Hum Ecol (2008) 36:789–805
DOI 10.1007/s10745-008-9203-4

An Anthropogenic Escape Route from the "Gulliver Syndrome" in the West African Savanna

Paul Laris

Published online: 22 November 2008
© Springer Science + Business Media, LLC 2008

Abstract A major challenge for ecologists has long been to develop a model to explain the coexistence of grasses and trees in the savanna. The recent shift in emphasis to non-equilibrium-based theories has resulted in a rethinking of this problem. As resource allocation models have been replaced by demographic ones, the focus has shifted to plant life histories. The tree/grass ratio is now conceptualized as a function of disturbance history. Empirical studies demonstrate that repeat fires trap tree sprouts in perpetual juvenile states. Ecologists suggest natural pathways for juveniles to escape, reach maturity, and maintain tree/grass ratios. This study documents how long-fallow agriculture serves as an anthropogenic pathway. The study compares tree cover on long-fallow and unfarmed savanna plots in southern Mali where burning is annual. Tree height, girth, and species were recorded for 29 quadrats. The results demonstrate a significant difference in the size, number, and species of trees; those on fallow plots were taller, more numerous, and more diverse.

Keywords Savanna · Fallow · Gulliver syndrome · Fire · Natural experiment · Mali

> Hence, repeated fires can keep individuals small, but individuals rarely suffer mortality and large individuals are virtually immune to fire damage. The syndrome has been called…the Gulliver syndrome (after Jonathan Swift's character Lemuel Gulliver), which emphasizes a tree's potential to be a giant once it escapes fire (Higgins *et al.* 2007: 1124)

P. Laris (✉)
Department of Geography, California State University,
Long Beach, CA, USA
e-mail: plaris@csulb.edu

Introduction

In 1936 Andre Aubréville, a preeminent French colonial botanist and forester set up an experiment to study the impacts of fire on savanna vegetation in northern Ivory Coast (Aubréville 1953; Louppe 1995). Like many scientists of his time, Aubréville was convinced that vast tracks of savanna in West Africa were of anthropogenic origin, derived from tropical dry forests (which he theorized was the vegetation climax for the region) rather than occurring naturally due to edaphic and other conditions. Aubréville designed an experiment to end the debate over the cause of savanna and to corroborate his conviction that the savanna had been anthropogenically derived through a process of cutting trees, farming and repeated burning (Aubréville 1947, 1949, 1953).

Aubréville interpreted the results of his experiments as providing quantitative evidence supporting the theory of regional savannization (Aubréville 1947, 1953). He argued that restrictions needed to be imposed to limit "indiscriminant burning and land clearing" in order to prevent all unnecessary destruction (Aubréville 1947, 11). And indeed, fire suppression and anti-tree cutting policies were eventually implemented throughout the West African region (Laris and Wardell 2006).[1]

Although not the first of its kind, Aubréville's fire experiment proved to be influential as experiments of

---

[1] It is interesting to note that in South Africa and parts of East Africa, scientists were not concerned about savannization, rather they were concerned about the opposite effect—so called "shrub encroachment" because the predominant economic activity in the region was livestock grazing and thus increasing woodiness was viewed as degradation (e.g., Ward 2005).

similar design were established in numerous African savannas (Charter and Keay 1960; Jouvanceau 1962; Ramsay and Rose-Innes 1963; Onochie 1964; Rose-Innes 1971; Biggs *et al.* 2003; Higgins *et al.* 2007; Van Wilgen and Scholes 2007).[2] In general, data gathered from these experiments demonstrated that frequent burning has important effects on the savanna structure by favoring grasses over trees. Specifically, regular annual fires (especially intense, late dry-season fires) repeatedly burn-back new tree sprouts and shoots preventing them from reaching maturity unless an escape route is provided. This phenomenon has appropriately been dubbed the "Gulliver syndrome" because when trees manage to escape fire, they quickly grow to large heights (see quotation above).

While most ecologists and biogeographers agree a defining feature of a savanna landscape[3] is the coexistence of grasses and trees (e.g., Cole 1986; Scholes and Archer 1997); the causes of coexistence remain a conundrum (Higgins *et al.* 2000; House *et al.* 2003). Indeed, during the past 50 or so years the fundamental scientific model for explaining tree and grass coexistence has shifted several times from an equilibrium model based on resource partitioning (Walter 1971; Walker and Noy-Meir 1982), to a disequilibrium model based on disturbance regimes (e.g., Scholes and Archer 1997), and most recently to patch-dynamic and/or "demographic bottleneck" models (Higgins *et al.* 2000; Sankaran *et al.* 2005). These latter models emphasize tree "life histories" recognizing the importance of disturbance regimes in creating opportunities and constraints for tree establishment and growth. From this perspective, the Gulliver syndrome is a critical factor governing savanna tree/grass ratios (Higgins *et al.* 2000). Ecologists have documented three natural routes for trees to escape the Gulliver trap: several years of unusually high rainfall, several years of fire suppression, or intense termite activity (Higgins *et al.* 2000). Each of these three escape routes allows trees to reach sufficient height so as to escape the damaging flames of regular fires and thus to grow to fire resistant size.

A number of recent studies in savannas cast doubts on how Aubréville and others interpreted the results of the burning experiments; however, these studies suggest an anthropogenic escape route from the Gulliver syndrome. In the most well-known example, Fairhead and Leach (1996) found that farming, strategic use of fire, and other daily life activities such as tree planting on intensively managed plots tended to increase woody vegetation cover at the expense of grasses in the Guinean savanna-mosaic. A host of other studies appear to support this general conclusion (Spichiger and Pamard 1973; Avenard *et al.* 1974; Guelly *et al.* 1993; Amanor 1994; Bucini and Hanan 2007).

The present study was designed to compliment the original burning experiments by addressing several key weaknesses (see below). It uses a natural experimental design to conduct a comparative study of long-term fallow and unfarmed savanna plots to explore the impacts of cutting, farming and regular burning on woody savanna vegetation. Specifically, this study compares tree cover on eight plots that were farmed and then fallowed (for at least 30 years) with tree cover on unfarmed savanna plots at two sites in southern Mali where burning is a near annual event. The study seeks to test the hypothesis that cutting and farming of "virgin" savanna vegetation followed by fallowing and repeated burning will result in a savanna with fewer and smaller trees. "Virgin" vegetation is defined here as savanna vegetation that has not been farmed or at least not farmed in living memory.

Although several studies have examined the long-term effects of farming, abandonment and burning in the more humid savanna-mosaic or Guinea savanna of West Africa, this study is one of the first to systematically explore this issue in the more mesic southern Sudan Savanna. Specifically, this study uses a natural experiment to address three main questions: (i) What is the vegetation structure (number and size of trees and grass cover) on abandoned agricultural plots subjected to regular burning after more than 30 years? (ii) How does the vegetation on these plots compare with that on neighboring unfarmed plots? (Specifically, how does the tree density, species type and diversity differ on the plots subject to different disturbance regimes?) And (iii), what explains the differences in the vegetation cover on the farmed and unfarmed plots.

A natural experiment is one in which the researcher does not manipulate variables and instead strives to locate "naturally" occurring differences in initial conditions, perturbation, or processes. Natural experiments are especially useful for analyzing environmental changes over long time frames and large spatial scale where they may achieve a higher level of realism and generality than field or laboratory experiments (Diamond 1986). By using a natural experimental design this study seeks to address some elements of bias or weaknesses associated with the original burning experiments. These weaknesses derived in large part from the fact that the original experiments were designed to test the convictions of colonial scientists that the savanna had anthropogenic origins rather than explore the impacts of the

---

[2] The Nigerian Forest Department established what might be the first fire experiment in the Olokemeji Forest Reserve in 1929 (Mackay 1936; Charter and Keay 1960).

[3] Due to the wide range of what constitutes a 'savanna' debates persist in the literature over how this vegetation should be classified, especially when it comes to distinguishing "savanna" from "woodland" (e.g., Lawesson 1994). Here I adopt the term "savanna landscape" from Bourliere and Hadley (1983) who recognized that savannas are complex landscapes that may be interspersed with patches of gallery forests, dense woodlands, marshes or other vegetation forms.

actual farming, fallowing and burning practices of rural Africans (Laris and Wardell 2006). As such, critical variables such as the seasonal timing of fires employed in the studies did not necessarily reflect local burning practices (Moss 1982). Rather, burns dates were selected to document two extremes: early and late dry season fires (the latter presumably because scientists wanted evidence that fire could *cause* savannization).[4] This bias, among others, was not surprising given that the experiments were designed to simulate a "laboratory-like" environment that controlled for a single variable—fire treatment—which colonial scientists thought was critical. As a result, the experiments tell us much, or more, about the views of the scientists that created them as they do the impacts of the actual farming and burning practices of Africans.

Savanna Biogeography and Fire Ecology

Issues of Origin and Maintenance

Savanna debates often revolve around issues of cause (origin) and maintenance. For example, it has long been argued that anthropogenic fires play two key roles in savanna ecosystems: first they serve as a buffering force that *maintains* the structure of a savanna and prevents the transition from savanna to dense woodland or forest; and second, they serve as a destabilizing force that *causes* a transition from a dry forest or savanna-woodland to a more grass dominated ecosystem. The latter process has often been referred to as savannization.[5] Savannization in Africa is often thought to be associated with an increase in human disturbance, notably a change in fire regime. Indeed, there is evidence that humans impacted the West African landscape through modification of the natural fire regime at least thousands of years ago (Bird and Cali 1998), but the precise impacts of human disturbances remain a matter of considerable debate.

