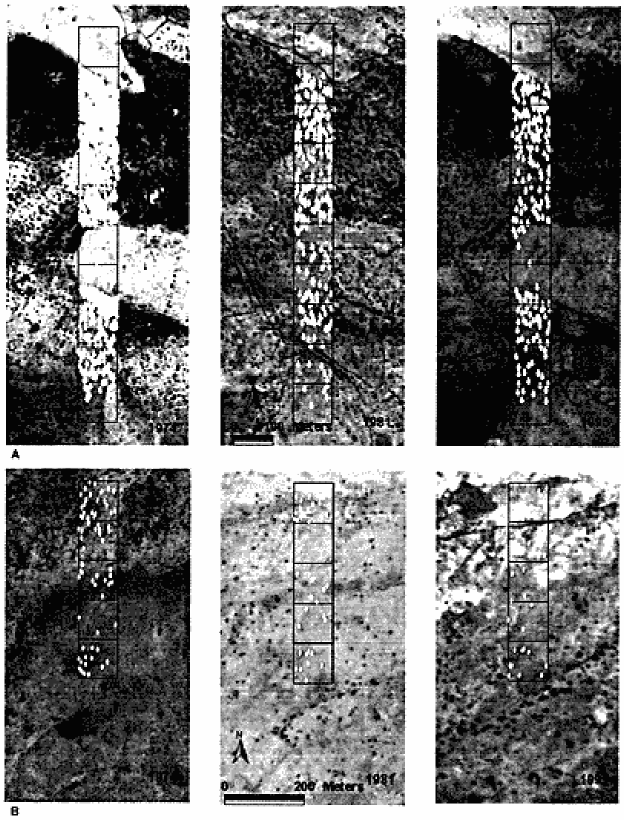

Figure 3 a&b: An example of a detailed study of the development of the woody vegetation between 1974 and 1995 in A) valley and B) plateau. Individual trees within the transect have been marked by visual interpretation. Each signature indicates one tree.

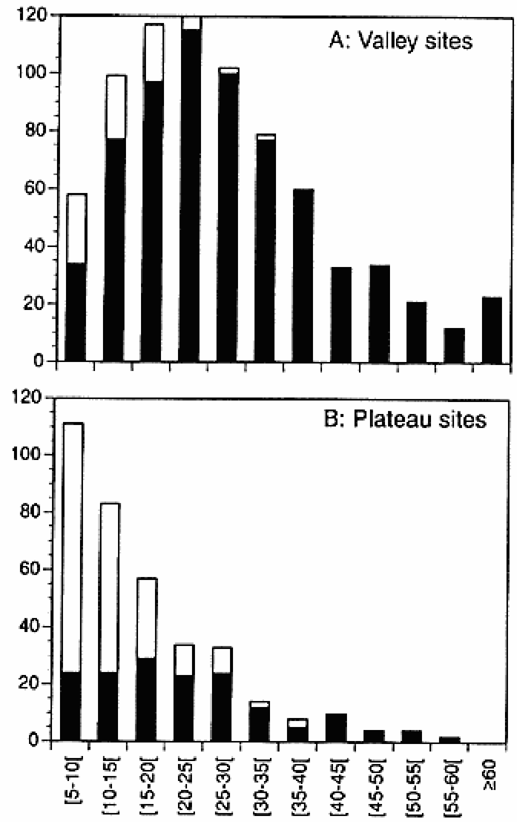

Figure 4: Size class distributions of 20 valley sites and 18 plateau sites. Individuals of Acacia tortilis are indicated by white, the remainder species are indicated by black.

been in the area (App. 1). Valleys were characterised by significantly higher density, species number, and basal area than plateaus (App. 2). Also the species composition was different in the two habitats: *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Feretia apodanthera*, and *Mitragyna inermis* dominated valleys, whereas *Acacia tortilis* and *Maerua crassifolia* characterised plateaus.

Size class distributions from valley sites revealed a lack of individuals in small size classes, despite the fact that sampling covered some of the area's best protected valley sites (Fig. 4A). On plateaus an exponentially decaying slope was found, but one species, *Acacia tortilis*, dominated the rejuvenation (Fig. 4B). For the remaining species the rejuvenation was less than would be expected for populations with good and continuous rejuvenation.

