Accuracy of aerial photos for recognizing trees in West African cultural landscapes

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Abstract

A Geographical Information System (GIS) was used to combine digital aerial photo interpretation with a botanical ground mapping of six 25 ha study plots in order to test the accuracy of tree recognition in cultural landscapes of West Africa. The study documents and discusses a variety of factors which influence tree recognition on digital photos and it is also shown that tree recognition is linked to land use patterns.

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Keywords

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Woody plants are key elements in all terrestrial tropical ecosystems and sustain the livelihood of local people in West Africa in general. Consequently, rational land use planning is feasible only if reliable baseline data on the woody vegetation cover is available. The need for objective vegetation monitoring work has been further actualized lately. Thus, it is generally assumed that extra-Saharan drylands are exposed to intensified anthropogenic land occupation followed by reductions in woody vegetation cover (Aubreville, 1938; Gornitz & NASA, 1985), but a number of recent papers have questioned the rate and degree of depletion of woody vegetation in the region (Schlesinger & Gramenopoulos, 1996; Wøien, 1995).

Digital aerial photos constitute one of the strongest remote sensing tools for studies of environmental modifications at a landscape level and have regained much popularity in recent years due to improvements in technology and handling. Aerial photos have generally a better spatial resolution than available satellite images (Groten, 1987), which is important when monitoring woody vegetation. Moreover, scales are flexible and it is even feasible to produce detailed, low-altitude aerial photos using balloons and microlight aircrafts (Beck et al., 1986; Buerkert et al., 1996). Even though panchromatic aerial photos lack the possibilities related to the analysis of multi-spectral information, they possess good object recognition possibilities suitable for studying detailed vegetation information.

In the Sahelian-Sudanean agroecological zones, time series of aerial photographs have been used for studies of land use dynamics and agricultural expansion (Hansen & Reenberg, 1998; Reenberg et al. 1997), monitoring of forest resources and tree counting (Daus et al., 1986; Schlesinger & Gramenopoulos, 1996), analyses of physiognomic changes in vegetation cover (Anhuf & Frankenberg, 1993; De Wispelaire, 1980, Lykke et al.,1999), and to document land degradation and desertification processes (De Wispelaire & Toutain, 1976; Chamard & Courel, 1979; Lindquist & Tengberg, 1993). Several of the studies cited quantify vegetation by estimating woody vegetation cover or by counting individual trees. None of the studies, however, use Geographical Information Systems (GIS) to combine digital object recognition with a detailed botanical ground inventory.

Aerial photo interpretation is traditionally considered 'correct' without ground confirmation (Congalton, 1991) and the interpretation procedure becomes rather subjective

(Biging et al., 1991). Many studies fail to indicate whether 'ground validation' took place or was limited to merely a 'walk through'. It is nevertheless important to know if 'ground truth' was actually omitted (e.g. Wøien, 1995) or realised afterwards (e.g. Whiteman & Brown, 1998).

With the on-going development of scanning equipment and computer technology it has become easier to interpret aerial photos in digital form. Many labor-intensive manual interpretation procedures are now readily overcome by improved computer manipulation facilities (Carmel & Kadmon 1998). The possibility to scan aerial photos with a high resolution ensures the maintenance of the original resolution obtained through the chemical development of the original photo. When the photography has been scanned, rectification of geometrical distortion and contrast enhancement can be performed in most image processing applications. GIS and image processing systems furthermore offer a variety of possibilities to manipulate and visualize data on a computer screen and to refine object recognition.

Objectives

The objective of the present paper is to assess the characteristics of woody vegetation that can be recognized on aerial photos by means of objective criteria in a context limited to cultural landscapes of West Africa. The methodology involves the use of GIS to combine digital image interpretation with a botanical ground inventory. The immediate objectives are:

- to test the accuracy of tree recognition for different landscape formations
- to test the accuracy of tree recognition for various parameters (individuals, species, size-classes, phenological stages)
- to test the accuracy of extrapolating tree density on digital aerial photos
- to test the accuracy of tree recognition on digital aerial photos from earlier years

Study area

The study took place at the SEREIN test areas at Bidi-Ménegou (Oudalan province) and Ningaré (Boulgou province) in Burkina Faso (Figure 1). Six landscape sections of 25 ha each were pre-selected by use of aerial photos. The sites are intended to be used simultaneously as permanent reference areas for studies of long-term dynamics of woody vegetation in cultural landscapes and are therefore relatively large. The plots represent as a consequence of their size heterogeneous formations shaped by the spatial complexity of land use patterns and environmental factors. The tree density is low to moderate outside depressions and river basins. Geographical data and brief site descriptions are outlined in Table 1, next page, along with the dates for the botanical ground truth inventory.