Recent findings from paleoecological research suggest that natural, rather than anthropogenic, fires were the primary force extending the areas of flammable vegetation (savanna grasses) in Africa (Scott 2000; Keeley and Rundel 2005). In particular, natural fires fostered the spread of C_4 grasses during the last glacial maximum (Harrison and Prentice 2003) when anthropogenic effects were minor (Scott 2002). Indeed, evidence from paleoecological studies in southern Sudanian savanna suggests that the vegetation cover never consisted of closed canopy dry forest even during the mid-Holocene period when precipitation was significantly higher. Moreover, Salzmann and colleagues (2002) found no charcoal evidence to suggest an anthropogenic change in the fire regime during the transition period.[6] These authors note that frequency of fire remained remarkably constant even in late Holocene, and they reject the hypothesis of anthropogenic origin of the Sudanian savanna. Thus, although it has been commonly argued that the West African savannas are anthropogenically *derived*, it may be more appropriate in many cases to consider these formations anthropogenically *maintained*, because regardless of origin, savannas in certain climatic zones require repeated disturbances to persist.

Recent research has also served to narrow the dividing line between what can be considered human-maintained versus "natural" savanna. Several studies have found that the majority of the mesic savanna are unquestionably human maintained, that is, they would not persist without frequent human disturbances (Bond *et al.* 2005; Bond 2005; Sankaran *et al.* 2005). For example, Sankaran and colleagues (2005) determined that disturbances are required for trees and grasses to coexist in Africa's savannas where mean annual precipitation is greater than 650 mm (as is the case in the Sudan Savanna) because rainfall levels are sufficient to support the closure of the woody canopy and the elimination of grasses. It is readily apparent, then, that these savanna ecosystems persist in a state of disequilibrium where frequent disturbances, such as fire or browsing, are required to prevent the extinction of grasses.[7] As such, regardless of origin, these savannas are maintained by frequent disturbances.

For the case of the West African savanna, which is the focus of this study, it is abundantly clear that the main forces of disturbance are, and have long been, anthropogenic (although these undoubtedly act in tandem with drought). The two factors having the greatest and most enduring impact are arguably fire and farming (Bucini and

---

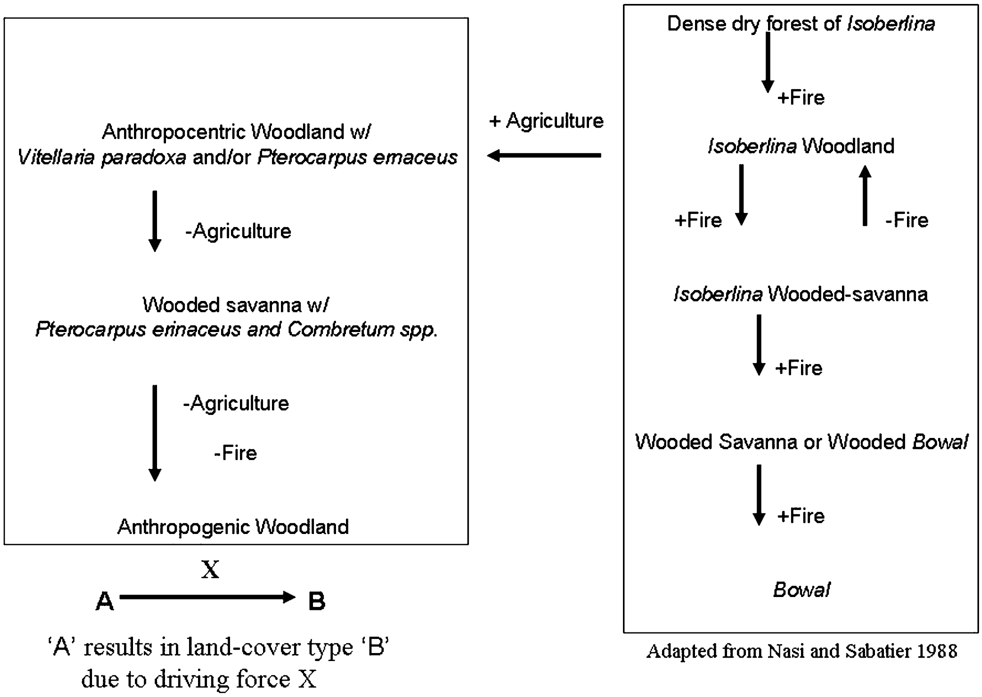
[4] The "degradation" bias was sometimes recognized in later reports. For example, South African researchers reviewing early findings of one experiment concluded that, "a number of treatments were included to illustrate or prove the damaging impacts of natural and artificially ignited fires rather than to meet the needs of the original objectives." Their report concluded that this "value-loaded" agenda resulted in the inclusion of unnecessary treatments and the exclusion of necessary ones (Biggs *et al.* 2003:2).

[5] The term "savannization" has two meanings: in the first it concerns the processes through which tree cover declines as grass cover expands, and in the second, it concerns the processes through which forest species are replaced by savanna species. I use the term in reference to the former throughout the text.

[6] It is possible, for example, that a shift from a regime of late to early fire caused by humans would not be detectable in the charcoal records.

[7] While some scholars think of savannas as ever moving between what are called "multiple equilibrium states" such as open grassy savannas, wooded savannas, and woodlands (e.g., Dublin *et al.* 1990), others, including Stott (1991), are of a more radical disposition and regard savannas as being intrinsically non-equilibrium systems, in which every savanna organism responds individualistically to changes in the ecological determinants.

Fig. 1 Possible succession pathways for *Isoberlina* forest according to Nasi and Sabatier (1988)



Hanan 2007), although grazing is also important in some cases. Although the evidence remains mixed on whether fire alone can cause savannization, it is clear that fire in combination with rotational agriculture favors grasses over trees at least when fallow cycles are short. Indeed, following Aubréville, the predominant human–ecological model for the study region holds that rotational agriculture combined with frequent anthropogenic burning serves to reduce tree cover and to suppress or prevent regrowth of savanna tree species (Fig. 1) (e.g., Nasi and Sabatier 1988).[8]

Savanna Fire Ecology

The evidence that fire maintains the savanna by suppressing tree regrowth derives primarily from two sources: long-term burning experiments and field observations. The burning experiments confirmed two basic principles: (i) when entirely protected from fire savanna patches succeed to a near-closed canopy forest or dense woodland; and (ii) the tree/grass ratio in particular, is a function of the fire regime. The fire regime is commonly defined as the frequency, intensity, and type of fire (Bond and van Wilgen 1996). In savannas, intensity is closely linked with fire seasonality because late dry season fires burn more intensely than early ones. The burning experiments clearly demonstrated that a regime of late dry season fires suppresses the regrowth of trees and causes a decrease in the tree/grass ratio over time (Aubréville 1953; Charter and Keay 1960; Ramsay and Rose-Innes 1963; Rose-Innes 1971; Brookman-Amissah *et al.* 1980; Swaine *et al.* 1992; Louppe *et al.* 1995). These studies also found that early dry season (EDS) fires are less damaging to small trees and over time.

There are three key weaknesses associated with the burning experiments of relevance. First, the initial conditions and land-use history of the sites selected for study were rarely documented in detail (Ramsay and Rose-Innes 1963). In many cases the plots were cleared of all trees prior to the experiments because it was thought this practice mimicked slash and burn agriculture and that existing vegetation cover might bias the results. This was unfortunate because it is common practice to leave individual trees standing in farmed plots where they ultimately serve as an important source of seeds for natural regeneration (e.g., Gautier *et al.* 2006).[9] Second, (as noted above) the timing of the burns employed in the studies did not necessarily reflect the actual burning practices of the indigenous population in the region (Moss 1982). A third and final weakness of the experiments was that they failed to consider burning in the context of other factors including grazing and a suite of landscape-scale factors including soil type, topography, and spatial pattern of vegetation and fire regime (Laris and Wardell 2006).

Numerous field studies support the general findings of the burning experiments that fire is a critical determinant of

---

[8] Several scholars have documented the persistence of what can be termed a regional degradation narrative for West Africa. The narrative has its origins in the colonial era and Aubréville's ideas played a central role (Fairhead and Leach 1996; Bassett and Koli Bi 2000).

[9] In some cases plots had been previously farmed, but in most cases details are absent from the published accounts.

tree recruitment in savannas because seed mortality, seedling mortality and topkill increase with fuel load and fire intensity. Fires burning late in the dry season burn more intensely (because vegetation has low moisture content) and tend to be more damaging to trees (especially young ones) than fires burning early in the dry season (Menaut *et al.* 1995; Sawadogo *et al.* 2002; Govender *et al.* 2006; Russell-Smith and Edwards 2006). Intense late dry season fires, reduce tree regeneration and retard transition to adulthood (Biggs *et al.* 2003; Sankaran *et al.* 2004, Wiegand *et al.* 2006; Govender *et al.* 2006; Zida *et al.* 2007). Fire may kill tree seedlings or seedlings may persist as juveniles, known as "gullivers" (Bond and van Wilgen 1996), for many years because such stems continue to resprout repeatedly after being burnt back by fires (Higgins *et al.* 2000) (Fig. 2). Conversely, it has been demonstrated that if fire is suppressed for a number of years, gullivers may grow tall enough to escape the flames and become large, mature trees (Van Wilgen *et al.* 1990). As such, fire—particularly late dry season (LDS) fire—serves as a buffering force preventing the establishment of new trees in existing patches.