Size class distributions were also investigated for individual species (Fig. 5). Most species had fewer young individuals than would be expected for species with a good

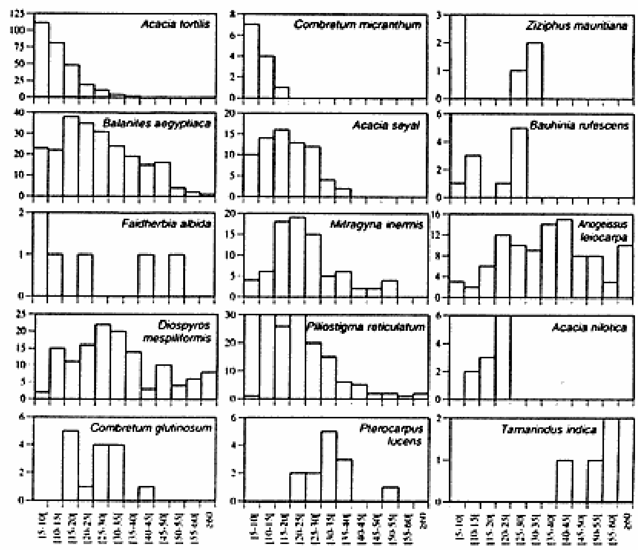

Figure 5: Size class distributions of the 15 most common species.

population structure: individuals in the smaller size classes were few (e.g. *Anogeissus leiocarpa, Diospyros mespiliformis, Mitragyna inermis*, and *Piliostigma reticulatum*) or absent (e. g. *Acacia nilotica , Tamarindus indica, Pterocarpus lucens*, and *Combretum glutinosum*). Two species seemed to have a good and constant rejuvenation (*Acacia tortilis* and *Combretum micranthum*).

Size class distribution analysis cannot be carried out for small shrubs, but field research revealed that most shrubs (e.g. *Combretum aculeatum, Feretia apodanthera*, and *Maerua crassifolia*) were heavily browsed (Fig. 6A). The woody ground vegetation is characterised by a large number of individuals that are kept low and gnarled by browsing. Seedlings and saplings from less browse resistant species (e.g. *Tamarindus indica*) were observed sprouting during rains, but rarely remained into the dry season. The structure of the woody vegetation is thus often characterised by a number of relatively large trees of varying density, a ground cover of gnarled shrubs, and an obvious lack of well-developed shrubs and young trees (Fig. 6B).

Discussion

Potentials and limitations of the three methods

Interviews with local people, aerial photo interpretation, and botanical investigations focus on different aspects of vegetation dynamics, but also have different limitations. By combining the three methods it seems possible to derive a detailed and reliable picture of the vegetation changes that have occurred during the last decades, because there is a large accordance between information derived from different methods. The main discrepancy is that local people often accuse drought for the vegetation degradation, whereas botanical investigations reveal that browsing is also a cause for the degradation of the woody vegetation cover.

Information from interviews outlined local perceptions of the vegetation modifications that have occurred during the passing decades. A comprehensive number of informants asked exactly the same questions revealed a large consistency in the answers. And these were also consistent with other studies from the Sahel (Cross & Barker, 1991; Lindskog & Tengberg, 1994). When informants describe vegetation dynamics for individual species, they focus on useful and common ones, whereas rare and less used species often remain unnoticed. Therefore, the species most frequently mentioned as declining are in reality not necessarily the most declining ones, but rather a mixture of both declining and useful species. Informants therefore highlight the role vegetation changes play in the livelihood of local people, whereas a direct species ranking according to declining tendency is difficult to obtain through free-listing techniques.

Aerial photos, unlike interviews, were unaffected by public opinion. Despite the earlier mentioned shortcomings, digital aerial photos represent a good tool to look at temporal changes in the canopy layer if used carefully and with sufficient ground validation (Madsen et al., 1999). The evaluation and comparison of the two methods applied in the analysis of aerial photos indicate that the classification method, based on a simple threshold of pixel values, is