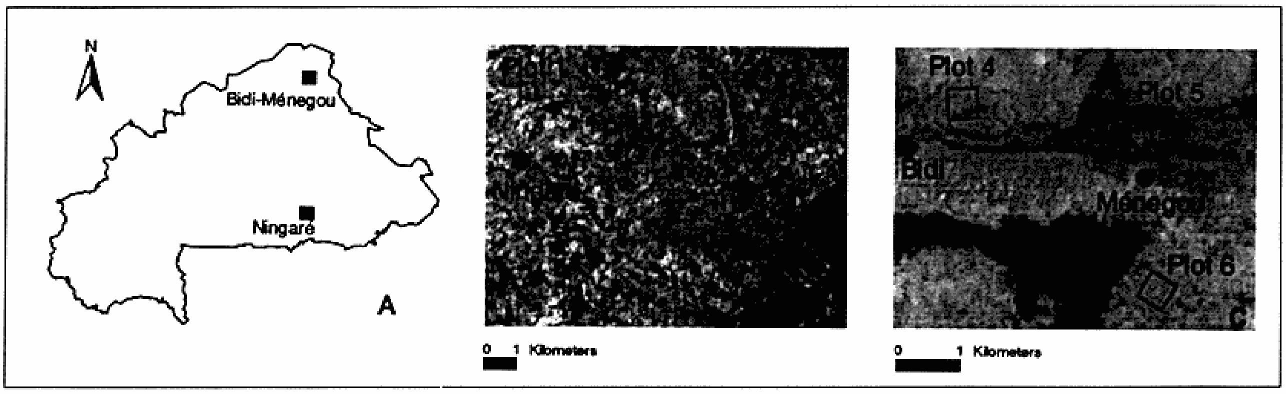

Figure 1: Location of study area. A: Test areas Bidi-Ménegou and Ningaré in Burkina Faso. B: Position of plots 1-3 on SPOT image (1994). C: Position of plots 4-6 on Landsat TM image (1990).

Table 1: Geographical information, dates for ground inventory in 1998, and brief landscape descriptions.

Plot	Date	Coordinates [UTM, zone 30]	Zone	Landscape description	Fields
1	Jan 5-8	790085E, 1292617N; 790044E, 1293126N 790606E, 1292593N; 790586E, 1293100N	Sudan	Agricultural parks dominated by Parkia biglobosa. Site penetrated by stream.	>50%
2	Jan 9-11	793587E, 1290589N; 793543E, 1291084N 794110E, 1290607N; 794064E, 1291140N	Sudan	Agricultural parks with Vitellaria paradoxa. Site penetrated by stream.	c. 80%
3	Feb 5-8	799014E, 1287095N; 799307E, 1287470N 799328E, 1286699N; 799620E, 1287096N	Sudan	Species rich savanna (old fallow) on land once abandoned due to river blindness.	<10%
4	Jan 16-18	789797E, 1591624N; 789818E, 1591127N 789311E, 1591601N; 789332E, 1591089N	Sahel	Xeric plateau with scattered Acacias. Also a few transient inhabitations.	0%
5	Jan 19-20	792478E, 1588248N; 792720E, 1588652N 792893E, 1587989N; 793131E, 1588396N	Sahel	Seasonal depression with riverine vegetation fringed by xeric plateau.	0%
6	Jan 21-23	792700E, 1590705N; 792672E, 1591192N 793185E, 1590755N; 793177E, 1591249N	Sahel	Almost pemanently cultivated dune dominated by Faidherbia albida.	100%

Sudan = Sudanean agroecological zone
Sahel = Sahelian agroecological zone

Methodology

Botanical ground truth inventory

Six permanent plots of 500 X 500 m (250.000 m^2) each were set up. The position of the four corners in each quadrate were measured with a hand-held GPS (acu-lock 600, 1 fix/1.5 sec.) to a precision of 10-20 m. Each study plot was subdivided into 400 subplots. In practice, this was done by dividing the entire plot into twenty transects of 25 X 500 m each which were further delimited into subplots of 625 m^2 (25 X 25 m) by colored strings (Figure 2). Trees to be included in the sample were then located and the various botanical parameters measured. Each subplot of 625 m^2 was divided by means of a visual division into twenty-five 25 m^2 parcels in order to position the trees with a reasonable accuracy. The method implies that every tree is placed into one of the 10,000 possible 25 m^2 parcels constituting the plot and that several trees may occupy the same parcel. The inventory was undertaken by a team consisting of 6 persons and required nineteen days of field work.

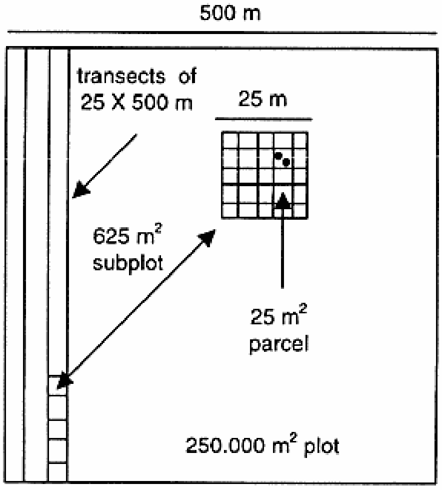

Figure 2: *Setting up a ground grid to position trees in 25 m^2 parcels. Two trees (dots on the diagram) occupy the same parcel and hence position (X,Y) = (67.5 m, 117.5m) (see note under 'grid density).*