Event Driven Models

A recent and growing body of literature demonstrates that savannas (especially mesic savannas) are event driven systems. Specifically, if a disturbance regime is halted or modified for a period of years (for example, if a high intensity fire regime is replaced by a low intensity or fire free one) trees have an opportunity to mature and a grass-dominated savanna will shift to a tree-dominated one which may persist for decades or longer. It follows that savanna models need to incorporate the disturbance interactions between grasses and trees and other key events (Higgins *et al.* 2000; Wiegand *et al.* 2006). Models based on this approach have been called "demographic-bottleneck" approaches (Sankaran *et al.* 2004) because they focus on the factors that limit tree establishment and/or maturation in savannas. For example, Higgins and colleagues (2000) proposed a model based on the concept of the "storage effect" to explain tree recruitment fluctuations in savannas. The storage effect governs savanna seedling establishment rates as a function of three factors: unusual rainfall events, fire regimes, and tree life expectancy. Other studies demonstrate the importance of termites as a factor that favors tree recruitment by loosening the soil and facilitating water infiltration and root development (Furley *et al.* 1992). Given that disturbance is critical to savanna dynamics, it is surprising that few ecological and biogeographical researchers have explicitly incorporated human practices into their analyses and models.[10, 11]

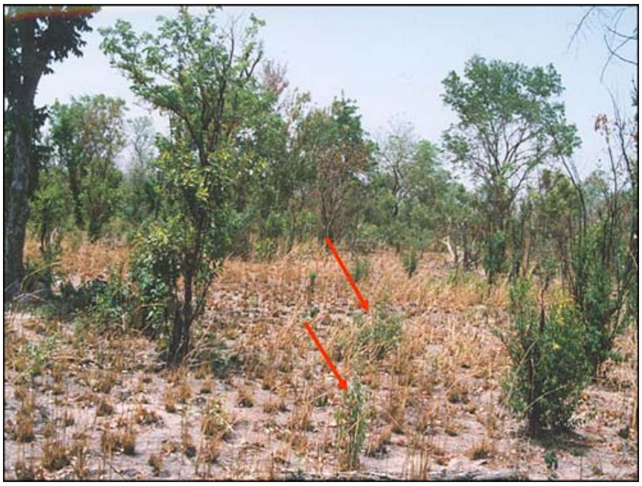


Fig. 2 Gullivers in an unfarmed savanna landscape. Note the thick tufts of perennial grasses that were burned earlier in the dry season

Finally, scholars have recently begun to explore the interactions of multiple factors, including fire, grazing, browsing and tree cutting on tree recruitment in West Africa (Zida *et al.* 2007). These studies, like the burning experiments before them, take a deductive and "laboratory" approach and seek to isolate the impacts of one or two variables. Far fewer studies employ a methodology based on natural experiments that explicitly incorporate local human practices. Thus although studies such as the burning experiments demonstrate some *potential* impacts of land clearing and fire on tree regeneration, we know little about the *actual* impact of farming, burning and fallowing. The present study addresses this gap.

Study Area

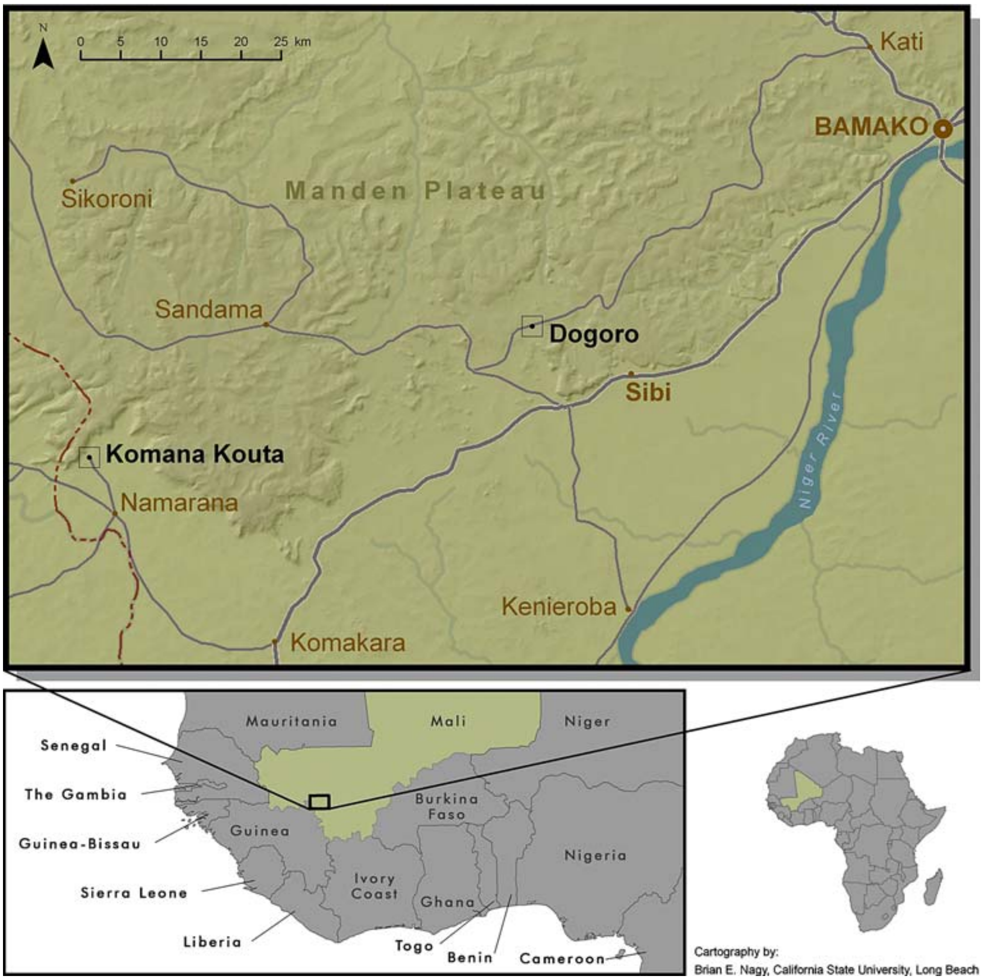
Climate and Fire Regime

The study area is located in south-western Mali at the southern edge of the Sudanian Savanna belt (Fig. 3). The vegetation is wooded-savanna comprised of a complex mosaic of trees and grasses. The region is characterized by a rainy season that typically begins in late May and ends in October. The average annual rainfall is approximately 1,000-1,200 mm (Diarra and Sivakumar 1995; Nasi and Sabatier 1988). The rainy season is followed by a fire season that normally runs from November through March

---

[10] It could be argued that our knowledge of the role of "natural" factors in savannas is far better developed than that of human ones in terms of disturbance and storage effect models. To give but one example, Higgins and colleagues (2000) (see above) fail to mention that the latter two factors in their model are a function of human practices because people set fires and cut trees.

[11] See Mistry and Berardi (2006) for an exception.



Cartography by:
Brian E. Nagy, California State University, Long Beach

Fig. 3 The study area consists of two villages located on the fringes of Manden Plateau in southern Mali. The village of Komana Kouta is located at the base of the plateau while Dogoro is situated on the southern edge of the plateau

(Laris 2005). Burning is an annual event. Research conducted in the Guinean and southern Sudanian savanna finds that between 25% and 80% of the landscape burns on an annual basis.[12] I found that 57% of the landscape burned for the broader study area with the bulk of the burning occurring in December and January (Laris 2005). The cut-off between early and late season fires is defined by the Malian Forest Service as January 1st in the zone covered by the study region (Republic du Mali 2006).[13]

General Characteristics of the Vegetation Cover

The vegetation is predominantly composed of a mixture of grasses, trees, and shrubs arranged in a complex mosaic (Nasi and Sabatier 1988). Ferricrete outcrops often referred to as *Bowé*, cover considerable areas.[14] *Bowé* cover up to 25% of the Sudanian and Guinean savanna in southern Mali, but their distribution is highly uneven (Nasi and Sabatier 1988: 90). Soil on *Bowé* generally has high gravel content and is shallow, creating xeric conditions. Unproductive soils such as on *Bowé* support sparse vegetation compared with the deeper, loamy soils in the valleys or depressions. *Bowé* are dominated by short, annual grasses, (principally *Loudetia tongoensis*, but also *Andropogon pseudapricus*) with only widely scattered trees. Except for the intensively cultivated areas, a near-continuous layer of tall perennial grasses (often up to 2 m in height) (*Andropogon gayanus, Hyparrhenia*

---

[12] For example, Menaut and colleagues' (1991) found that 25–50% of the Sudan Savanna, and 60–80% of the Guinean Savanna in West Africa burned annually. Eva and Lambin (1998) found slightly lower values of 28.2% for the Sudan zone and 51.8% of the Guinea zone of central Africa. Barbosa and colleagues (1999) found higher levels of burning in the Sudan zone—70.1%, and lower values in the Guinea zone—57.7%.

[13] Cut-off dates are problematic because the point in the dry season at which trees become susceptible to fire damage will vary from year to year depending upon rainfall and micro-environmental factors which play a key role in determining soil moisture content. As such, the drying point of grasses and trees tends to vary widely across the landscape.

[14] Here I use *Bowé* as a generic term for all areas with similar upland soils on Ferricrete that support vegetation cover dominated primarily by annual grasses (*Loudetia tongoensis* and *Andropogon pseudapricus*) with few scattered trees.

dissolute, Cymbopogon giganteus, and *Schizachyrium pulchellum*) covers the more fertile soils although there are pockets where tree canopy is closed. The vegetation in settled areas has been significantly modified. Perennial grasses are less common (except on long fallow plots of over 15 years), and large portions of the landscape are covered by shorter annual grasses, particularly *Andropogon pseudapricus* and *Pennisetum pedicellatum* with scattered trees.