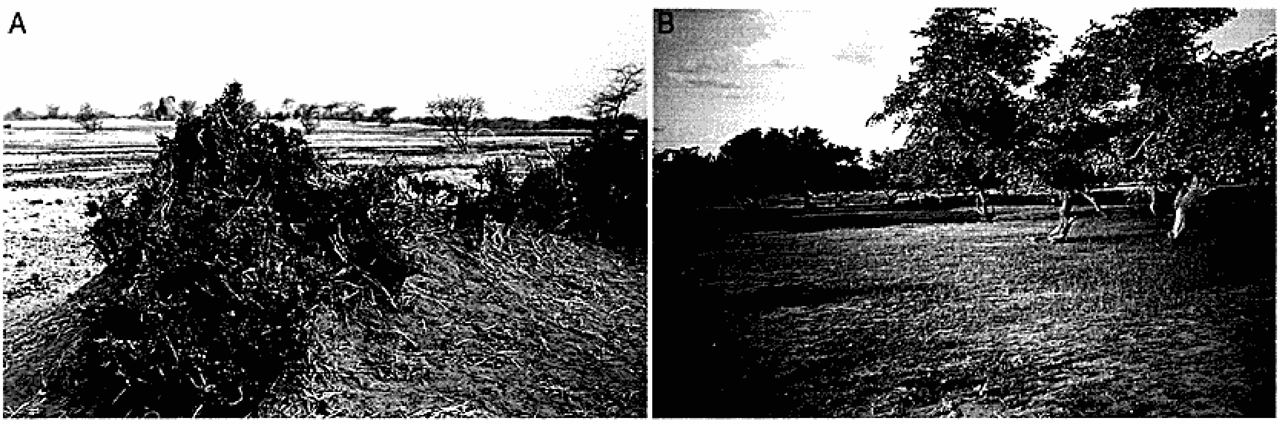

Figure 6: Typical vegetation types of the study area. A) plateau with a gnarled Maerua crassifolia in the foreground. B) valley dominated by Piliostigma reticulatum, well-developed shrubs and small trees are rare.

valuable in order to get an overview of the spatial variation of woody density and vegetation changes during the last three decades within village territories or larger areas. The application of aerial photos for studying woody vegetation changes gives, in combination with extensive field work, the possibility to extrapolate findings in time and space. As aerial photo interpretation only allows recognition of larger trees, the method only provides information about the canopy layer, therefore botanical fieldwork is particularly important to supplement data about regeneration and dynamic aspects of the woody vegetation cover.

Botanical ground analyses lead to more accurate density measurements than aerial photos and more detailed descriptions of species composition and regeneration capacity than interviews, but are also more time consuming. Data about the floristic composition of the woody vegetation is an important supplement to aerial photos to judge the quality of the vegetation. A restriction of vegetation data is that they are generally fixed in time as long-term data rarely are available. Size class distributions, however, made it possible to indicate which species were formerly abundant and which ones will be so in the nearest future. In dry savannas where woody species grow slowly, it is possible to predict vegetation changes longer into the future than in humid areas with more fast growing species. The interpretation of size distributions in undisturbed vegetation is not simple, since both species performance and demographic parameters, such as growth and mortality, affect size class distributions (Condit et al., 1998). In highly disturbed areas, however, disturbances seem to have a greater impact on size classes than other demographic parameters and size classes have therefore been found useful to identify declining species (Lykke,1998a). In natural populations certain species regenerate with time intervals (cohort regeneration) and therefore at points in time are without, or with few, young individuals, but in undisturbed environments it is unlikely that all except a few species synchronously appear without or with extremely few young individuals, as was found in the present study.

Vegetation changes

The study documented changes in the direction of a reduced and impoverished woody vegetation cover, which more specifically can be summarised under the following headings (I, A and B refer to the data on which the statement is based: interviews, aerial photos, and botanical investigations, respectively):

- a general decline of canopy trees which was most pronounced in valley systems (I, A),
- a lack of smaller trees to replace existing populations (I, B),
- a rarefaction or disappearance of less stress tolerant species (I, B),
- a suppression of certain shrub species by repeated browsing (B),
- a shrub encroachment of *Acacia tortilis* (I, B).

The general decline of trees observed in this study corresponded to results from earlier investigations of aerial photos from the Oudalan province (IEMVT, 1977; Lindqvist & Tengberg, 1993), except that Lindqvist & Tengberg (1993) found a recovery of valley vegetation during the last decade, which contrasts results from the present study. An increasing scarcity of the vegetation cover was also reported on the basis of earlier vegetation investigations from the region (Penning de Vries & Djitèye, 1982; Grouzis, 1988; Claude et al., 1991; Ganaba & Guinko, 1996). This coincides with the general tendency in the Sahel (Le Houérou, 1996).