Only fairly large trees with trunk diameters above 20 cm were included in the botanical ground inventory because field tests revealed that smaller trees are hard to recognize on medium-range aerial photos with a resolution of 1:20.000 and 1:50.000. Trees were identified as to species according to Hutchinson & Dalziel (1954-1972) and based on the latest nomenclature (Lebrun & Stork 1991-1997). Selected voucher specimens from the study area and near-surroundings were deposited at Aarhus University and DAKAR (acronyms according to Holmgren et al. 1990) and two local herbaria without acronyms (i.e. University of Ouagadougou and IRBET/CNRST). The following parameters were taken for each tree:

- dbh (diameter at breast height = 1.3 m above ground level)
- crown diameter (estimated for the following classes: <5 m, 5-10 m, 10-15 m, 15-20 m, >20 m).
- phenological stage (foliaceous: >50% leaves; sub-leafless <50% leaves).

Aerial photo processing

Panchromatic photos on the scale of 1:50.000 (for 1955) and 1:20.000 (for 1972, 1994) were available for the Ningaré area (Boulgou) while photos on the scale of 1:50.000 were available for the years 1955, 1974, 1981 and 1995 for the Bidi-Ménegou area (Oudalan). The recording dates of all photos are within the period of late October until early February (see Appendix for further documentation).

The aerial photos have all been scanned at a 600 dpi resolution using a flatbed scanner and this corresponds to a theoretical average ground resolution of 0.85 m for the scale of 1:20.000 and to 2.12 m for the scale of 1:50.000. The photographs are deliberately scanned with a lower resolution than the optimum resolving power of commonly used photographic systems, which is 0.5 m for the scale of 1:20.000 and 1.25 m for the scale of 1:50.000 (Lillesand & Kiefer, 1979). Since the resolving power of a lens is higher in the center than in the corners of an image, and since a sampling error is introduced when scanning the photography, it is recommended to stay somewhat below the optimum resolution. The geometrical rectification was performed in the image processing system, Winchips (Chips Development Team, 1998). Ground control points were used as inputs in a 2nd order deformation model and the resampling procedure was performed by use of the "nearest neighbor" method to maintain the maximum number of gray levels originally present in the image. The photos were geometrically corrected to the UTM coordinate system using a rectification procedure performed in two steps. The first step was an image to image rectification in order to make a strong positional correspondence between images of different years. The accuracy of this rectification is most important for the subsequent analysis concerning the inter annual development in woody vegetation and in general it lies within a few meters. The latest photography recorded was used as the reference image, i.e. the 1994 image for the Ningaré area and the 1995 image for the Bidi-Ménegou area. To ensure a continuity in the choice of ground control points, e.g. between 1955 and 1995, the temporal intermediate images were considered too. The second step consisted of an "image-tree" to "ground truth-tree" rectification of the images using the ground collected UTM tree positions. This rectification was first performed between the latest image recorded and a vector file representation of the ground truth-tree positions in UTM coordinates collected in January 1998. Using the rectification grid file obtained from this procedure, the earlier recorded images were rectified to ground truth-tree positions as well.

There has been no attempt made to normalize the image gray values since the interpretation exclusively relies on whether or not a tree is present at a particular position at a given time. Normalizing gray values between different images and within the single image has the drawback of reducing the spectral information. Thus, the original level of gray values is found to be the most efficient indicator for the separation between trees and surroundings.

GIS analysis

Digital photos were combined with vector point layers of tree positions from the botanical ground inventory. A digital photo in the background layer (Figure 3A) was mingled with a vector point layer showing the actual position of trees (Figure 3B). The method allows background layers representing time series of aerial photos at different scales to be combined with tree point layers for various attribute data (individuals, species, trunk diameters, crown diameters, phenological stages). A time span of three to four years exists between latest photography recorded and time of ground inventory. Consequently, some trees may have perished within this period and yet other trees may have remained unmarked or misplaced in the ground inventory. This implies that a perfect match between ground inventory and latest recorded image is not to be expected. Moreover, a few of the tree-like spots on the digital photos inevitably depict 'noise' in the form of wooded termitaries or man-made physical structures (homes, huts, hay stacks, fences etc.).

Definitions

The following categories and definitions were used to recognize trees from the botanical ground inventory on the digital photos:

- *recognized and distinct.* Used when a tree could be recognized and easily delimited (category of 'solitary' trees; example Figure 4B).

- *recognized but indistinct.* Used when a tree could be recognized as pertaining to a patch of two or more trees but not definitively delimited (category of trees growing in 'clumps'; example Figure 5B).