Farming and Settlement Practices

The farming practices of inhabitants of the West African savanna belt have been well documented. The study region is composed of an extensively farmed landscape intermixed with pockets of intensive agriculture. Although there are a great variety of farming systems in the region large areas practice some form of rotational or shifting agriculture (e.g., Koenig *et al.* 1998). As is the case for large tracts of the West Africa savanna and woodland, settlement and farming patterns in southern Mali are not fixed in time and space (Duvall 2007; Stone 1996). Patterns of shifting land uses occur at multiple spatial and temporal scales and result in a patchwork of utilized and fallow plots. For example, shifting occurs at the level of individual plots or farms, as farmers often abandon agricultural plots to fallow after farming them for 3 to 5 years. At the level of hamlets and villages, shifting may occur at longer time and greater spatial scales such as when the population of a hamlet moves in search of more fertile land or returns to the central village (e.g., Duvall 2007). Finally, at the regional level or level of village clusters, shifting may occur over longer time frames as a result of climate shifts, disease, and/or warfare.

Burning Practices

Throughout the study area, rural inhabitants begin setting fire to the savanna grasses at the onset of each dry season in mid to late October. According to my research, people capitalize on the varying desiccation rates of different grass species on differing soil types to manage fire. Interviews conducted in 2000 with villagers who regularly light fires indicated that they seek to set fire to the same patches of vegetation at approximately the same time of the dry season each year. In general, they follow a simple rule seeking to set fire to the grasses as soon as they are “dry enough to burn.” For example, short annual grasses found on Ferricrete outcrops are burned at the onset of the dry season while taller, thicker perennial grasses on deeper soils are burned in mid-dry season. A survey of rural inhabitants found that 80% of the areas covered by the previous study that burned did so at approximately the same time each year. Fallow lands tended to burn early (before January 1st) 67% of the time and wooded areas burn late the majority (64%) of the time (Laris 2002: 166). These interview results are supported by an analysis of a multi-year data set (Laris 2008). Based on these findings and information provided by key informants living in the study villages, the assumption is made that the study sites have been annually burned for decades and that the timing of the fires on a given patch of vegetation has been relatively consistent from year to year.

Study Methods

To determine whether long-fallow plots have more or fewer trees than the unfarmed (virgin) savanna a comparison was made between the vegetation cover on long-fallow plots, known locally as *jaban*, with savanna plots that had never been farmed, known as *kandan koro*. Two areas were selected for the study after survey and interview data indicated that there were a number of fallow plots over 30 years of age and a relative abundance of virgin land. Indeed the vast majority of the land in both study areas had not been farmed according to village elders. The first study area is located near the village of Komana Kouta near the Mali-Guinea border. The second area is near the village of Dogoro located at the edge of a large wilderness area.

In each study area, local farmers identified four sites located near abandoned hamlets where there was a known boundary between plots that were farmed in the past and land that had never been farmed. In Mali, as is the case throughout much of West Africa, clearing and farming of a plot of land connotes ownership and as such, boundaries of farm plots are passed down from father to son. For each study site a farmer with knowledge of the land use history marked the boundary between farmed and virgin land. According to their accounts, there was no difference in soil type between the two plots at the time of initial clearing for farming. Moreover, topographic, soil and other conditions were examined at each site to assure that these were consistent on either side of the boundary. Soil type varied from rocky soil on the plateau near Komana, to sandy soils in parts of Dogoro, to soils with a higher clay content on the plain in Komana.

Once the boundaries between the virgin and fallow plots were established transects were plotted across the land approximately 20 m on either side of the dividing line. Twenty meter diameter quadrats were marked off at 20-m intervals along each transect.[15] The number of quadrats varied from two to five depending upon the size of the

---

[15] The methods used were adapted from Fairhead and Leach (1996) and Nyerges (1989).

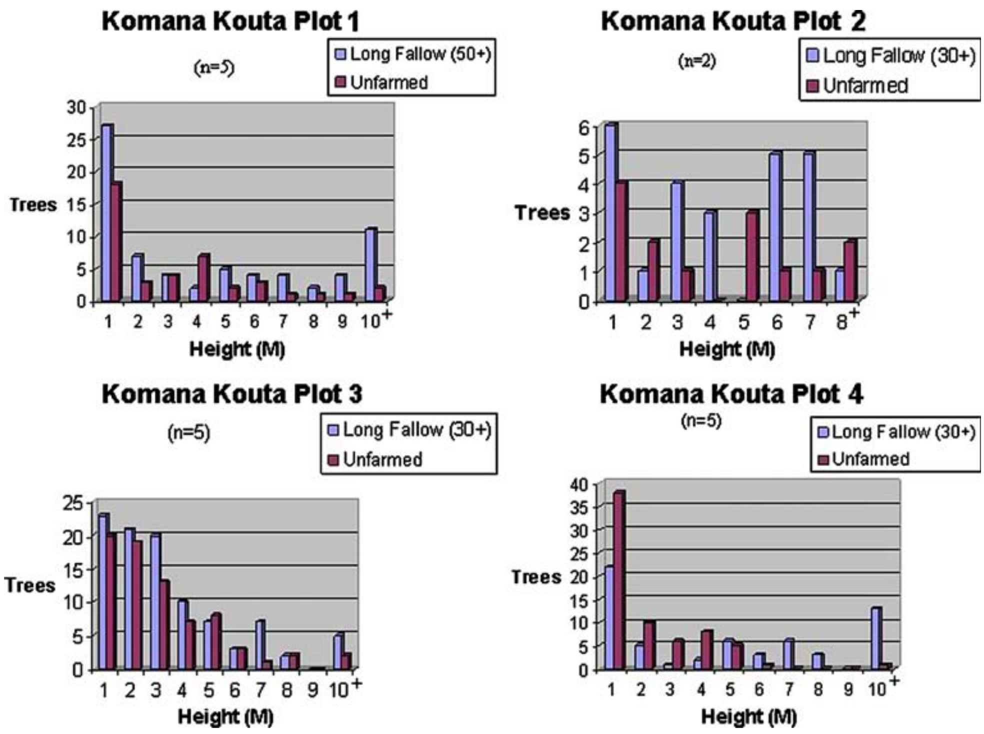


Fig. 4 Data on tree measurements for four plots at the Komana Kouta site. Note the high number of gullivers (trees 2 m or less) on all sites and the greater numbers of tall trees on the farmed plots, especially for trees 10 m and above. (*n* is the number of quadrats)

farmed plots. A total of 29 quadrats were studied. In each quadrant, tree species were counted, and measured for height and girth. Two local tree experts identified tree species using local names and assisted in the data collection. Height was estimated using a 6-m pole and girth was measured at chest height for all trees with a girth of over 20 cm. The predominant grass types were also recorded. Each of the plots at both sites had been burned prior to the study. Finally, interviews were conducted with farmers who were familiar with each study site.

Results

Results for all study sites are shown in Figs. 4, 5, 6 and 7 and Table 1. Figure 4 shows the distribution of trees for the

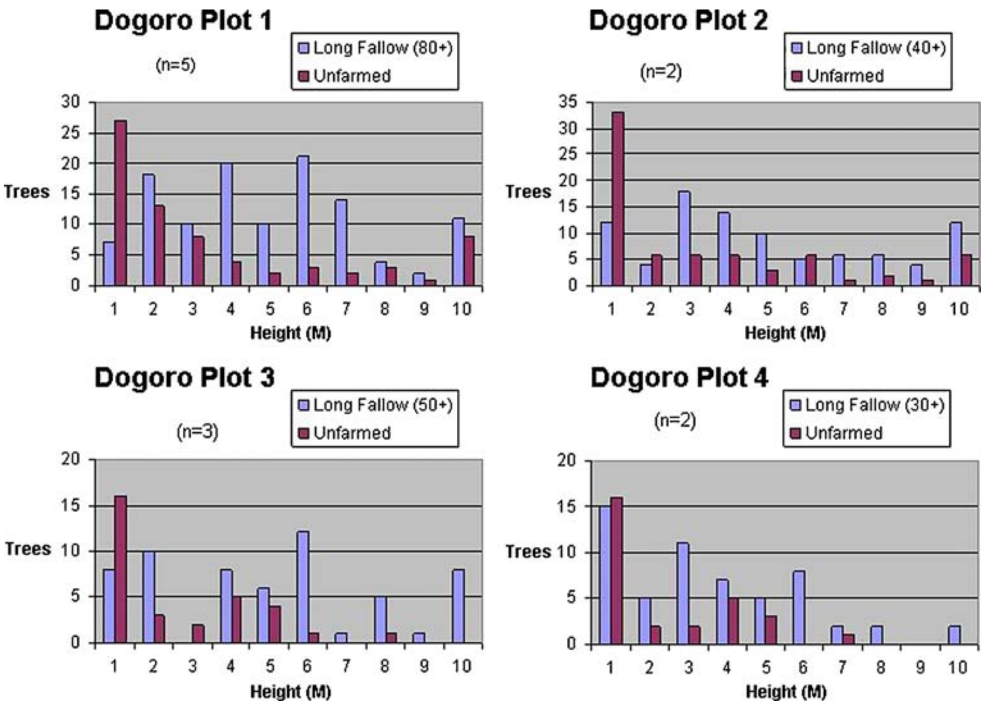


Fig. 5 Data on tree measurements for four plots at the Dogoro site. Note the high number of gullivers on all unfarmed sites and the greater numbers of tall trees (especially for trees 10 m and above) on the farmed plots