Not all species are affected in the same way and to the same extent by degradation. Many shrubs have a good capacity to resprout after being damaged, and therefore exist in large numbers in a low and gnarled condition suppressed by repeated browsing. Many trees have a poorer capacity to resprout, and therefore have few small individuals, although populations of larger trees, that are out of reach of livestock, exist. Some of the less resistant and most favoured species had become extinct or rare, including both shrubs and trees: *Grewia bicolor*, which is favoured by livestock, was rare and frequently cited as declining by local people, this species was also mentioned among the most declining species from other areas (Kinlund, 1996; Ganaba & Guinko, 1998). *Grewia bicolor*, however, was found to resprout when protected from browsing (Claude et al., 1991). Other species, that in the study area were rare (e.g. *Boscia angustifolia*, *Commiphora africana*, *Grewia tenax*, and *Maerua crassifolia*), heavily browsed (e.g. *Combretum aculeatum*, *Guiera senegalensis*), or in lack of rejuvenation (e.g. *Pterocarpus lucens*) were similarly found to restore themselves naturally after a few years of protection from browsing (Claude et al., 1991). Some of the species that were extinct or lacked rejuvenation in the present study area had during the last 20 years become extinct in a neighbouring area (e.g.

Acacia polyacantha, Crateva adansonii, and *Diospyros mespiliformis*), others were considered threatened (e.g. *Acacia nilotica, Acacia senegal, Grewia bicolor*, and *Pterocarpus lucens*), and finally others had declined (e.g. *Acacia ataxacantha, Adansonia digitata, Anogeissus leiocarpa, Dalbergia melanoxylon, Feretia apodanthera, Grewia bicolor, Grewia tenax*, and *Grewia villosa*) (Ganaba & Guinko, 1998). *Adansonia digitata, Khaya senegalensis*, and *Pterocarpus lucens* were considered threatened in the whole Sahelian and sub-Sahelian zone (Guinko, 1984; Cisse & Wilson, 1985). There is a large consistency in results about floristic changes from different studies, indicating that a group of less stress tolerant species are severely affected by degradation.

For the species with fewest individuals in the small size classes, e.g. *Acacia nilotica, Combretum glutinosum*, and *Pterocarpus lucens*, it will take many years before new populations can be established. In contrast, a single species, *Acacia tortilis*, has become extremely dominant in the study area and frequently forms dense populations of low shrubs. This phenomena, often referred to as bush encroachment, has been described from heavily grazed areas in other parts of Africa (Kennenni & Maarel, 1990; Ganaba, 1994).

Consequences for local societies

Local people in the Sahel depend on woody plants for food, medicine, firewood, and construction materials. Edible fruits and leaves are particularly important in the dry season as supplements to an otherwise poor diet, and people also increase their income by selling products from trees and shrubs on markets. Degradation of the woody vegetation has therefore direct impact on the livelihood of local people. Many of the food species have become increasingly difficult to find (e.g. *Adansonia digitata, Grewia bicolor, Grewia villosa, Grewia tenax*, and *Ziziphus mauritiana*) or have become extinct (e.g. *Celtis toka, Vitex doniana*, and *Ximenia americana*). The most valuable construction species (*Acacia nilotica, Anogeissus leiocarpa, Mitragyna inermis*, and *Pterocarpus lucens*) had few individuals in the size classes used for construction (from about 5 to 20 cm dbh) (Fig. 5). *Dalbergia melanoxylon*, which produces the wood that attains the highest price in the Sahel (Maydell, 1990), had become extremely rare.

Woody plants are also important for ensuring an uninterrupted fodder provision for livestock year round. It is the main source of protein, vitamins, and minerals during the dry season when grass and herb production ceases (Le Houérou, 1980; 1989). Nevertheless, many of the important browse species were rare (e.g. *Acacia nilotica* and *Dalbergia melanoxylon*) or gnarled by browsing (e.g. *Bauhinia rufescens, Combretum aculeatum*, and *Guiera senegalensis*). A degradation of the browse resources has great implications for agro-pastoral societies.

Finally, trees and shrubs have an important role in sustaining and ameliorating the soil and grass components of savanna systems. In dry savannas there is generally a higher productivity under canopies than in the surroundings caused by increased shade and soil amelioration (Stuart-Hill & Tainton, 1989; Dunham, 1991; Belsky & Canham, 1994). Also the regeneration of trees is stimulated under canopies (Pearce, 1988; Akpo & Grouzis, 1996). The observed decline in the canopy layer therefore makes it increasingly difficult for new plants to establish themselves and grow.