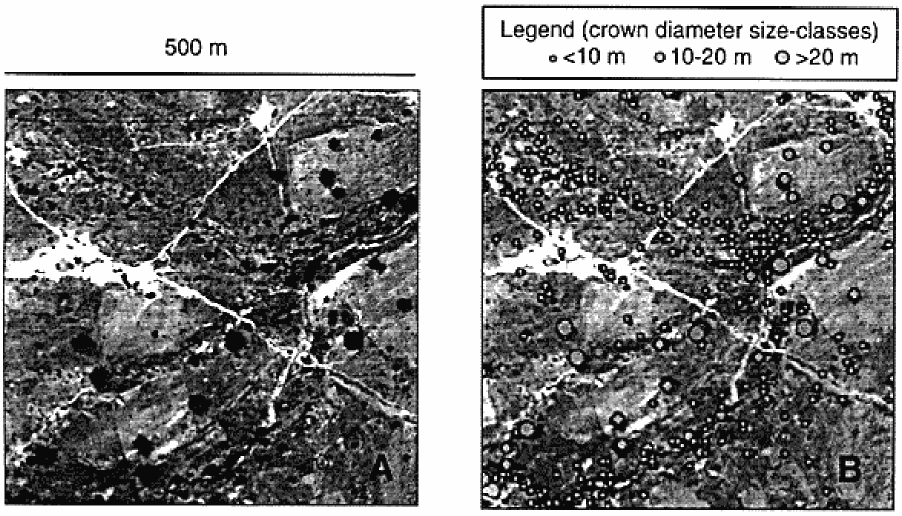

Figure 3: *Sudanean landscape (plot 1). A: View of site December 1994. B: Overlay showing position of trees in crown diameter size-classes of 10 m based on botanical field inventory January 1998.*

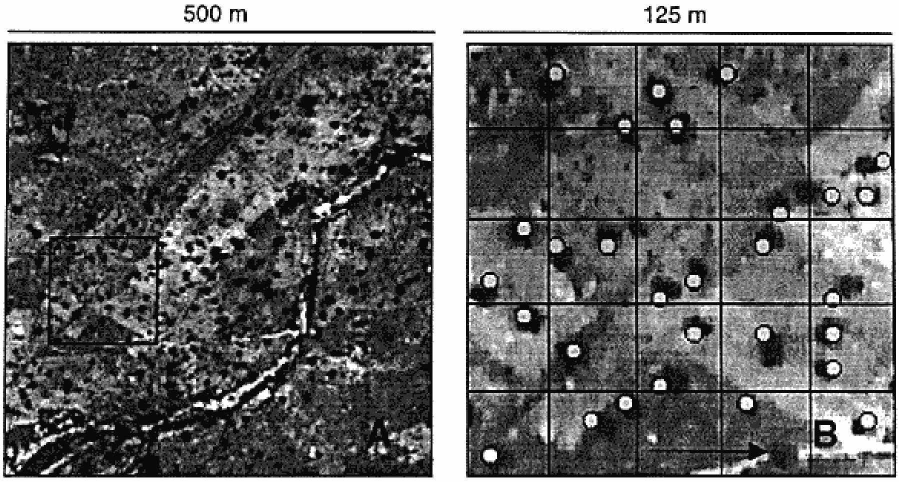

Figure 4: *Sudanean landscape (plot 2). A: View of site. B: Enlarged grid with dot-layer showing position of trees according to botanical ground inventory. Arrow points at human inhabitation.*

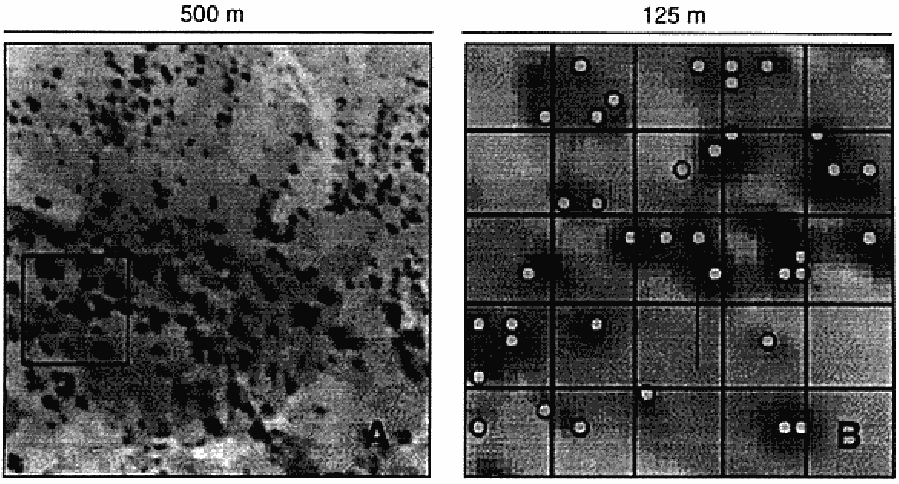

Figure 5: *Sahelian landscape depression dominated by riverine vegetation (plot 5). A: View of site. B: Enlarged grid with dot-layer showing position of trees according to botanical ground inventory. Arrow points at dot representing two trees (see note under 'grid density').*

- *unrecognized.* Used when a tree remained unmatched (category of 'invisible' trees and eventual 'errors').

- *actual density.* The density of trees according to the botanical ground inventory.

- *grid density.* The density of trees according to the grid-layer (vector point layer). Thus, each tree on the grid is positioned to the center of its 25 m^2 parcel and several trees may occupy the same parcel and keep identical positions (Figure 2). Consequently, the grid density is lower than, or equals, the actual density.