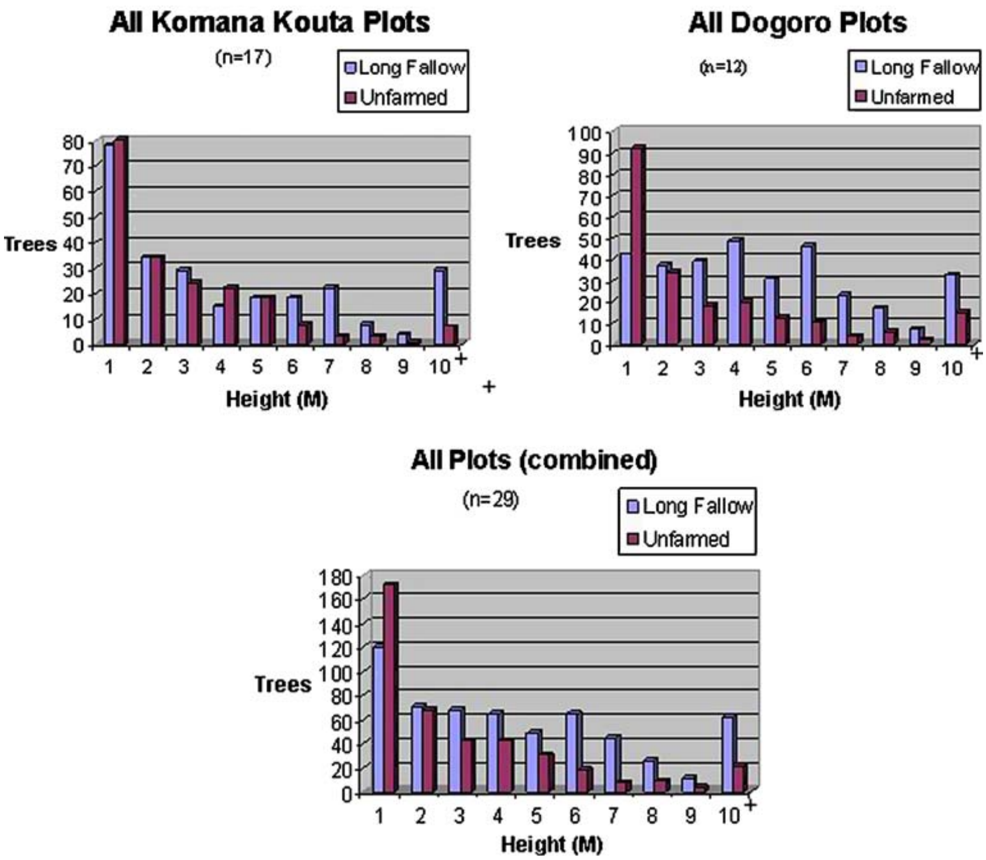


Fig. 6 Combined data for Komana Kouta and Dogoro. Note that tree cover is greater on farmed plots for all height categories except for 1 m tall

four plots at the Komana Kouta site. The results for the Dogoro site are shown in Fig. 5. Figure 6 shows the combined results for all sites.

As can be seen in the figures, the single most striking difference between the fallow and unfarmed plots is the greater number of trees, especially trees over 5 m in height on the fallow plots. When gullivers are excluded from the tree counts, there were over twice as many trees on fallow plots when both sites are combined (388–173). In general the trees found on the fallow plots were straighter and taller,

Fig. 7 Contrasting tree heights, structure and density of unfarmed trees (*left*) and farmed trees (*right*). The photographs above are from Komana Kouta during the dry season (February)

Table 1 Tree density (#trees/hectare) and diversity for each site

Study site	Tree density		Tree diversity	
	Fallow	Unfarmed	Fallow	Unfarmed
Komana	268	161	37	20
Dogoro	650	213	53	39

while the trees on the virgin plots were twisted and stunted, an indication that they had been subjected to repeated stress (Fig. 7).

Species diversity (species richness) was also greater, indeed nearly double, on the fallow plots at each site. At the Dogoro site a total of 53 species were identified; 39 species were found on the fallow plots compared with 20 on the unfarmed plots. Similarly for the Komana site, 43 species were identified with 37 found on the fallow plots versus 20 on the unfarmed plots (Table 1).

Specific species were identified as more prevalent on the fallow plots. Most notably, the fallow sites had four times as many *Pterocarpus erinaceus* (88/22). According to Nasi and Sabatier (1988) *Pterocarpus erinaceus* is commonly associated with secondary growth woodlands. *Lannea acida* trees were also more prevalent on the fallow plots (37/11), while *Combretum lecardii,* which Nasi and Sabatier also associate with secondary growth, were much more common on the fallow sites at Dogoro (83/17) but found in roughly equal numbers at Komana Kouta (22/24). Somewhat surprisingly, *Vitellaria paradoxum* and *Parkia biglobosa* trees, which are known to propagate on farmed plots, were not significantly more common on fallow plots. Also surprising was the fact that *Isoberlina doka,* which are thought to be associated with "original"[16] vegetation cover (Nasi and Sabatier 1988), were not more common on unfarmed plots (20/9). Considering that there are roughly twice as many trees on fallow plots, *Isoberlina doka* make up a similar percentage of the total trees on farmed and unfarmed plots.

A comparison of the data from the two sites finds a few important differences. First, there were far fewer gullivers on the fallow plots at the Dogoro site than at Komana although both sites had a high number of gullivers on the unfarmed plots. Second, tree densities were greatest on the Dogoro fallow plots (650 trees/hectare) versus 268 trees per hectare on the Komana fallows. Specifically, Dogoro fallow plots had much greater numbers of trees at least 3 m tall compared with the Komana site. Third, while there was a fairly even number of trees in the three to 5 m range on both fallow and unfarmed plots at the Komana site, there was a greater number of trees in the three to 5 m range on the fallow plots at the Dogoro site.

Many of the medium- and large-sized trees found on the un-farmed plots were clustered in clumps on termite mounds, a common pattern in savannas (Furley *et al.* 1992). The predominant feature of the unfarmed plots was the presence of thick tufts of deep-rooted perennial grasses, particularly *Andropogon tectorum* and *Andropogon gayanus*. Conversely the trees on the fallow plots were more evenly distributed across the landscape. This factor along with the greater number of large trees meant that the canopy appeared nearly fully closed in some areas especially at the Dogoro site (Fig. 8). Grass cover was diminished compared with the virgin plots and in particular, the tufts of perennial grasses were notably absent. Annual grasses commonly found on fallow plots, such as *Pennisetum pedicellatum* and *Andropogon pseudapricus*, were intermixed with the coarser perennial grasses.

Discussion

This study finds clear evidence of the Gulliver syndrome on the unfarmed plots at both sites. It also finds strong evidence that farming and fallowing is a mechanism allowing gullivers to escape fire and mature. In general unfarmed plots are characterized as having relatively low densities of large, mature trees, a large number of gullivers, and a near continuous covering of perennial grasses. By contrast, farmed plots had a higher density of large, mature trees, fewer gullivers (specifically at the Dogoro site) and a sparser covering of grasses composed of more annuals.

Evidence from the Dogoro site, which had the fewest gullivers, the highest overall tree density, and greatest number of trees, suggests that a threshold was reached whereby the closing of the tree canopy created the conditions allowing new tree sprouts to grow and mature.

Fig. 8 Near closed canopy woodland on a long-fallow plot at the Dogoro site

---

[16] *Isoberlina doka* are known locally as the "first tree."

This is exemplified by the fact that the Dogoro site has a relatively even distribution of trees by height especially in the medium range of three to 6 m as compared to the Komana site. As the tree canopy closes, grasses diminish and fire intensity decreases giving young trees the opportunity to escape.

As noted, the literature on savanna ecology suggests three common mechanisms by which gullivers escape fire: a number of consecutive high rainfall years, a number of consecutive fire free years, and/or high termite activity. Each of these can be ruled out as cause of the difference in tree cover between fallow and unfarmed sites. Rainfall is ruled out because rainfall variation alone can't explain why adjacent plots have such different tree densities. In addition, the fallow periods, which vary in age from 30 to over 80 years, means that original fallowing covered periods of both extreme drought (1970s), and above average rainfall (1950s) (Nicholson 2000)[17]. Similarly fire-free years can be ruled out as a cause because it is highly unlikely that the fallowed plots were kept fire-free for consecutive years while the neighboring plots burned. Moreover, remotely-sensed and interview data both indicate that in most areas fire is a near annual event and that fallows are regularly burned (Laris 2002, 2008). Indeed, all plots had been burned prior to the study. Finally, termites are ruled out as a factor. There was no obvious influence of termites except on the unfarmed plots where clumping associated with termite mounds was apparent. It is thus concluded that farming and fallowing caused the increase in tree cover, size and diversity.

A number of factors combine to account for the increase in tree density, size, and diversity on the fallow plots. First, on the virgin plots new tree seedlings must compete with the well-established perennial grasses which are tall (over 2 m) with thick root systems that allow them to compete vigorously with new tree seedlings for water, soil nutrients, and light. Perennial grasses hold moisture later into the dry season and thus burn at a later date than annuals. For example, at the time of the field study at Komana in early March, the unfarmed plots had been recently burned, probably in late February. When tall perennial grasses burn at this point in the dry season, the intensity of the fire is high and fire completely engulfs new tree seedlings either killing them or leaving them severely stunted. Indeed numerous dead tree sprouts were identified on many virgin plots. Conversely, on fallow plots there was a notable absence of well-developed perennial grasses, as such, fires were probably less intense.

Second, by removing the thick grass tufts and breaking the soil with hand-held hoes farmers loosen the soil and allow water to penetrate to deeper levels. New tree seedlings are thus better able to establish on land that has been "broken" than on land covered by tough grasses and crusted soils, as Fairhead and Leach (1996) have also noted.