Conclusion

This case study documented that woody vegetation has become impoverished and dispersed during the last decades and that many species are severely affected by degradation. Shrubs are generally low and gnarled because of repeated browsing, trees often lack a good and continuous rejuvenation, and many species have become rare or locally extinct. Valley systems were particularly affected by degradation. The observed vegetation modifications, that had lead to a decline in of some free and most desirable resources, were perceived by local people as a severe degradation of their environment.

Latin species names *	Density per ha				Lifeform	Mentioned as declining (no. of groups)	Estimate of species status (based on botanical inventories, personal observations, and local information) **
	<5		≥5				
	vall.	plat	vall.	plat			
Acacia ataxacantha	<0.5	—	0.03	—	shrub	—	rare
Acacia macrostachya	—	—	—	—	shrub	—	rare
Acacia nilotica	6	2	0.48	0.04	tree	5	relatively common, poor rejuvenation
Acacia polyacantha	—	—	—	—	tree	3	extinct
Acacia senegal	—	—	0.07	—	tree	3	rare
Acacia seyal	12	6	3.67	1.58	tree	5	common, relatively good rejuvenation
Acacia sieberiana	1	1	—	—	tree	—	rare
Acacia tortilis	82	137	5.75	12.1	tree	—	very common, good rejuvenation
Adansonia digitata	—	—	—	0.04	tree	16	rare
Andira inermis	<0.5	—	0.24	—	tree	2	rare
Anogeissus leiocarpa	2	—	6.16	0.33	tree	4	common, poor rejuvenation
Azadirachta indica	—	—	—	—	tree	—	rare
Balanites aegyptiaca	51	25	8.74	4.29	tree	4	common, relatively good rejuvenation
Bauhinia rufescens	2	1	0.28	0.15	shrub	—	relatively common, heavily browsed
Borassus aethiopum	—	—	—	—	tree	—	rare
Boscia angustifolia	—	—	—	—	shrub	—	rare
Boscia salicifolia	—	—	—	—	shrub	—	rare
Boscia senegalensis	—	—	—	—	shrub	3	rare
Cadaba farinosa	—	<0.5	—	—	shrub	—	rare
Calotropis procera	—	—	—	—	shrub	—	rare
Capparis sepiaria	—	—	—	—	shrub	—	rare
Celtis toka	—	—	—	—	tree	4	extinct
Combretum aculeatum	37	7	—	—	shrub	3	common, heavily browsed
Combretum glutinosum	<0.5	—	0.89	0.16	tree	—	relatively common, poor rejuvenation
Combretum micranthum	13	—	1.12	—	shrub	5	relatively common, good rejuvenation
Commiphora africana	—	—	—	—	tree	—	rare
Crateva adansonii	<0.5	—	0.03	—	tree	—	rare
Dalbergia melanoxylon	<0.5	—	—	—	tree	3	rare
Dichrostachys cinerea	—	<0.5	—	—	shrub	3	rare
Diospyros mespiliformis	11	—	7.52	—	tree	—	common, poor rejuvenation
Faidherbia albida	1	1	0.11	0.15	tree	—	relatively common, relatively good rejuvenation
Feretia apodanthera	39	1	—	—	shrub	2	common, heavily browsed
Ficus sycomorus	—	—	—	—	tree	—	rare
Flueggea virosa	1	—	—	—	shrub	—	rare
Gardenia ternifolia	—	—	0.06	—	shrub	—	rare
Grewia bicolor	1	1.4	—	—	shrub	19	rare, heavily browsed
Grewia flavescens	—	—	—	—	shrub	—	rare
Grewia tenax	—	—	—	—	shrub	2	rare
Grewia villosa	1	—	—	—	shrub	9	rare
Guiera senegalensis	44	11	0.06	—	shrub	4	common, heavily browsed
Hyphaene thebaica	1	<0.5	—	0.04	tree	—	rare
Khaya senegalensis	—	—	—	—	tree	4	extinct
Kigelia africana	—	—	—	—	tree	—	rare
Leptadenia hastata	—	—	—	—	liana	—	rare
Leptadenia pyrotechnica	—	—	—	—	shrub	—	rare
Maerua angolensis	—	—	—	—	shrub	—	rare
Maerua crassifolia	<0.5	1	—	0.02	shrub	—	rare, heavily browsed
Mitragyna inermis	5	—	4.24	—	tree	2	common, poor rejuvenation
Phoenix dactylifera	—	—	—	—	tree	—	rare
Piliostigma reticulatum	5	1	6.08	0.83	tree	2	common, poor rejuvenation
Pterocarpus lucens	<0.5	—	1.27	—	tree	9	relatively common, poor rejuvenation
Sclerocarya birrea	—	—	0.03	—	tree	—	rare
Stereospermum kunthianum	—	—	—	—	tree	—	extinct
Tamarindus indica	—	—	0.38	—	tree	2	relatively common, poor rejuvenation
Vitex doniana	—	—	—	—	tree	—	extinct
Ximenia americana	—	—	—	—	tree	—	extinct
Ziziphus mauritiana	6	3	0.11	0.17	shrub	3	relatively common, heavily browsed
Ziziphus mucronata	<0.5	—	—	—	shrub	—	rare

* Species are named according to Lebrun & Stork (1991–1997).