- *extrapolated density.* The density according to extrapolations from small plots. A procedure was developed based on interactive classification using pixel value thresholds acquired from selected "training areas". In each plot, approximately 5-10% of the trees present were retrieved from the botanical 'ground truth' and used as a basis for extrapolation. Tree-like markings representing 'noise' were also indicated (see for example arrow pointing at human inhabitation in Figure 4B).

Results and discussion

Brief landscape descriptions are provided in Table 1. Percentages given for land covered with fields are based on coarse estimates only. The study plots occupy mainly rain fed cultivation (plots 1,2,6) or livestock raising (plots 3,4,5). Three sites (plots 1,2,6) could be defined as so-called agricultural parks (see Sturm, 1998) and are typically characterized by a single dominant tree species (cf. Table 1). Structural and phenological characteristics of the woody vegetation based on the 1998 botanical ground inventory are presented in Table 2. Floristic composition (density and dominance), along with documentation for the identification of the tree species, is shown in Table 3.

Tree recognition for different landscapes

Percentages of trees recognized on the latest available digital photo for each of the six study sites are summarized in Table 4. It is shown that 65.7-96.5% of the trees on the grid layer could be located on the digital photos. Our data confirm the usefulness of setting a lower size-class limit at 20 cm dbh, because more than 80% of the trees could be recognized in all but one of the study sites (plot 4). Although the photo resolution was higher in landscapes of the Sudanean zone (plot 1-3; resolution 1:20.000) than in the Sahelian zone (plots 4-6; resolution 1:50.000) there was no clear difference in tree recognition across zones. This is probably because a lower tree density in the Sahel (except in riverine depressions, plot 5) counterbalances a lower overall photo resolution.

A comparison of tree recognition for landscape sections underlying different land use patterns showed that trees were especially easy to recognize on cultivated land, whereas the picture was less clear in pastoral areas. Thus, in Sudanean landscapes dominated by cultivated fields, a notable 61.2% of the trees could be recognized as 'distinct' for a site with 80% arable land (plot 2), whereas only 38.2% of the trees were 'distinct' in a site with 50% arable land (plot 1). Most of the 'recognized but indistinct' trees in both plots occurred crowded along seasonal watercourses. Trees were also easy to recognize in a cultivated Sahelian dune landscape (80.3% 'distinct', plot 6).

Tree recognition was particularly difficult in a site with Sahelian plateau vegetation (34.3% of 67 trees 'unrecognized', plot 4). This was unexpected in as much as the photo in question contained well-delimited patches of woody vegetation at a remarkable low tree density. It is evidently hard (i.e. at available photo resolution and site conditions) to separate individual medium-sized *Acacias* from clumps

***Table 2:** Quantitative data for trees >20 cm dbh.*

Plot	*actual density*	*No. sp.*	*aver. dbh (cm) [c.v.]*	*basal area (m^{2}ha^{-1})*	*crown diameter class (%ind.)*					*phenology (%ind.)*	
					<5 m	*5-10 m*	*10-15 m*	*15-20 m*	*>20 m*	*foliag.*	*s.leafl.*
1	299	20	34.3 [61.1]	1.5	35.8	52.8	6.4	2.3	2.7	57.2	42.8
2	392	23	31.0 [52.5]	1.5	37.2	58.4	3.8	0.3	0.3	54.8	45.2
3	274	21	26.1 [22.1]	0.6	32.1	63.1	4.4	0.4	0.0	21.5	78.5
4	68	5	26.4 [21.0]	0.2	36.8	58.8	4.4	0.0	0.0	63.2	36.8
5	375	15	44.4 [61.0]	3.2	13.0	59.2	21.9	5.1	0.8	8.3	91.7
6	70	9	38.0 [39.4]	0.4	31.4	52.9	14.3	1.4	0.0	2.9	97.1

*No. sp. = number of species; aver. dbh = average trunk diameter at breast height; c.v. = coefficient of variation = stdev*100/average; basal area = sum of areas of cross sections of trunks at breast height; %ind. = percentage of individuals; foliag. = foliageous (>50% leaves); s.leafl. = sub-leafless (<50% leaves).*

Table 3: Floristic data and herbarium documentation for trees > 20 cm dbh.