Third, research on fallow plots in West Africa finds that the majority of trees on fallow lands establish by coppicing (Nyerges 1989) or from "seedling sprouts" (Ky-Dembele *et al.* 2007). Seedling sprouts are defined as a plantlet of seed origin that was affected by shoot dieback, but resprouted from the root collar (Ky-Dembele *et al.* 2007). On fallow plots coppices and seedling-sprouts develop deeper root systems allowing them to eventually out-compete grasses. Following clearing and burning, numerous small trees from seedlings and coppice will sprout during the rainy season on a plot of tilled farmland. Farmers typically cut new trees with a hoe at the beginning of the rainy season to allow crops to grow. However, once the crops are established, these young trees may resprout and continue to grow until the beginning of the next farming season when they may be cut again. The end result is that after several years of farming (a typical farming period is 3 to 5 years) there are a number of new trees with well-established root systems on the plot (Fig. 9).

Finally, the grasses and forbs that initially invade the newly fallow plots are short and highly desired by cattle as fodder. As such, recently fallowed plots are often grazed by cattle and other animals (Laris 2002; Fairhead and Leach 1996). Fires, if they occur at all on these plots, are usually of low intensity. After 2 or 3 years taller annual grasses such as *Pennisetum pedicellatum* and *Andropogon pseudapricus* establish themselves. These grasses do not retain moisture for long and as such they quickly dry out and are regularly burned early.[18]

In summary, it is suggested here that trees on fallow plots are able to develop deeper and perhaps wider root systems on farmed plots than on unfarmed ones. Because shorter annual grasses will dominate fallow plots for 10–15 years or more trees are able to get a "jump" on grasses on farmed plots allowing them to reach sufficient heights to withstand the heat of fires from perennial grasses that gradually invade. In addition, as trees grow and a canopy develops, grasses are shaded out, further shifting the balance in favor of trees. The end result is that by the time perennial grasses have re-established, the trees on these

---

[17] According to Nicholson (2000), mean rainfall in the Sahel decreased by 25–40% between 1931–1960 and 1968–1997; every year in the 1950s was wet, and nearly every year since 1970 has been anomalously dry.

[18] Note that fires can burn annual grasses earlier during the dry season since these grasses tend to desiccate before perennials; however, when these early fires reach a boundary composed of perennial grasses, they often extinguish due to the higher moisture content of perennials. As such, patches of perennial grasses are commonly burned at later dates even if they are in close proximity to patches of annuals.

Fig. 9 A recently burned fallow plot of approximately 10–15 years of age (*background*). Note the large number of small trees. Also note the numerous tree sprouts on the farmed plot in the foreground

plots are several meters tall with well-established root systems and even later fires do not pose problems for them.

Indigenous Explanation

Local farmers are quite aware of the dynamics described above. The farmers I interviewed agree that *jaban* (fallow) plots have more and taller trees than *kandan koro* (unfarmed) plots (Fig. 10). It was no surprise to them that the previously farmed plots had more and larger trees than the virgin ones. From their perspective farming causes trees to overtake grasses in the savanna. Indeed one farmer who graciously agreed to assist in the field study exclaimed that he was happy to help since he wanted the authorities to understand that farming *increases* the number of trees on a newly farmed plot. Farmers point out that cultivation breaks up the hard crust on the surface of the land allowing trees to establish and grow. One farmer described how the process works, “Roots can spread-out to the sides after the grasses are cut back and the field is farmed…Unfarmed tree roots only go in a downward direction.”

Indeed when farmers speak of clearing a previously unfarmed plot of land, they speak of the labor required to pull the grasses (*ka bin bo)* rather than the effort required to cut and burn trees. Some farmers prefer farming the *kandan koro* because although the initial labor of pulling the grasses is more than that of cutting and burning trees on long-fallow plots, the land can remain in production for a longer period because weeds are slower to invade.

Limitations

While it is possible that other unaccounted for factors could give rise to the differences documented here, such as differing underlying soil conditions between the farmed and unfarmed plots, the farmers in the area assured that this was not the case. Indeed, several elder farmers had first hand information of the initial conditions on both farmed and unfarmed plots. Furthermore as noted, Nasi and Sabatier (1988) determined that *Pterocarpus erinaceus* is associated with secondary growth woodlands and this species was prevalent on the long fallow plots adding credence to the study design (that the boundaries between the fallow and virgin plots were correctly drawn). As noted, while it is not impossible that fire may have been prevented from entering the fallow plots, it is highly unlikely. Finally, although a larger number of sample plots would strengthen the results of this study, the findings were substantiated by interviews with elder farmers, all of whom agreed that more and larger trees are found on long fallow plots. Indeed, one elderly farmer at the Komana site argued that all areas on the plain that are densely wooded today were farmed in the 1950s.

Fig. 10 Effects of cultivation on woody vegetation for a long-fallow plot. The area foreground dominated by thick tufts of perennial grasses (*Andropogon)* has ‘never’ been farmed. The area in the background was farmed and abandoned by this man about 15 years prior

Comparisons with Other Studies

Chris Duvall (2007) defines “vegetation turnover” as the process which occurs when disturbance increases the abundance of previously uncommon species, often increasing plant diversity through intentional or unintentional plant introduction. Several West Africa studies have shown that farming causes vegetation turnover by increasing tree density and diversity. In the most cited example, Fairhead and Leach (1996) found that fallowed plots experienced a dramatic increase in tree cover in Guinea.[19] Yao and Roussel (2007) compared unfarmed plots with long fallow plots in southwest Ivory Coast and found that the long fallow plots contained numerous rare species and that the diversity on the fallow plots was on par with that of the unfarmed rainforest.

While there are obvious parallels between the Mali case presented here and the findings of these other studies there are also important differences. Duvall (2007) argues that research demonstrating turnover through human action has relied primarily on sampling in ruins or intensively managed fields, and not in less intensively disturbed fields and fallows (e.g., Amanor 1994; Fairhead and Leach 1996; Spichiger and Pamard 1973). The Malian case is thus an example of vegetation turnover on less intensively managed fallow land.[20, 21] It is also important to recognize that long-fallow plots are relatively rare in Mali (although there may be a greater number than once thought and there remain large pockets of long fallow in northern Guinea). In addition, it is worth noting that the majority of the other studies concern areas with significantly higher levels of annual rainfall which is known to favor trees over grasses in the absence of disturbance (Bond 2005).

Finally, the findings of the Mali study seem to contradict those of a study by Lykke (1998) in the zone. For a wooded-savanna in Senegal with similar rainfall, Lykke (1998) found that the species composition and vegetation structure were changing in favor of shrubby species which Lykke argues were better adapted to cope with fire and other disturbances. She argues that these changes also imply a shift from a vegetation type valued by the local population to one with less value. Lykke concludes that,

> "An undesired change of the vegetation type from one with predominance of the most valuable large single-trunked trees to one dominated by shrubs and treelets seems to be taking place. It is therefore important to emphasize the large trees for conservation" (1272).

It is worth noting that the area studied by Lykke was a protected one where farming has long been prohibited. This may explain the lack of large trees.

Conclusion

According to the findings presented here, farming and fallowing together provide an important mechanism whereby new tree shoots are able to escape the Gulliver syndrome and reach maturity. Moreover, it is probable that farming and fallowing alone provide the escape route. That is, the escape mechanisms suggested in the ecological literature can not explain the differences in tree cover documented here. Furthermore, it is improbable that the indigenous system of long-fallow, rotational farming has been the cause of savannization in southern Mali. On the contrary, long-fallow systems appear to shift the tree-grass ratio toward the direction of more and taller trees with increased biodiversity when compared with unfarmed savanna even in the presence of annual burning.

Although this study documents that farming can provide a clear pathway through which trees can increase on savanna plots, this is not to dispute the point that *some* farming systems result in increased grass cover at the expense of trees. Indeed, in much of southern Mali where shorter fallow cycles are the norm (e.g., less than 20 years) and have been for decades if not centuries, annual grasses predominate and tree density appears to have declined. It is thus concluded that in regularly farmed areas, it is the frequency and duration of cropping and not the combination of clearing, farming and burning *per se* that causes a decrease in the tree to grass ratio.[22]

The findings raise questions about the origin of savannas and in particular the commonly held notion that the "natural" state of the savanna is dense woodland which has been savannized through the processes of clearing and farming followed by repeated burning. According to this study the sequence appears to *begin* with a landscape that is dominated by perennial grasses with scattered trees; once an area is farmed and let fallow, tree cover increases *despite* regular burning (Fig. 11). Closing of the tree canopy may occur if land is kept in fallow over a long period of time or if fire is reduced. If land is repeatedly farmed on a shorter fallow cycle, the number of large trees will diminish gradually except for those desired species, such as *Vitellaria paradoxum* and *Parkia biglobosa*, resulting in the characteristic park-like landscape of the more densely populated areas in Mali.

---

[19] It should be noted that the northern most case, which still receives more rainfall than the Mali sites, experienced only minor increases in tree cover (Fairhead and Leach 1996).

[20] One could make the case that farmed and burned fields are "intensively" managed. My point here is that compared with other sites, the Mali sites are relatively less intensively managed. The plots studied were on former hamlets and were typically farmed for 4 or 5 years and then completely abandoned.

[21] Dauget and Menault (1992) also document a case in the Guinea savanna where trees have "naturally" (without the presence of agriculture or grazing) encroached on a savanna plot despite frequent burning.

[22] It is also probable that the method of farming is equally important; as Nyerges (1989) has found, hoe farming tends to be far less disruptive of tree cover than farming with an ox plow.