** Status as extinct is based on local information. Status as rare, relatively common, common or very common is based on botanical inventories (*Andira inermis* is estimated on the basis of personal observations to be rare although relatively common in the sample). Rejuvenation status is based on size class distributions. And finally, status as heavily browsed is based on personal observations.

Appendix 1: Characteristics of species observed on plateaus and in valleys (or said to have been) in the study area.

Plot no.	Coordinates X	Y	< 5 cm dbh density (ha⁻¹)	species no.	≥ 5 cm dbh density (ha⁻¹)	species no.	basal area m^2ha^{-1}	≥ 10 cm dbh density (ha⁻¹)	species no.	basal area m^2ha^{-1}
Sites in valleys										
25	783849	1595634	428	13	62	5	2.1	48	6	2.2
24	785944	1593186	305	9	55	6	5.0	53	6	5.3
33	791463	1595673	788	6	51	6	2.6	45	6	2.7
34	791647	1593347	383	10	69	7	3.5	43	6	2.3
37	792715	1590773	330	13	29	5	4.2	29	5	4.2
39	795002	1593758	490	10	52	6	1.8	45	6	1.7
41	797348	1590568	125	7	15	6	1.6	15	6	1.6
22	778947	1585821	318	12	42	8	3.2	40	7	3.3
21	779545	1585820	165	8	50	8	2.9	47	8	3.0
23	777415	1585920	188	10	41	5	2.2	39	5	2.1
20	773308	1585906	533	15	44	8	3.8	44	8	3.8
19	779538	1586405	215	13	50	6	4.6	49	6	4.7
13	779538	1586405	275	9	56	6	5.2	54	6	5.1
7	782937	1588135	248	10	49	4	2.4	49	4	2.4
11	800724	1590250	375	10	29	7	2.0	29	7	2.0
12	808545	1590591	103	3	24	8	2.6	24	8	2.6
8	790526	1590529	400	11	—	—	—	—	—	—
9	795768	1590836	340	6	25	8	2.6	24	8	2.5
14	779580	1590681	170	5	76	7	5.4	69	7	5.3
3	786365	1592511	288	5	80	10	3.7	56	10	3.5
average			323	9	47	7	3.2	42	7	3.2
Sites on plateaus										
31	789340	1590730	313	8	15	7	0.6	13	7	0.6
32	790355	1592316	80	1	4	2	0,0	2	2	0,0
42	791301	1595796	463	6	25	3	0.7	13	4	0.6
36	791917	1591428	370	14	15	9	1,0	12	10	0.9
40	794871	1594624	43	3	7	3	0.1	3	2	0.1
35	795299	1596877	90	6	16	6	0.6	14	7	0.6
17	787248	1584782	298	7	35	3	0.7	24	3	0.6
4	787391	1590932	350	9	—	—	—	—	—	
10	789416	1591592	193	3	—	—	—	—	—	—
18	788137	1591712	310	3	—	—	—	—	—	—
15	784051	1591663	73	3	—	—	—	—	—	—
26	793599	1591996	143	3	—	—	—	—	—	—
27	794146	1593227	125	4	—	—	—	—	—	—
1	791340	1594429	395	6	55	3	0.6	21	4	0.8
28	795862	1594857	48	2	—	—	—	—	—	—
2	796695	1597842	63	4	8	5	0.4	8	3	0.5
29	798718	1598881	25	2	—	—	—	—	—	—
30	797735	1599908	193	2	—	—	—	—	—	—
average			199	5	20	5	0.5	12	5	0.5
Differences between valleys and plateaus										
significance			p=0.016	p=0.000	p=0.001	p=0.008	p=0.000	p=0.000	p=0.020	p=0.000

Appendix 2: *Characteristics of 38 sites investigated for woody plants. Density, species number, and basal area are tested for differences between valley and plateau sites.*

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