	No. individuals						**basal area ($m^2 25ha^{-1}$)**					
Species, authors and voucher specimen(s)*1)** ***plot:	***1***	***2***	***3***	***4***	***5***	***6***	***1***	***2***	***3***	***4***	***5***	***6***
Acacia dudgeoni Craib ex Holl. (6151)			2						0.1			
Acacia gourmaensis A. Chev. (5372,5989)	2		15				0.0		0.2			
Acacia hockii De Wild. (6617)			1						0.0			
Acacia nilotica (L.) Willd. ex Del. (5356,5542)				4	17	3				0.2	0.5	0.4
Acacia seyal Del. (5110,5142)					11						0.8	
Acacia sieberiana DC. (5111,5144)	6	1			10	1	0.0	0.1			0.8	0.0
Acacia tortilis (Forsk.) Hayne (5629,5204)				48	23	12				2.4	0.5	1.0
Adansonia digitata L. (no specimen)	1	1					3.5	6.2				
Albizia chevalieri Harms (5134,5147)	3						0.0					
Anogeissus leiocarpa (DC.) Guill. & Perr. (5362,5799)	62	43	3		45		5.5	3.5	0.1		22	
Balanites aegyptiaca (L.) Del. (5208,5275)	45	5	32	14	32	6	1.4	0.1	1.4	0.6	2.1	0.4
Bauhinia rufescens Lam. (5667)					2						0.0	
Bombax costatum Pellegr. & Vuill. (5523)	1	15					0.2	2.5				
Combretum glutinosum Perr. ex DC. (5107,5158)	3	4	20		8		0.1	0.1	0.2		1.4	
Combretum molle R. Br. ex G. Don (5854,6602)		2	1					0.1	0.0			
Crossopteryx febrifuga (G. Don) Benth. (5159)			1						0.0			
Diospyros mespiliformis Hochst. ex A. DC. (5229,5323)	11	3	1		64		0.7	0.2	0.0		34.0	
Entada africana Guill. & Perr. (5864)		1	3					0.0	0.0			
Faidherbia albida (Del.) A. Chev. (no specimen)				1	1	40				0.1	0.9	7.2
Ficus sycomorus L. (5146,5584)	5	1					2.0	0.0				
Hyphaene thebaica (L.) Mart. (6018)					5	4					0.2	0.4
Kigelia africana (Lam.) Benth. (5125)					1						0.6	
Lannea acida A. Rich. (5137,5509)	29	6	59				1.8	0.5	2.8			
Lannea microcarpa Engl. & K. Krause (5145)	49	7	3				3.2	0.8	0.3			
Maytenus senegalensis (Lam.) Exell (no specimen)		1	1					0.0	0.0			
Parkia biglobosa A. Chev.(5113)	21	7					12.0	1.4				
Piliostigma reticulatum (DC.) Hochst. (5329,5641)					154	1					15.0	0.1
Piliostigma thonningii (Schumach.) Milne-Redh. (6615)	3						0.1					
Pseudocedrela kotschyi (Schweinf.) Harms (6611)			1						0.0			
Pterocarpus erinaceus Poir. (no specimen)	1	1	20				0.0	0.1	1.4			
Pterocarpus lucens Lepr. (5002)				1						0.1		
Sarcocephalus latifolius (Smith) Bruce *(5148,5979)*		2						0.0				
Sclerocarya birrea (A. Rich.) Hochst. (5127)	14	11	11		1	1	1.0	0.9	0.7		0.2	0.1
Sterculia setigera Del. (5114)		8	6			1		1.9	0.5			0.0
Stereospermum kunthianum Cham. (5132)	2						0.1					
Tamarindus indica L. (5326)	23	7	5				1.7	0.4	0.5			
Terminalia laxiflora Engl. & Diels (6619)		10						0.8				
Terminalia schimperiana Hochst. (5031)		1						0.0				
Vitellaria paradoxa C.F. Gaertn. (5117)	14	253	88				1.6	15.0	4.9			
Vitex doniana Sweet (6189,6620)	4	2					0.5	0.5				
Ziziphus mauritiana Lam. (5396,5797)			1		1	2			0.1		0.0	0.2
	299	392	274	68	375	71	35.4	35.1	13.2	3.4	79.0	9.8

1)Collector = Madsen et al.

Table 4: Tree recognition on digital photos. For 1995 (plot 1-3) and 1994 (plot 4-6).

Plot	***grid density***	***individuals (%)***			
		recognized			***unre-cognized***
		distinct	***indistinct***	***all***	
1	*293*	*38.2*	*42.3*	*80.5*	*19.5*
2	*371*	*61.2*	*35.3*	*96.5*	*3.5*
3	*261*	*51.0*	*39.1*	*90.0*	*10.0*
4	*67*	*50.7*	*14.9*	*65.7*	*34.3*
5	*367*	*20.2*	*65.4*	*85.6*	*14.4*
6	*66*	*80.3*	*6.1*	*86.4*	*13.6*

and thickets composed of shrubs and treelets. The difficulty encountered seems to reflect distribution patterns of native trees in arid environments in general. Thus, whereas large trees commonly are randomly or regularly spaced due to resource limitations, small trees and saplings exhibit more aggregated distribution patterns (Skarpe, 1991), and clumps of regrowth may easily be mistaken for solitary trees on a digital photo, especially because saplings more often than adults prevail in sub-evergreen stages.

Tree recognition was also complicated in a site with Sudanean savanna vegetation on old fallow land (plot 3) due to a high tree density of medium sized individuals of almost equal size (average dbh = 26.1 cm [c.v. = 22.1], Table 2). Thus, 274 trees over 20 cm dbh had to be matched on a photo that also included 649 trees in the next highest size-class (dbh = 10-20 cm). Consequently, the 90% 'recognized' trees surely represent an overestimate because many trees may have been mistaken for nearly equally large neighbors. The case highlights a limitation in the methodology applied. Hence it is difficult to discern individuals in very dense stands because trees are positioned to a precision around 10 m only (estimated to nearest 25 m^2 parcel). Finally, the highest number of 'recognized but indistinct' trees was recorded for a Sahelian riverine depression where adult trees predominantly occurred in contagious distribution patterns (65.4%, plot 5).