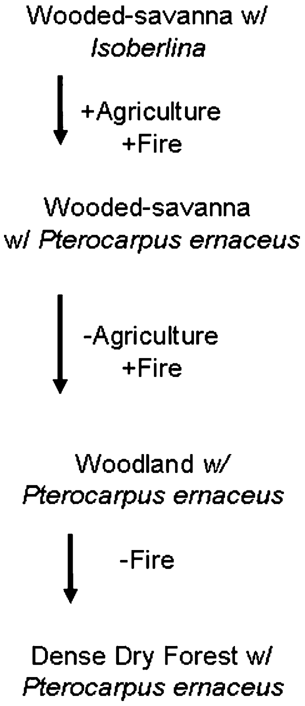


Fig. 11 Succession pathway for southern Sudanian savanna w/ hoe farming

Role of Natural Experiments in Human Ecology

Batterbury and colleagues (1997) and Forsyth (2003) have argued that human ecologists need to recognize the constructed nature of all environmental knowledge, but also seek to reveal biophysical processes by using hybrid sources of data. They argue for an approach that combines biophysical research with a critical analysis of history especially the history of how environmental problems are constructed and how scientists can be involved in the process of establishing and perpetuating false orthodox views. The present study demonstrates the usefulness of natural experiments for challenging so-called orthodox views. It is argued here that the natural experiment, long considered a less rigorous form of scientific experiment when compared to laboratory or field experiments, offers a potentially more "objective" view of reality (Diamond 1986). Natural experiments should be the preferred method of challenging or testing scientific views such as those with origins in the colonial era.

It is important to remember that while Aubréville (and others) designed the burning experiments in accordance with the principles of an "objective" scientific method that required strict control over variables, the variables were selected with the explicit goal of proving the savannization hypothesis. Moreover, when discussing the results of his experiment Aubréville was overtly political in his *interpretation*:

> "We must remember that these experiments are meant not only to support our conception of forestry policy but also to convince others of our conclusions, especially administrative and policy authorities. They must be like propaganda and not remain secret…I remind the reader that the principle of these demonstrations, being conducted [is to] prove the effects of bush fires and conversely the effects of their suppression" (Aubréville 1953: 5, *author's translation*).

Elsewhere I have described how this view or interpretation was incorporated into an environmental narrative or orthodoxy which proved to be influential in the policy arena (Laris and Wardell 2006). In retrospect it is clear that the experiments did not prove human origins of the savanna, they merely provided evidence of a mechanism by which a specific type of fire regime can prevent tree regrowth. In other words, the experiments provide evidence that a regime of intense fires can *maintain* the savanna, while the *cause* of the savanna remains a mystery.

Although natural experiments may insert uncertainties into the study design, these uncertainties can be tempered by incorporating multiple sites (e.g., eight plots at two sites with diverse soil types) and conducting interviews with elder farmers who were involved in the land management of the plots.[23] Thus whereas the burning experiments were useful for determining a basic element of savanna fire ecology—fire regime effects tree cover—the natural experiments are most useful for providing insights into the actual human impacts on savanna vegetation cover. In tandem these two experiments have provided insights into the critical issues of savanna origin and maintenance.

Towards a Human–Ecological Theory of the Savanna Landscape

Jeltsch and colleagues (2000) have argued that a shift in perspective is needed if we are to solve the savanna riddle. They argue that rather than search for the origins of savannas or seek the mechanisms that allow trees and grasses to coexist, researchers should conceptualize savannas as ecosystems in disequilibrium that are kept from shifting to a state of pure grassland or forest by various "ecological buffering mechanisms." As such, buffering mechanisms prevent savanna from converting to forest due to disturbances such as fire or browsing and they prevent them from shifting grasslands by mechanisms that promote tree establishment, such as termite activity or an increase in rainfall.

A key benefit of Jeltsch's approach is that it places the *unstable* savanna at the center of analysis. For the human ecologist, this shift is important because from this new

---

[23] In this study for example, the precise age of the fallow plots, the original land cover, the duration of farming, and the exact burning regime were unknown to the scientist who relied upon local knowledge for this information.

perspective, anthropogenic disturbances are viewed as one of the mechanisms through which savanna are *maintained*. For the human ecologist the issue is more than one of simple semantics. If a savanna is conceptualized as a legacy of a disturbance regime, then the persistence of *both* grasses and trees is a function of the compound effects of multiple anthropogenic disturbances. Too often humans have been considered the driving force of degradation rather than a force maintaining an important heterogeneous landscape. In an era when the global area of savanna is rapidly declining (Mistry 2000), this shift in perspective is long overdue.

References

Amanor, K. S. (1994). *The new Frontier: farmer responses to land degradation*. Zed Books, London.

Aubréville, A (1947). *The disappearance of the tropical forests of Africa*. Food and Agricultural Organization, Rome.

Aubréville, A. (1949). *Climats, forêts et désertification de l'Afrique Tropicale*. Société d'Editions Géographiques, Maritimes et Coloniales, Paris.

Aubréville, A. (1953). Les expériences de reconstitution de la savane boisée en Cote d'Ivoire. *Bois et Forêts des Tropiques* 32: 4–10.

Avenard, J.-M., Bonvallot, J., Latham, M., Renard-Dugerdil, M., and Richard, J. (1974). *Aspects du contact forêt-savane dans le centre et l'ouest de la Côte d'Ivoire: étude descriptive*. ORSTOM, Paris.

Barbosa, P., Stroppiana, D., Grégoire, J.-M., and Pereira, J. (1999). An assessment of vegetation fire in Africa (1981–1991): burned areas, burned biomass, and atmospheric emissions. *Global Biogeochemical Cycles* 13: 933–950.

Bassett, T., and Koli Bi, Z. (2000). Environmental discourses and the Ivorian Savanna. *Annals of the Association of American Geographers* 90: 67–95.

Batterbury, S. P. J., Forsyth, T. J., and Thompson, K. (1997). Environmental transformations in developing countries. *The Geographical Journal* 163: 126–224.

Biggs, R., Biggs, H. C., Dunne, T. T., Govender, N., and Potgieter, A. L. F. (2003). Experimental burn plot trial in the Kruger National Park: history, experimental design and suggestions for data analysis. *Koedoe* 46: 1–15.

Bird, M. I., and Cali, J. A. (1998). A million year record of fire in sub-Saharan Africa. *Nature* 394: 767–769.

Bond, W. J. (2005). Large parts of the world are brown or black: A different view on the 'Green World' hypothesis. *Journal of Vegetation Science* 16: 261–266.

Bond, W. J., Woodward, F. I. and Midgley, G. F. (2005). The global distribution of ecosystems in a world without fire. *New Phytologist* 165: 525–538.

Bond, W., and van Wilgen, B. (1996). *Fire and Plants*. Chapman and Hall, London.

Bourliere, F., and Hadley, M. (1983). Present-day savannas: an overview. In F. Bourliere (ed.), *Tropical Savannas, Ecosystems of the World*. Elsevier, Amsterdam, 13: 1–18.

Brookman-Amissah, J., Hall, J., Swaine, M., and Attakorah, J. (1980). A re-assessment of a fire protection experiment in north-eastern Ghana. *Journal of Applied Ecology* 17: 85–99.

Bucini, G., and Hanan, N. P. (2007). A continental-scale analysis of tree cover in African Savannas. *Global Ecoogy and Biogeography* 16: 593–605.

Charter, J., and Keay, R. (1960). Assessment of the Olokomeji fire control experiment (investigation 254) 28 years after institution. *Nigerian Forestry Information Bulletin* 3: 1–32.

Cole, M. (1986). *The Savannas: Biogeography and Botany*. Academic, London.

Dauget, J.-M., and Menault, J.-C. (1992). Evolution sur 20 ans d'une parcelle de savae boisée non protégée du feu dans la réserve de Lampto (Côte-D'ivoire). *Candollea* 47: 621–630.

Diamond, J. (1986). Overview: laboratory experiments, field experiments, and natural experiments. In Diamond, Case, J.T. J. (ed.), *Community Ecology*. Harper and Row, New York, pp. 3–22.

Diarra, B., and Sivakumar, M. V. K. (1995). *Climat de Bamako*. Direction Nationale de la Météorologie, Bamako.

Dublin, H. T., Sinclair, A. R. E., and McGlade, J. (1990). Elephants and fire as causes of multiple stable states in the Serengeti-Mara (Tanzania) woodlands. *Journal of Animal Ecology* 59: 1147–1164.

Duvall, C. S. (2007). Human settlement and baobab distribution in south-western Mali. *Journal of Biogeography* 34: 1947–1961.

Eva, H., and Lambin, E. F. (1998). Remote sensing of biomass burning in tropical regions: sampling issues and multisensor approach. *Remote Sensing and Environment* 64: 292–315.

Fairhead, J., and Leach, M. (1996). *Misreading the African landscape: society and ecology in a forest-savanna mosaic*. Cambridge University Press, Cambridge.

Forsyth, T. (2003). *Critical political ecology*. Routledge, New York.

Furley, P. A., Proctor, J., and Ratter, J. A. (eds). (1992). *Nature and dynamics of forest-savanna boundaries*, Chapman and Hall, London.

Gautier, D., Bazile, D., and Picard, N. (2006). Interactions between Sudano–Sahelian savannas and parklands in space and time: the effects on biomass and biodiversity with regards to stakeholder strategies. In Mistry, J., and Berardi, A. (eds.), *Linking people with nature: lessons from savannas and dry forests*. Ashgate, London, pp. 227–240.

Govender, N., Trollope, W., and Van Wilgen, B. (2006). The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in South Africa. *Journal of Applied Ecology* 43: 748–758.

Guelly, K. A., Roussel, B., and Guyot, M. (1993). Initiation of forest succession in savanna fallows in SW Togo. *Bois et Forêts des Tropiques* 235: 37–48.

Harrison, S. P., and Prentice, C. I. (2003). Climate and CO_2 controls on global vegetation distribution at the last glacial maximum: analysis based on palaeovegetation data, biome modeling and palaeoclimate simulations. *Global Change Biology* 9: 983–1004.

Higgins, S. I., Bond, W. J., and Trollope, W. S. W. (2000). Fire, resprouting and variability: a recipe for grass–tree coexistence in savanna. *Journal of Ecology* 88: 213–229.

Higgins, S. I., Bond, W. J., February, E. C., Bronn, A., Euston-Brown, D., Enslin, B., Govender, N., Rademan, L., O'Regan, S., and Potgieter, A. (2007). Effects of four decades of fire manipulation on woody vegetation structure in savanna. *Ecology* 88: 1119.

House, J., Archer, S., Breshears, D. D., Scholes, R. J., and NCEAS Tree–Grass Interaction Participants (2003). Conundrums in mixed woody–herbaceous plant systems. *Journal of Biogeography* 30: 1763–1777.

Jeltsch, F., Weber, G., and Grimm, V. (2000). Ecological buffering mechanisms in savannas: a unifying theory of long-term tree–grass coexistence. *Plant Ecology* 150: 161–171.

Jouvanceau, J. (1962). Les travaux de protection totale contre les feux dans les forêts classées de la Région de Ségou au Mali. *Bois et Forêts des Tropiques* 81: 18–28.

Keeley, J. E., and Rundel, P. W. (2005). Fire and miocene expansion of C_4 grasses. *Ecology Letters* 8: 683–690.

Koenig, D., Diarra, T., and Sow, M. (1998). *Innovation and individuality in African development*. University of Michigan Press, Ann Arbor, MI.

Ky-Dembele, C., Tigabu, M., Bayala, J., Ouédraogo, S. J., and Odén, P. C. (2007). The relative importance of different regeneration mechanisms in a selectively cut savanna–woodland in Burkina Faso, West Africa. *Forest Ecology and Management* 243: 28–38.

Laris, P. (2002). Burning the seasonal mosaic. preventative burning strategies in the wooded savanna of Southern Mali. *Human Ecology* 30: 155–186.

Laris, P. (2005). Spatiotemporal problems with detecting seasonal-mosaic fire regimes with coarse-resolution satellite data in savannas. *Remote Sensing of Environment* 99: 412–424.

Laris, P. (2007). Conservation implications of the spatially explicit fire regime for the humanized savanna landscape of Mali. Paper presented at the Society for Conservation Biology 21st Annual Meeting Port Elizabeth, South Africa.

Laris, P., and Wardell, D. A. (2006). Good, bad or "necessary evil?": reinterpreting the colonial burning experiments in the savanna landscapes of West Africa. *Geographical Journal* 172: 217–290.

Lawesson, J. E. (1994). Some comments on the classification of African vegetation. *Journal of Vegetation Science* 5: 441–444.

Louppe, D., Oattara, N., and Coulibaly, A. (1995). The effects of brush fires on vegetation. the Aubréville Fire Plots after 60 years. *Commonwealth Forestry Review* 74: 288–291.

Lykke, A. M. (1998). Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local information. *Biodiversity and Conservation* 7: 1261–1275.

Mackay, J. (1936). Problems of ecology in Nigeria. *Empire Forestry Journal* 15: 190–200.

Menaut, J.-C., Abbadie, L., Lavenu, F., loudjani, P., and Podaire, A. (1991). Biomass burning in West African savannas. In Levine, J. S. (ed.), *Global biomass burning*. MIT, Cambridge, pp. 133–142.

Menaut, J. C., Lepage, M., and Abbadie, L. (1995). Savannas, woodlands, and dry forests in Africa. In Bullock, S. H., Mooney, H. A., and Medina, E. (eds.), *Seasonally dry tropical forests*. Cambridge University Press, Cambridge, pp. 64–92.

Mistry, J. (2000). *World Savannas Ecology and Human Use*. Harlow: Longman.

Mistry, J., and Berardi, A. (2006). (eds) *Linking people with nature: lessons from savannas and dry forests*, Ashgate, London.

Moss, R. (1982). Reflections on the relation between forest and savanna in Tropical West Africa. *University of Salford Discussion Papers in Geography* 23.

Nasi, R., and Sabatier, M. (1988). *Projet Inventaire des ressources Ligneuses au Mali*. DNEF, Bamako.

Nicholson, S. E. (2000). Land surface processes and Sahel climate. *Reviews of Geophysics* 38: 117–140.

Nyerges, A. (1989). Coppice swidden fallows in tropical deciduous forest: biological, technological, and sociocultural determinants of secondary forest successions. *Human Ecology* 17: 379–400.

Onochie, C. (1964). An experiment in controlled burning in the Sudan zone. Proceedings of the 1st Nigerian Forestry Conference, Kaduna, pp. 131–155.

Ramsay, J., and Rose-Innes, R. (1963). Some observations on the effects of fire on the Guinea savanna vegetation of Northern Ghana over a period of eleven years. *African Soils* 8: 41–85.

Republic du Mali. (2006). République du Mali. 2006. La problématique des feux de brousse: impact and stratégie de lutte. Ministère de l'environnement et l'assainissement. Republique du Mali, Bamako.

Rose-Innes, R. (1971). Fire in West African Vegetation. *Proceedings Tall Timbers Fire Ecology Conference* 11: 175–200.

Russell-Smith, J., and Edwards, A. C. (2006). Seasonality and fire severity in savanna landscapes of monsoonal northern Australia. *International Journal of Wildland Fire* 15: 541.

Salzmann, U. (2002). Late Quaternary climate and vegetation of Northeast Nigeria. *Quaternary Research* 58: 73–83.

Sankaran, M., Hanan, N., Scholes, R., Ratnam, J., Augustine, D., Cade, B., Gignoux, J., Higgins, S., Le Roux, X., Ludwig, F., Ardo, J., Banyikwa, F., Bronn, A., Bucini, G., Caylor, K., Coughenour, M., Diouf, A., Ekaya, W., Feral, C. J., February, E., Frost, P., Hiernaux, P., Hrabar, H., Metzger, K., Prins, H., Ringrose, S., Sea, W., Tews, J., Worden, J., and Zambatis, N. (2005). Determinants of woody cover in African savannas. *Nature* 438: 846–849.

Sankaran, M., Ratnam, J., Hanan, N. P. (2004). Tree–grass coexistence in savannas revisited – insights from an examination of assumptions and mechanisms invoked in existing models. *Ecological Letters* 7: 480–490.

Sawadogo, L., Nygard, R., and Pallo, F. (2002). Effects of livestock and prescribed fire on coppice growth after selective cutting of Sudanian savannah in Burkina Faso. *Annals of Forestry Science* 59: 185–195.

Scholes, R., and Archer, S. (1997). Tree–grass interactions in savannas. *Annual Review of Ecology and Systematics* 28: 517–544.

Scott, A. C. (2000). The pre-Quarternary history of fire. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164: 297–345.

Scott, L. (2002). Microscopic charcoal in sediments: Quarternary fire history of the grassland and savanna regions in South Africa. *Journal of Quarternary Science* 17: 77–886.

Spichiger, R., and Pamard, C. (1973). Recherches sur le contact forêt-savane en Côte-d'Ivoire: Etude du recrû forestier sur des parcelles cultivées en lisière d'un îlot forestier dans le sud du pays Baoulé. *Candollea* 28: 21–37.

Stone, G. D. (1996). *Settlement ecology: the social and spatial organization of Kofyar agriculture*. University of Arizona Press, Tucson, AZ.

Stott, P. (1991). Recent trends in the ecology and management of the world's savanna formations. *Progress in Physical Geography* 15: 18–28.

Swaine, M., Hawthorne, W., and Orgle, T. (1992). The effects of fire exclusion on savanna vegtation at Kpong, Ghana. *Biotropica* 24: 166–172.

Van Wilgen, B. W., Everson, C. S., and Trollope, W. S. W. (1990). Fire management in southern Africa: some examples of current objectives, practices and problems. In G. J. Goldammer (Ed.), *Fire in the Tropical Biota: Ecosystem Processes and Global Challenges*. Springer Verlag, Berlin, pp. 179–209.

Van Wilgen, B. W., and Scholes, R. J. (1997). The vegetation and fire regimes of southern hemisphere Africa. In van Wilgen, B. W., Andreae, M. O., Goldammer, J. G., and Lindesay, J. A. (eds), *Fire in southern African savannas: ecological and atmospheric perspectives*. Witwatersrand University Press, Johannesburg.

Walker, B. H., and Noy-Meir, I. (1982). Aspects of the stability and resilience of savanna ecosystems. In Huntley, B. J., and Walker, B. H. (eds.), *Ecology of tropical savannas*. Springer, Berlin, pp. 556–590.

Walter, H. (1971). *Ecology of tropical and subtropical vegetation*. Edinburgh, Oliver and Boyd.

Ward, D. (2005). Do we understand the causes of bush encroachment in African savannas? *African Journal of Range & Forage Science* 22(2): 101–105.

Wiegand, K., Saltz, D., and Ward, D. (2006). A patch-dynamics approach to savanna dynamics and woody plant encroachment – Insights from an arid savanna. *Perspectives in Plant Ecology, Evolution and Systematics* 7: 229–242.

Yao, C. Y., and Roussel, B. (2007). Forest management, farmers' practices and biodiversity conservation in the Monogaga protected coastal forest in Southwest Cote D'Ivoire. *Africa* 77: 63–85.

Zida, L., Sawadogo, M., Tigabu, D., Tiveau and P. C. Odén, D. (2007). Dynamics of sapling population in Sudanian woodlands subjected to grazing, early fire and selective cutting for a decade. *Forest Ecology and Management* 243: 102–115.