Tree recognition for different botanical parameters

A single site (plot 1) was used as 'ground truth' in order to differentiate between various attributes (species, size-classes etc.) that may influence tree recognition on digital photos (Table 5). It was found that the broad-crowned *Parkia biglobosa* was easy to recognize as 'individuals' (85.7%), whereas *Tamarindus indica* grew in 'clumps' (72.7%). Indeed, *Parkia biglobosa* is the only tree that can be identified as a separate species in the Sudanean study plots, because the few other evergreen giants in the area (*Manigefera indica* and *Ficus* spp.) are less common and mainly found around home sites. It may be added that *Faidherbia albida* was the only recognizable 'species' in the Sahelian study area. More surprisingly, it was found that two deciduous species of *Lannea* (*L. acida* and *L. microcarpa*) were as easy to detect as two sub-evergreen species, namely *Anogeissus leiocarpa* and *Balanites aegyptica*. The finding pin-points a dilemma: deciduous trees, which supposedly are difficult to observe on digital photos due to lack of foliage, predominantly grow on plateaus with highly contrastive backgrounds, whereas sub-evergreen species chiefly are found crowded in moist areas where a dense undergrowth blurs the visibility of trees on digital photos. Our data also confirm that tree recognition increases proportionally with tree size. More than 95% of all trees with crown diameters over 10 m or trunk diameters over 40 cm could thus be recognized on the aerial photos.

Table 5: *Tree recognition for various parameters. Based on plot 1 (1994 photo).*

Parameters (attributes)	***individuals (%)***		
	recognized		***unre-cognized***
	distinct	***indistinct***	
taxon			
Anogeissus leiocarpa	*44.1*	*44.1*	*11.9*
Balanites aegyptiaca	*34.1*	*40.9*	*25.0*
Lannea acida and *L. microcarpa*	*44.9*	*42.3*	*12.8*
Parkia biglobosa	*85.7*	*14.3*	*0.0*
Tamarindus indica	*13.6*	*72.7*	*13.6*
crown diameter			
<5 m	*28.6*	*34.7*	*36.7*
5-10 m	*38.6*	*43.8*	*17.6*
10-15 m	*57.9*	*42.1*	*0.0*
>15 m	*93.3*	*6.7*	*0.0*
dbh			
20-40 cm	*29.3*	*50.2*	*20.4*
40-60 cm	*44.4*	*51.1*	*4.4*
>60 cm	*77.8*	*22.2*	*0.0*
phenology			
sub-leafless	*41.2*	*45.6*	*13.2*
foliageous	*41.2*	*44.2*	*14.5*

Accuracy extrapolating tree density

Table 6 shows the result from a test of the accuracy of extrapolating tree density from small plots using known 'training areas'. Major deviations were noticed in two Sudanean plots penetrated by seasonal rivers (plots 2-3; 14.8-38.9%) and a Sahelian riverine depression (plot 5; 36.2%). The data show that it is complicated to recognize individual trees in patches. This difficulty is highlighted in Figure 5B where an arrow points at two large intergrown individuals of *Diospyros mespiliformis* which are represented as a single dot in the vector point layer. Only minor deviations were, on the other hand, noticed in relatively homogenous landscape sections (plots 3,4,6; 1.9-4.5%).

Table 6: *Accuracy extrapolating tree densities using photos from 1994 (plot 1-3) and 1995 (plot 4-6).*

Plot	***actual density***	***grid density***	***extrapolated density***	***dev. (%)***
1	*299*	*293*	*179*	*-38.9*
2	*392*	*371*	*316*	*-14.8*
3	*274*	*261*	*256*	*-1.9*
4	*68*	*67*	*70*	*4.5*
5	*375*	*367*	*234*	*-36.2*
6	*70*	*66*	*64*	*-3.0*

$$\text{dev.} = \text{deviation} = 100 \times \frac{\text{grid dens.} - \text{extrap. dens.}}{\text{extrapolated density}}$$

This, in turn, calls attention to the difficulty of extrapolating tree densities on panchromatic aerial photos picturing heterogeneous landscape formations.

Tree recognition on digital photos from earlier years
Numbers of trees recognized on earlier digital photos are shown in Table 7. Only trees with a dbh >40 cm in 1998 were considered. Notably, 68% of the trees on the Sahelian dune landscape (plot 6) could be recognized on the 1981 photo and represented almost uniquely *Faidherbia albida.* Likewise, 44.3% of the trees in the Sudanean landscape located closest to Ningaré village (plot 1) could be recognized on the 1972 photo, essentially individuals of *Parkia biglobosa.* These species, as well as *Vitellaria paradoxa,* are well-known protected tree species on cultivated land in the traditional agrarian practices in the area (Fontès & Guinko, 1995). It may be added here that although trees were not marked individually, larger trees can generally be recognized and re-measured for growth increments, mortality etc. in studies to come.

Figure 6 illustrates a time series of digital photos based on the area selected in Figure 5B. The superimposed vector point layer shows the actual position of trees >40 cm dbh for two different crown diameter size-classes in a section of a riverine depression. The oldest photo from 1955 is of inferior quality and trees are hardly discernible. On the other hand, woody vegetation looks particularly exuberant in 1981. This, however, seems to be a transient phenomenon because a careful look at the photos shows that exactly the same stand of large trees remained at identical positions on the site during 1974-1998. Interestingly, Lindquist & Tengberg (1993) reported that a partial recovery of vegetation took place in depressions of northern Burkina Faso from 1972 through 1984 (i.e. including the site described here), whereas Lykke et al. (1999) came to the opposite conclusion based on almost identical photos, albeit including a more recent photographic series. The example demonstrates the difficulty in interpretating long-term vegetation dynamics using aerial photos. Many misreads of changes in woody vegetation cover based on photo interpretation relate to the difficulty in distinguishing between 'trends' and 'fluctuations'. Bakker et al. (1996) pointed out that permanent plots represent an ideal way to overcome this particular problem.

***Table 7:** Recognition of trees >40 cm dbh on photos from 1972 (plot 1-3) and 1981 (plot 4-6).*

Plot	*actual density*	*individuals (%)* recognized distinct	*recognized indistinct*	*unrecognized*
1	*64*	*32.8*	*44.3*	*23.0*
2	*54*	*11.1*	*9.3*	*79.6*
3	*11*	*27.3*	*9.1*	*63.6*
4	*1*	*100.0*	*0.0*	*0.0*
5	*153*	*27.9*	*68.0*	*4.1*
6	*25*	*68.0*	*12.0*	*20.0*

Conclusion

The present study confirms that aerial photos represent a highly relevant and useful tool in studies of woody vegetation in West African agro-pastoral landscapes. Trees and large shrubs are detectable as individual objects or continuous patches, and present-day distributions, stand structure, and stand age of populations of protected tree species are unmistakably linked to former and present land use patterns.

On the other hand, the study also reveals that aerial photo interpretation is subject to some uncertainties. It is therefore not feasible to come up with simple answers on the type of woody vegetation that can be recognized on panchromatic digital photos and it is always necessary to carefully design the type of ground reference data required in

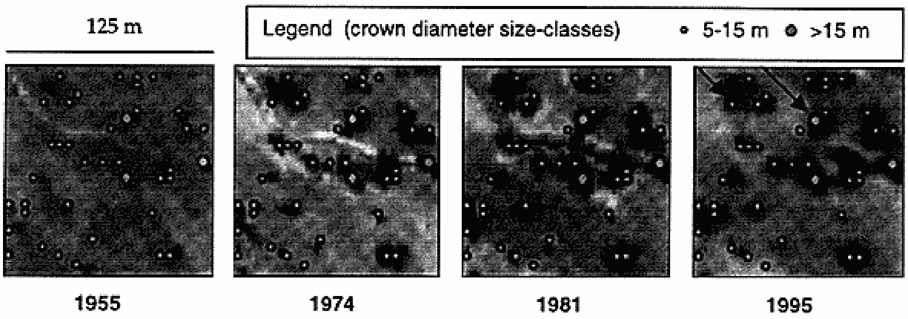

***Figure 6:** Combining time series of digital photos with actual position of trees based on measurements in January 1998. Arrows indicate trees grouped in crown diameter classes below/above 15 m, respectively. The landscape selection shown corresponds to figure 5B.*

order to correctly interpret woody vegetation on aerial photos.

Future investigations on the interpretation of woody vegetation could benefit from the combined use of panchromatic photography with color-infrared photography. Whereas panchromatic photos are preferable in terms of geometrical resolution, they suffer from a lack of spectral information concerning species-dependent variations in red and near-infrared reflectance. Color-infrared photography may also provide additional information necessary to distinguish different species and to separate woody plants from non-woody physical structures, especially when photographic recording is correlated with tree phenology. The interpretation process could furthermore be improved through stereo viewing of images to provide an aspect of height. This might be a valuable tool in the effort of distinguishing between height-limited undergrowth and trees.

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Appendix: Reference for aerial photos.

Photo ID	*Mission*	*Date D/M/Y*	*Scale*	*Area*
165, 166	*ND-30-XVIII*	*22/10/55*	*1:50.000*	*B/M*
378, 379	*74 HVO 10* *500 SAG 464*	*07/11/74*	*1:50.000*	*B/M*
2150, 2151	*81032-HV*	*22/12/81*	*1:50.000*	*B/M*
4685, 4686	*95141-B*	*08/02/95*	*1:50.000*	*B/M*
318, 319	*NC-30XXIV*	*04/02/56*	*1:50.000*	*Ning.*
412, 427 *429*	*72 HVO 003* */200*	*12/02/72*	*1:20.000*	*Ning.*
0386, 0429 *0503*	*132-B Boulgou*	*21/10/94*	*1:20.000*	*Ning.*

B/M = Bidi/Menégou
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318, 319	*NC-30XXIV*	*04/02/56*	*1:50.000*	*Ning.*
412, 427 429	*72 HVO 003 /200*	*12/02/72*	*1:20.000*	*Ning.*
0386, 0429 0503	*132-B Boulgou*	*21/10/94*	*1:20.000*	*Ning.*

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